Master's Thesis

An Analysis of the Swiss Money Market

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1 Introduction

The role international money markets play for the banking system and the real economy is outstanding. Term money market rates like the three-month Libor (London interbank offered rate) constitute an important benchmark for interest rates on loans and securities, from home mortgages to business loans (Taylor and Williams (2008, p. 2)). Furthermore, the money market represents the first stage of the monetary policy transmission channel. Central banks (CB) implement their decisions via open market operations on the money markets and provide interest rate channels (standing facilities) in order to steer money market interest rates. In the end, exerting an influence on the real economy is an aim as well. Therefore, a functioning money market is essential for financial markets and the economy as a whole.

In general, money markets describe a segment of the financial market where instruments like treasury bills, commercial papers, deposits and repurchase agreements with a maturity of up to one year are traded. The name money market emerges from the fact, that participants (which are mainly banks, central banks, money market funds and large corporations) are able to balance their liquidity (in the form of money) within hours. And this is the main function of it. It provides the possibility to even out excess liquidity and shortages. The core of the market is the interbank segment. For a long time, money markets did not gain much attention in public perception. The reason is, that they worked well and risks in the market were moderate (Kacperczyk and Schnabl (2009, p. 1)). However one day, the careless days were over.

It is August 9, 2007 and traders in New York, London and other financial centres sit in front of their desks. Suddenly, interest rates on overnight (ON) interbank loans start to unusually increase above CBs' interest rate targets. Additionally, interest rates on medium-term interbank loans (three-month Libor) surged even more and seemed to become disconnected from overnight rates (Taylor and Williams (2008, p. 1)). Did the Federal Reserve announce an unexpected interest rate target change? No, it is the start of a so far unseen turmoil in the money market. But what happened? The French bank BNP Paribas revealed that it wasn't able to orderly value their holdings of securitized U.S. subprime assets and halted withdrawals from three investment funds (Shin (2009, p. 121)). This incident was one of the first indications of the huge dimensions and the high interdependences resulting from securitization and subprime losses. A widespread uncertainty in the banking system, regarding the consistency of counterparties, was the result. The contagion of the interbank money market was the corollary. An increase in counterparty risk and high losses from subprime assets led to a high uncertainty in the idiosyncratic needs for liquidity in the banking system. CBs' reaction was to provide huge amounts of liquidity in order to enhance the stability of financial markets.

During global money market tumults, the Swiss money market turned out to be a robust source of funding for the banking system (Kraenzlin and von Scarpatetti (2012)). However, the preceding explained processes had a strong effect on Swiss money market conditions, turnover developments and short-term interest rate movements as well. One was able to observe a clear shift from unsecured to secured money market transactions. Especially in phases where counterparty risk is high and liquidity needs start to rise, the turnover in the secured money market tended to increase. The Swiss National Bank (SNB) massively provided liquidity to the banking system either, resulting in an increase of the reserves at the SNB, while the turnover in money markets decreased and money market interest rates were pushed down to the floor of the interest rate corridor of the SNB and CBs in general.

Berentsen et al. (2010, 2013) created a model, which reproduces many characteristics of the European repo market. In the following, it is calibrated to the Swiss money market case in order to simulate the turnover and interest rate movements in recent years. A special focus lies on detecting possible effects the model provides with regard to changes in the aggregate need for liquidity or increases in SNB sight deposits. Three hypotheses will be developed, based on empirical observations. A high variance of liquidity needs, a money supply shock or a collateral crisis may push money market interest rates to the floor or increase (the former)/decrease (the latter) repo market activity. These hypotheses are used in order to evaluate the outcomes of the simulations. By choosing two aggregate shocks, it becomes obvious that the model is able to track important changes in the Swiss franc repo market turnover and interest rate movements, such that the hypotheses can be confirmed on the base of the model. However, some drawbacks regarding the limited ability to implement the model into the Swiss money market environment need to be discussed at the end.

The structure of the paper has the following course. Section 2 presents a descriptive analysis of the Swiss money market. In order to simulate the model, one task is to divide the time series of interest (2005-2011) into different sub periods, which are all characterized by different patterns of financial turmoil on the money market. The insights from the analysis will help to find the accurate breakdown. Additionally, the three hypotheses will be developed on the basis of empirical observations, which significantly describe the money market developments. For this purpose, the monetary policy environment in Switzerland is introduced. How is monetary policy implemented by the SNB and which money market relevant actions had been undertaken? After that, developments on the unsecured and secured money market will be deeply analysed. The causes of the change in relevance of the two segments will have an exceptional focus. Section 2 closes with recent regulatory developments in money markets. Section 3 introduces the theoretical model of Berentsen et al. (2010, 2013). The most important equations, essential for the later simulation, will be developed and some first insights regarding the main statements are given. Section 4 covers the calibration and simulation of the model with respect to the Swiss money market environment. The optimality of the size of the interest rate spread provided by the SNB will be evaluated on the base of the model. After that, the initial calibration is applied, in order to track the money market interest rate in the course of time. It becomes obvious, that we need to adapt the calibration with respect to two shocks, the variance of liquidity needs and the relation between the stock of collateral and money, in order to be able to better explain the interest rate movements and turnover developments in times of money market turmoil. In the last section, the gained insights will be summarized and the simulations will discussed with respect to possible drawbacks.

2 A descriptive Analysis of the Swiss Money Market

2.1 The Monetary Policy environment 2004-2013

The most watched players in money markets are the CBs. They are the main driving force, decisively determining whether interest rates head up or down or whether the yield curve has a positive slope or inverts. The SNB ensures price stability and takes due account of economic developments (National Bank Act art. 5 para. 1 NBA). This legal mandate is similar to most other CBs in developed countries, however the SNB diverges regarding its operational monetary policy strategy. In contrast to other CBs, the SNB targets a longer-term interest rate, the CHF Libor 3M (three-month London interbank offered rate for unsecured Swiss franc transactions), whereas the ECB or FED aim to keep very short-term interest rates (ON) under control.[1] In order to manage the money supply and the Libor, the SNB uses

[1] Currently, there is a discussion whether the Libor still is the optimal operational target. Therefore, other reference rates (especially based on secured transactions) have been developed. However until now, the CHF Libor 3M still serves as the main target.

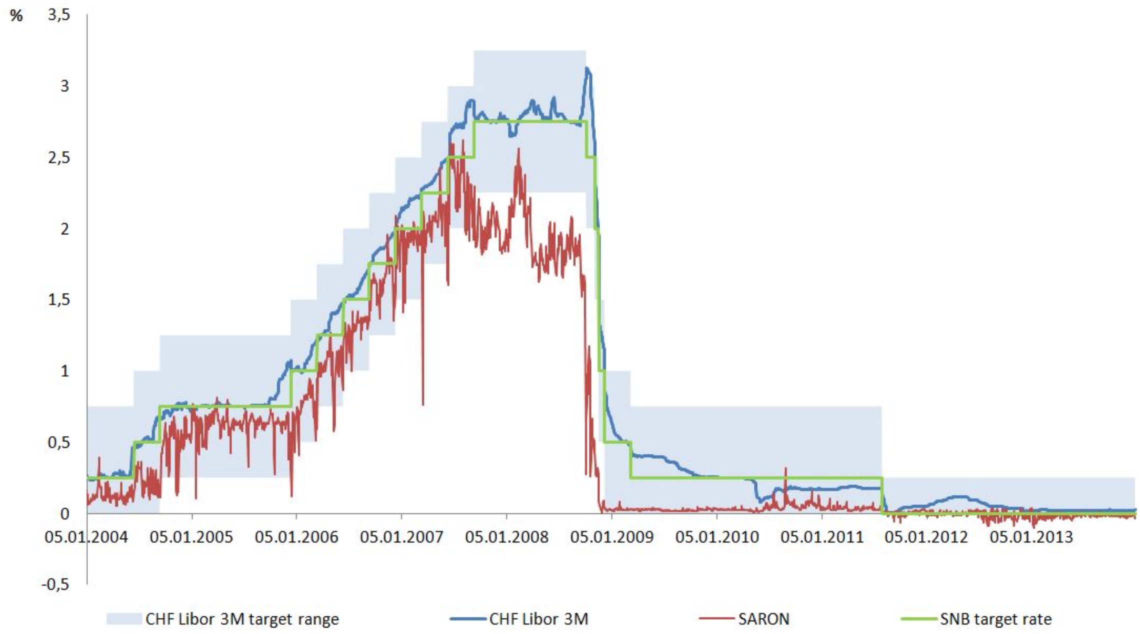

Figure 1: Interest rate movements and SNB monetary policy implementation (source: Swiss National Bank)

repurchase agreements (repos) as main instrument.[2] Other supplementary instruments are currency swaps, the issue of SNB Bills and purchases of foreign exchange. However, these are only relevant instruments in exceptional times, i.e. when interest rates are close to zero and additional expansive monetary policy decisions are needed. In the following, we will see how all these instruments were used by the SNB and more relevant, which effect they had during the analysed time frame 2004-2013.

The following analysis and especially the simulations distinguish between five different phases, every single one characterized by different peculiarities. Figure 1 is very useful to partly understand the subdivision of the whole period into different subperiods and to see how the SNB steers money market interest rates. Additionally, it is essential to understand the calibrations and simulations of chapter 4. But first of all some introductory comments. The figure shows the CHF Libor 3M (blue line) and its target range, which is regularly communicated to the public. It does not represent standing facilities as it is the case for the ECB, it has more the purpose of steering the expectations of the markets. An interest channel in the sense of a deposit and lending facility does not exist like in the European case. The SNB

[2] Briefly, in order to lower the Libor and to provide liquidity in the money market, the SNB buys securities from banks and credits the countervalue at the sight deposit account of the respective bank in return. Additionally, the bank committed to repurchase the securities at a later point in time when the repo matures. For the duration of the repo, the commercial bank has to pay a repo interest rate. (Kraenzlin (2007, pp. 243-244))

does not pay any interest on reserves. Therefore, the deposit rate is effectively zero. However, a lending facility is provided. The liquidity-shortage financing facility (ON special rate) can be used until the next bank working day (ON) through special-rate repo transactions. The red line illustrates the movements of the SARON (Swiss Average Rate Overnight)[3], which will be important for the later simulations of the repo market. The ON special rate is based on the SARON plus an interest premium. This fact constitutes an important drawback of adapting the theoretic model to the Swiss repo case. It will be discussed in the last section

The first division of the time series happens in August 2007. Until this point, money market stability played no decisive role in implementing monetary policy in Switzerland (Jordan et al. (2010, p. 48)). Therefore, the first period will be regarded as a phase of a "functioning money market", where interbank lending worked well and where no tension in the money market hindered the allocation of liquidity. We are able to see that the interest rate for secured ON repurchase agreements (SARON) constantly moved slightly below the Libor-3M (This refers to counterparty risk and maturity aspects). But from August 2007 on, a strong divergency between these two rates can be observed. With the onset of the US subprime crisis, increasing credit-risk and liquidity premia generated an upward pressure on the Libor-3M. In order to keep the target rate as stable as possible and close to it's aimed level, the SNB was able to move the repo rate for SNB transactions (one-week repo rate) in order to cushion the Libor (Amstad and Martin (2011, p. 4)).[4] This is the first indication of an increasing turmoil in the money market for CHFs and also represents the onset of the changing trading behaviour in the secured and unsecured money markets, that will be described in the following sections.

In addition to lowering the interest rates in SNB repo transactions, the SNB conducted other measures to support interbank trading. In order to counter the heightened pressure on money markets, the SNB provided measures to support the access to CHF and also USD liquidity.[5] For example, 28-day USD repo transactions were offered in return for SNB GC basket collateral (General collateral, eligible in SNB repos).[6]

The third phase begins with the Lehman Brothers default on September 15, 2008. In Figure 1, one is able to recognize an abrupt rise in the CHF Libor, which arouse

[3]It is a reference rate which depicts average interest rates of overnight transactions in the secured money market segment.

[4]For the Euro money market, contrary patterns could be observed. Because the ECB's interest rate target is short-term, the EUR Libor-3M experienced stronger fluctuations and an increase above the interest rate target.

[5]In these times, many non-US banks faced a global USD liquidity shortage.

[6]Many other measures are listed in the appendix of Jordan et al. (2010).

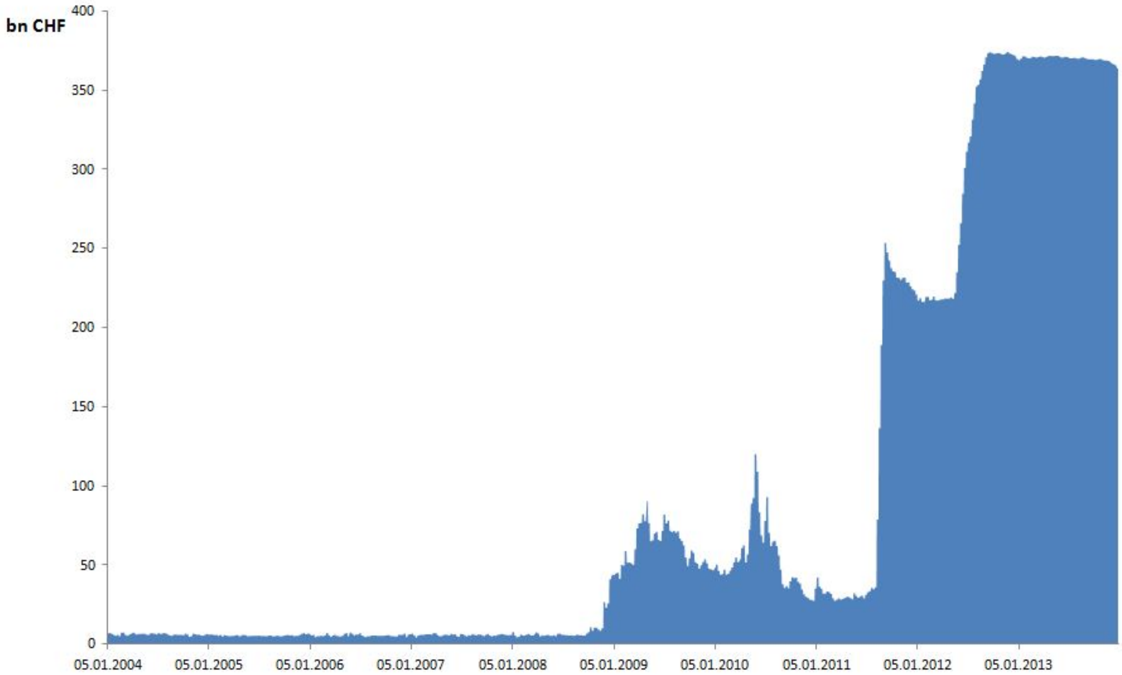

Figure 2: SNB sight deposits (source: Swiss National Bank)

from a reduced supply of Swiss francs in the interbank market, caused by high uncertainties about the Lehman turmoil. Additionally, many Eastern European banks were granting CHF denominated loans. According to the massive turmoil on the money markets, Swiss banks were no longer willing to provide liquidity in order to refinance these loans, finally resulting in a high excess demand, pushing up the CHF Libor 3M (Jordan et al. (2010, p. 49)). Therefore, the SNB needed to provide access to banks from abroad in order to avoid an undesired increase of the target rate. The EUR/CHF swap arrangements with the ECB led to a significant decrease in money market interest rates and a massive increase in SNB sight deposits (Jordan et al. (2010, p. 49)). The huge increase in reserves with the SNB illustrates Figure 2. Until the mid of the third period (December 2008), the stock of sight deposits at the SNB was around CHF 6 bn. With the peak of the turmoils in the money markets, the SNB sight deposits increased ten-fold. Parallel to these developments, the excess reserves emerged. The degree of minimum reserves fulfillment was around 120% in *Phase I* (January 2005 - August 2007). As soon as the sight deposits strongly increased, the fulfillment of the SNB's minimum reserves amount to 500 - 900%. A clear conclusion regarding these developments is that the banking system was satisfied with liquidity, having a negative effect on the trading activity in CHF money markets. In the further course of money market developments, the degree of fulfillment was even above 2000% in 2012 and 2013.

These recent developments have origin in the change of the SNB's monetary policy target. According to the European sovereign debt crisis, the CHF experienced a strong upward pressure compared to the EUR. Since September 6, 2011, the SNB has introduced a minimum exchange rate of CHF 1.20 in order to countervail losses in exports and tourism (Hildebrand (2011)). Consequently, the Swiss monetary policy is entirely focused on defending the minimum exchange rate and effective interest rate targeting became subordinate. The consequence has been a massive flood of money in the Swiss banking system (due to foreign exchange purchases), which resulted in dispensable interbank funding and high excess reserves.

Bech and Monnet (2013, p. 151-155) provide stylised facts appearing since 2008, which are all stemming from a massive increase in the amount of excess reserves in the banking system. Two of them are: (1) It drives down the overnight rate to the floor of the corridor and (2), it decreases the money market volume. These facts can also be transferred to the CHF money market and constitute the first hypothesis of this paper. An increase in sight deposits lowers money market interest rates and decreases money market turnovers. The following sections will specify this statement in more detail. In addition, in order to develop the other hypotheses and in order to further subdivide the time horizon, there is a need to deeper analyse the behaviour of the CHF money market. Despite the fact that the CHF repo market is the focus of this thesis, the developments on the unsecured money market need to be considered as well, because both segments are highly interconnected. Many developments on the secured money market result from changes in the unsecured money market environment and vice versa. What this exactly means will become clear in the following.

2.2 The Unsecured Market

Turnover analysis

The turnover developments in the CHF unsecured money market are characterized by a constant decrease since 2007. Figure 3 [7] depicts the day-to-day (ON, Tom-Next and Spot-Next) segment, which represents approximately 75% of unsecured money market transactions (Guggenheim et al. (2011, p. 12)). Until the mid of

[7] The figures for unsecured money market turnovers are built on estimates by the SNB, based on data from the Swiss Payment System (SIC). Guggenheim et al. (2011) describe the identification algorithm in their paper, which searches for transactions from bank A to bank B and vice versa. i.e.: for ON transactions the reverse payment needs to take place on the following working day. The interest rate of a transaction is calculated by taking the difference of the payment and repayment value. When it is within a certain search band, an ON transaction is identified.

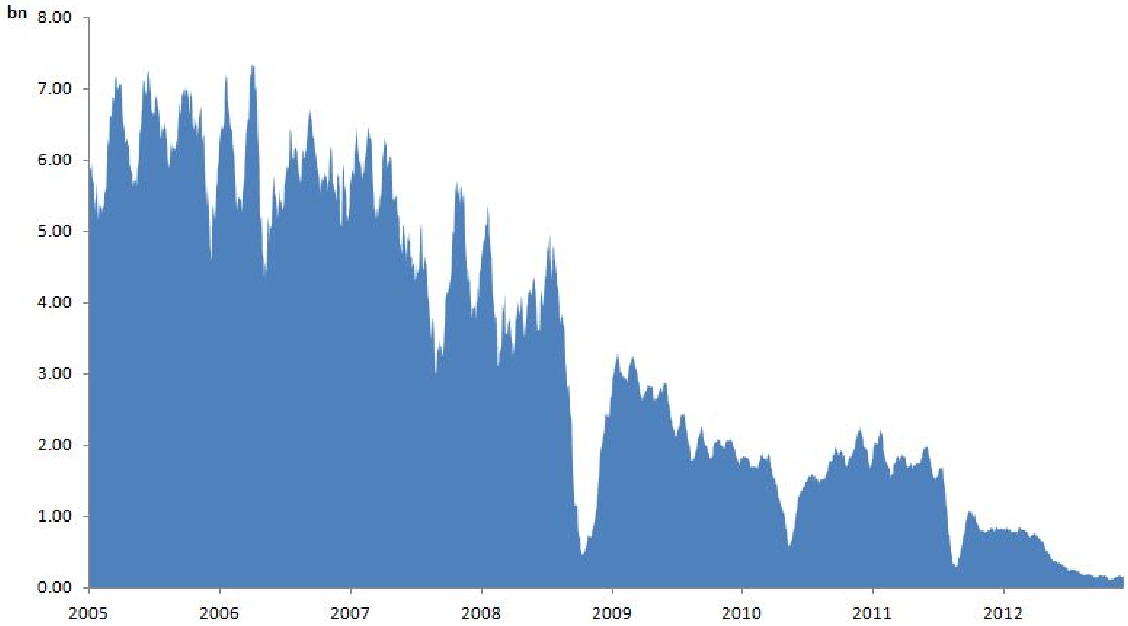

Figure 3: Unsecured Turnover (20 day moving average)(source: Swiss National Bank)

2007 (*Phase I*), the respective turnover moved around CHF 6 bn. But when the subprime phase of the crisis began, the onset of a constant decline in turnovers appeared, resulting in an average level of approximately CHF 4 bn in *Phase II*. But the large turmoil beginning in *Phase III*, resulting from the Lehman Brothers default in August 2008, led to a freezing up of transactions and a strong decline in the ON turnover of below CHF 1 bn. In the end of 2008, the SNB started to provide liquidity to the interbank market by using EUR/CHF swaps and longer-term repos, resulting in an increase in market confidence (Guggenheim et al. (2011, p. 12)). Hereby, unsecured lending started to increase again. Despite the slight recovery at the beginning of 2009, the unsecured money market continued to slowly contract until now, where it reached the minimum turnover since 2005 of below CHF 200 mio. Additionally, figure 3 reveals that further shocks, like the uncertainty about the excess indebtedness of Greece (May 2010) and the extended European sovereign debt crisis spreading in August 2011, hit the money market, bringing the unsecured turnover to a local minimum again. Finally, the liquidity provision since September 2011 completely disrupted the unsecured money market.

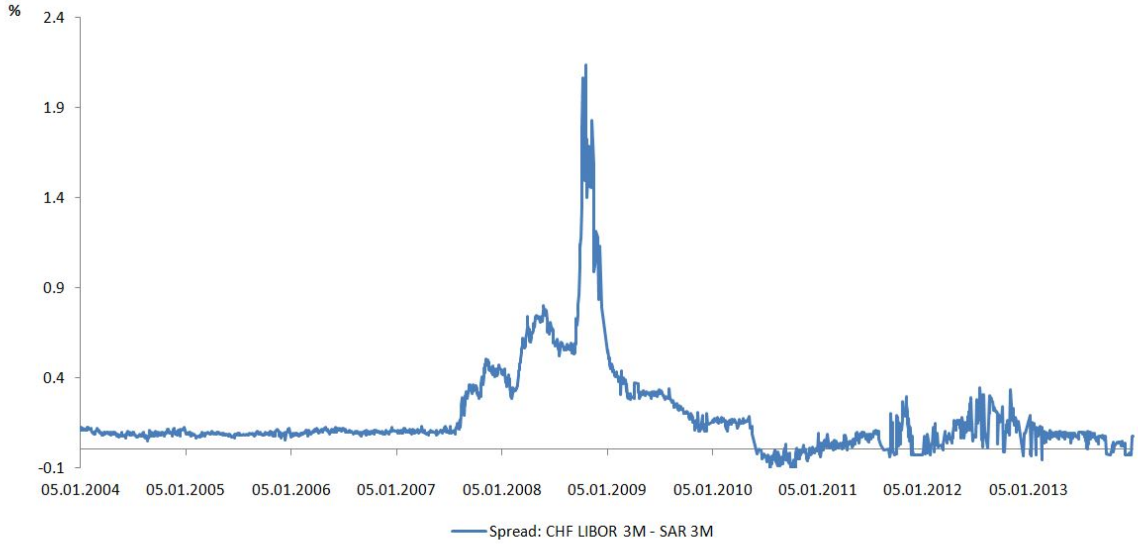

Figure 4: The risk premium in the Swiss franc unsecured money market (source: Swiss National Bank, SIX)

Counterparty risk and its role for unsecured money market activity

In comparison to the secured money market, the unsecured money market underlies higher counterparty risks in general, because transactions in this market are not backed by collateral. The spread between the CHF Libor 3M (unsecured) and the Swiss average reference rate (SAR3M; secured) with the same maturity can be used as a measure for risk premia in the unsecured money market. The only difference between both interest rates is the limitation of counterparty risk in the secured segment by using collateral in order to back up transactions. When counterparty risk starts to increase, investors demand a higher risk premium in the unsecured segment and the interest rates start to diverge. Figure 4 depicts this spread around the biggest turmoil in the financial crisis. Before the onset of the crisis in 2007, counterparty risk in the global interbanking markets seemed to be moderate. The risk premium for CHF unsecured transactions constantly averaged around 0.1 percent, describing a very low level of counterparty risk. In August 2007, the risk perception in the Swiss unsecured money market began to rise until it peaked on October 22, 2008. Afterwards, the turmoil in the money market seems to fade away. In May 2010, the spread reaches the pre-crisis level again for the first time and even becomes negative occasionally. But the increased variance in comparison to pre-crisis levels, still indicates some loss of confidence in the money market, possibly arising from the European sovereign debt crisis and its spillovers to the banking sector. Overall, it is obvious that decreases in the CHF unsecured money market turnover coincide with a higher risk premium.

SNB liquidity provision and unsecured money market activity

An increase in risk perception leads to decreased lending in the unsecured interbank market according to concerns about the credit quality of borrowers. But what additional conclusions can be drawn from this consideration? The strong decrease in unsecured money market activities in 2007-2008 mainly stems from a strong increase in perceived counterparty risk. After the tensions disappeared and risk premia reached normal levels again, other factors need to dominate from that point on. According to the evolution of sight deposits at the SNB, SNB reserves increased to CHF 100 bn in Mai 2010, to CHF 250 bn in September 2011 and currently move above CHF 350 bn (the pre-crisis level was around CHF 5 bn). This substantial stock of liquidity covers the funding needs in the banking system and makes it dispensable to operate in the money market at all. (Obviously, this will also have an impact on secured transactions in the money market, which we will see in the following section). Additionally, this drives down the interest rates in the money market to historically low levels and interbank lending becomes unattractive for return purposes (Guggenheim et al. (2011, p. 15)). Therefore, decreases in interbank money market turnovers, induced by expansive monetary policy, arise from both sides, the demand and the supply side.

From all these considerations, we are able to identify additional information on the classification of the different phases and link them to specific characterizations, which will be used in the last section in order to calibrate and simulate the model presented in section 3. As already mentioned, *Phase I* is obviously and reaches until the onset of the subprime crisis. It is characterized by functioning money markets and moderate counterparty and liquidity risk. The provision of central bank liquidity is moderate as well. The further *Phases II - V* will be divided according to some shocks that were mentioned before. However, there is a need to consider the developments in the secured money market segment either, as it provides additional insights for characterizing the different phases. Furthermore, the theoretical model focuses on the repo market, which is why the following section and conclusions should be highlighted.

2.3 The Secured Market

The secured CHF money market can be classified with respect to the different interacting counterparties. Like in the unsecured money market, banks are able to interact with each other. This partition describes the interbank part of the market.

Contrary to the unsecured money market, also the SNB provides a source of funding for the banking system. Therefore, the second partition is called the SNB market, where repo agreements involve the SNB. However, all transactions, if among banks or with the SNB, are conducted via the same trading platform, the EUREX repo.

Since 1997, the SNB is allowed to use repurchase agreements as an operating tool in order to implement monetary policy (Kraenzlin (2007, p. 242)). This decision and the fact that the Swiss franc repo market was finally launched in 1998 constitutes the ongoing growth of the secured money market in Switzerland. The secured Swiss franc money market, as the name indicates, is a market where short-term funding is conducted in response for collateral. So-called repurchase agreements (repos) describe the sale of securities with an agreement for the seller (cash taker) to buy back the securities at a prespecified date. Additionally, the cash taker bears an interest for the time to maturity of the agreement. According to the fact that repos are backed by securities, they are characterized by a limited risk of default.[8] This feature will be especially important, regarding the developments during the recent financial crisis and phases of stress (or counterparty risk) in interbank markets. As we have seen in the previous section, turnovers in the unsecured money market suffered from the increase in interbank counterparty risk. This is very different for the case of secured money market transactions.

Turnover analysis

With the launching of the Swiss franc repo market in 1998, the secured money market experienced a constant increase. Figure 5 depicts the turnover in the ON secured market segment, which constitutes the most important maturity in CHF money markets.[9] It illustrates the ongoing but steady increase of the secured money market turnover until August 2007. Starting with *Phase II*, a boom in turnover rates of this segment appeared, whereas the unsecured money market started to decline. Especially in September 2008, the secured segment peaked at nearly CHF 7 bn, whereas the unsecured segment dropped to CHF 600 mio in this phase. Therefore, the increase in counterparty risk not only leads to a freeze up in the unsecured money market, it furthermore led to a shift from unsecured to secured transactions, because the funding needs still had to be satisfied.

When the level of counterparty risk seemed to normalize, the secured turnover also

[8]See Kraenzlin (2007) for possible risks in the repo market.

[9]The ON maturity transactions amount to 77% in the secured segment and to 75% in the unsecured segment (Kraenzlin (2007, p.22)).

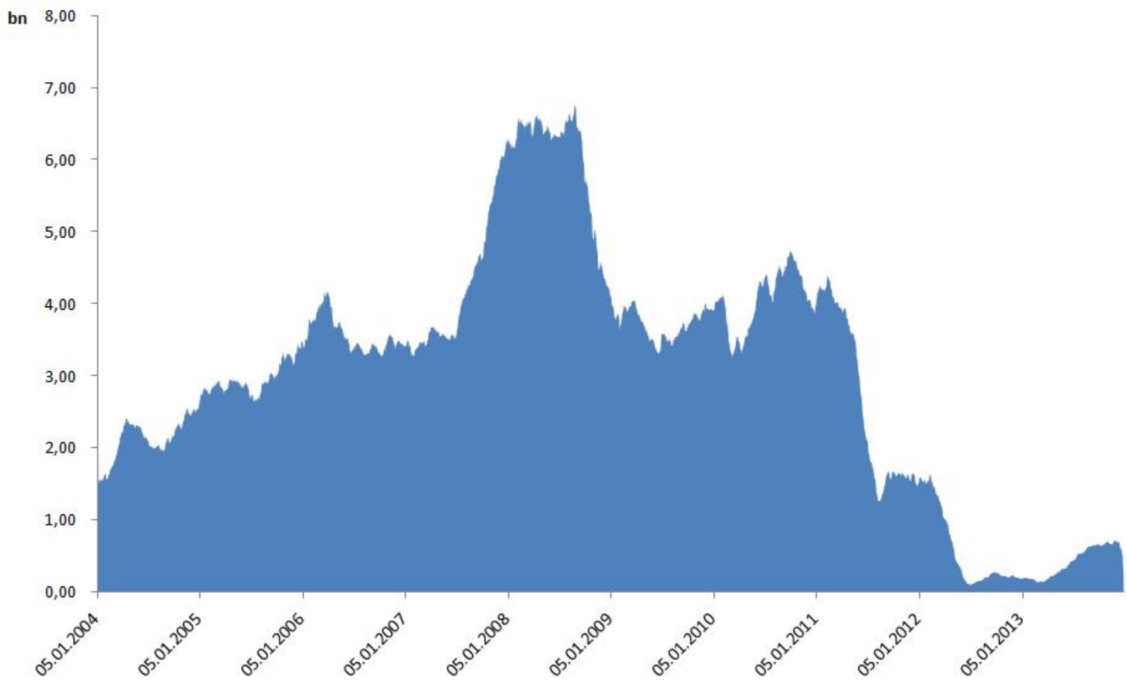

Figure 5: ON Secured Turnover (20 days moving average) (source: Swiss National Bank)

reached pre-crisis levels. In the end of 2008, the SNB started to provide large amounts of liquidity depicted in figure 2, which contributed to the decrease in liquidity risk and turnover rates. An overall decline in money market activities was the consequence and as already mentioned, this mainly stems from the satisfaction in liquidity and the resulting low interest rates. However, since the mid of 2011, the secured money market suffered even more and nearly completely dried up in the mid of 2012, which was clearly caused by the increased amount of sight deposits respectively the therewith related flood of liquidity in the banking system.

All these figures describe the aggregate secured money market (SNB and interbank transactions). The turnover movements in the interbank segment were even stronger. From 1999 to 2005, the interbank part gained more and more in importance. In the beginning, it accounted for 10 %, whereas in 2005, the interbank fraction of the secured segment was at 60 % (Kraenzlin (2007, p. 245)) and at 67 % in 2007. Thereafter, with the onset of the crisis, it became less important again (50 % in 2009). The total outstanding volume of the SNB market was constantly at CHF 20 bn until 2008. With the onset of the strong liquidity provision, the outstanding volume with the SNB increased to CHF 40 bn, whereas the volume in the interbank market decreased by 50 %. (Kraenzlin and von Scarpatetti (2012, pp. 80-81))

Counterparty risk, liquidity needs and the role for the secured money market

Figure 4 revealed that *Phases II - IV* were massively characterized by a high level of counterparty risk in the banking system, but this is of minor importance for the secured segment. However, the spread between secured and unsecured interest rates leaves space for further interpretations. As data on money market liquidity conditions (especially microstructural data on idiosyncratic funding needs) are not easily available, the increase in counterparty risk is linked to an aggregate shock to liquidity needs. Because the loss of confidence in counterparties was triggered by the "bursting of the housing bubble, combined with a large exposure by the levered financial institutions" (Pedersen (2009, p. 148)), banks faced significant losses associated with funding liquidity problems. Additionally, banks started hoarding their liquidity, anticipating bank runs of their clients resulting from the aggregate loss of confidence in the banking system (only 2/3 of the unsecured turnover reduction were picked up by the secured segment).[10] A result is the higher variance in idiosyncratic liquidity needs. Overall, lenders shift their excess liquidity not just into the secured segment, they additionally seek to lend their cash holdings in the very short-term money market (most liquid), constituting a positive relationship of liquidity needs variance and ON repo market turnover. The structural liquidity position of the banking system versus the SNB (Figure 15 in the appendix) is used in addition, in order to evaluate the liquidity needs in the Swiss money market. Until the mid of 2009, the banking system faced a liquidity deficit. From that point on, a big surplus in liquidity emerges. Consequently, the conclusions drawn from figure 4 need to be relativised. The higher variance in idiosyncratic liquidity needs only reaches until the end of *Phase III* (March 2009). This point in time constitutes the begin of *Phase IV*, a period with low aggregate liquidity needs. Until now, it is important to keep the possible effects of an increase in the aggregate liquidity needs variance in mind:

liquidity needs variance $\uparrow$ $\rightarrow$ ON secured money market turnover $\uparrow$

Kraenzlin and von Scarpatetti (2012, p. 80) show that even at the height of the crisis, a shift from long- to short-term transactions was not the case for the Swiss repo market. The average maturity stayed at 30 days in 2007/2008. The effect of an increased variance of liquidity needs on the ON repo market seems to be limited

[10]This assumption additionally builds on asymmetric information about counterparty risk in the interbank market. Banks with excess liquidity who cannot distinguish between safe and risky banks economize on their lending. Liquidity hoarding is a consequence and the variance in idiosyncratic liquidity needs increases.

in this regard. A conclusion which will be confirmed by the simulation in section 4.

Berentsen et al. (2010, p. 5) additionally assign the effect of an increase in the idiosyncratic liquidity needs variance on ON repo interest rates a negative sign and the model will later on confirm this assumption. At the first sight, this effect seems to be against expectations. But secured interest rates reflect both, demand for cash and demand for collateral. Therefore, it is important to consider the effect of an increase in demand for collateral, resulting from higher liquidity needs and a stronger preference for secured lending. The more scarce (and valuable) collateral becomes relative to supply, the lower the interest rate that cash providers demand for lending in response for collateral (ceteris paribus). (Jackson and Sim (2013, p. 229))

The role of collateral

Because every secured money market transaction needs collateral to be covered, the development of the stock of collateral is essential for the developments of the repo market. Eligible collateral for repo transactions is subdivided into different baskets, which contain different kinds of assets. Depending on which counterparty a cash taker chooses (bank or SNB), the range of eligible assets changes. For SNB transactions, assets listed in the SNB GC (general collateral) Basket are eligible. It consists of the CHF GC Basket, the GOV GC Basket and the INTL GC Basket. The former covers assets denoted in CHF, issued by various principles. They need a minimum rating[11] of A and a minimum issue size of CHF 100 mio. Assets issued by foreign central banks and sovereigns denoted in other currencies are included in the second basket. It contains securities denominated in euros, US dollars, pounds sterling, Danish kroner, Swedish kroner or Norwegian kroner with a minimum rating of AA- and a minimum issue size of CHF 1 bn. The international basket contains all other assets not issued by sovereign entities but fulfilling the same minimum standard as for the GOV GC Basket. (Instruction sheet on collateral eligible for SNB repos (2009))

For interbank transactions executed on the EUREX repo trading platform, additional baskets can be taken into account. These are the equity baskets SMI GC Equity Basket and DAX GC Equity Basket, which contain 20 SMI stocks and 30 DAX stocks. But as Fuhrer et al. (2014, p. 5) discovered, these additional baskets are of minor importance because more than 95% of the CHF repo market transactions are conducted via the SNB GC Basket. Furthermore, they point out that, compared to other CBs, the SNB collateral framework is rather restrictive with re-

[11] Here depicted as S&P and Fitch ratings.

gard to the asset quality, but liberal with respect to the range of eligible currencies. A very important change regarding collateral eligibility was launched in October 2007, where the SNB decided to enlarge the SNB GC basket by widening the range of eligible currencies, keeping all other minimum requirements equal. The consequence was a growth of the basket from CHF 6 to 10 tn (Fuhrer et al. (2014, p. 5)). Concluding, the amount of useable collateral massively increased at this point in time. But does this increase mean that collateral is sufficiently available? Fuhrer et al. (2014) linked the scarcity to the re-use of collateral[12] and found out that a positive relationship exists between these two factors. As the re-use of collateral decreased after the change in the collateral framework, the obvious conclusion is an increase in the stock or amount of collateral eligible in CHF money market transactions. A collateral crisis regarding the recognizability of securitized assets (like in the U.S.) seems to be of minor importance for Switzerland. As Danthine (2011, p.p. 2-3) describes, a collateral crisis in the repo market was more pronounced in the U.S., because collateral baskets were strongly widened to lower rated assets, whereas in Switzerland 99.8% of the secured money market transactions were backed by SNB GC basket collateral, satisfying stringent quality requirements.

Finally, according to the additional insights that have been gained in the last sections, a complete characterization of the different phases is possible. Taking the developments of the monetary policy environment and the unsecured and secured money market together, the periods (II-V) can be split the following:

- *Phase II*: August 2007 - September 2008 (subprime crisis)
- *Phase III*: September 2008 - March 2009 (Lehman default)
- *Phase IV*: March 2009 - May 2010 (high liquidity provision)
- *Phase V*: May 2010 - August 2011 (Greece debt crisis)

Table 1 illustrates the different changes of the sight deposits, the collateral stock, interbank counterparty risk, liquidity needs and repo turnovers in comparison to *Phase I*. In section 4, the explanatory power of the model will be checked by comparing the empirical developments with model provided simulations.

[12] The Financial Stability Board defines the re-use of collateral as "securities delivered in one transaction [that] are used to collateralize another transaction". (Financial Stability Board (2012, p. 22))

	Phase I	Phase II	Phase III	Phase IV	Phase V
sight deposits	0	0	+	+ + +	++
liquidity needs	0	++	+ + +	−	−
counterparty risk	0	++	+ + +	+	+
collateral	0	++	+	+	+
repo turnover (total)	0	+ + +	++	0	+
interbank repo turnover	0	+ + +	++	−	−

Table 1: Characteristics of the different phases

2.4 Recent regulatory developments

Before the financial turmoil started in 2007, asset markets were liquid and funding on international money markets was regarded as riskless and did not obtain much attention (Kacperczyk and Schnabl (2009, p. 1)). However, this situation changed and several institutions faced severe liquidity problems. This raised questions with respect to new regulatory issues, concerning the vulnerability of the banking system regarding liquidity risks. The outcome is the Basel III regulatory framework which has to be implemented stepwise until 2019. Beside a higher capital adequacy, two ratios will be implemented, aiming at achieving a more stable level of liquidity in the banking system. The first one is the Net Stable Funding Ratio (NSFR).

$$NSFR = \frac{Available\ amount\ of\ stable\ funding\ (ASF)}{Required\ amount\ of\ stable\ funding\ (RSF)} \geq 100\%$$

Stable funding means equity and liability like funding, expected to be reliable funds over a one year horizon of extended stress. The required amount is composed of the value of assets, which cannot be liquidized within one year. In a nutshell, it requires banks to fund their assets in a more stable way. The aim is to support the medium- to long-term funding of banking activities, reducing the mismatch between assets and liabilities.[13] The other ratio which will be implemented is the Liquidity Coverage Ratio (LCR). It is more concentrated on liquidity drawings in the short run (30 days) and forces banks to hold sufficient liquid assets on the asset side of the balance sheet in order to be able to compensate deposit drawings.

$$LCR = \frac{Stock\ of\ High\ Quality\ Liquid\ Assets}{Total\ net\ cash\ outflows\ over\ next\ 30\ days} \geq 100\%$$

[13]Term transformation is a main function of bank institutions and it is the key source of profits. In general, short-term refinancing is preferred in order to cover a bank's liquidity need because the cost of refinancing increases with the maturity.

It ensures that a bank holds sufficient High-Quality Liquid Assets (HQLA), easily convertible into cash in order to meet liquidity needs in a 30 days stress scenario.[14] In order to fulfill the LCR requirements, banks have different opportunities. First, they can increase their unsecured funding with a duration of more than 30 days, reducing the level of potential outflows during the stress scenario. For example, despite the fact that an ON unsecured interbank loan is a cash inflow, it also increases the cash outflow due to the next day. Therefore, it fully needs to be covered by HQLA and no improvement in the LCR occurs (unsecured short-term money market loans have a run-off rate of 100%). In general, any unsecured interbank loan of up to 30 days must be fully backed by HQLA, which increases the cost of this kind of funding, making it unattractive for borrowers (Schmitz (2013, pp. 146-147)). Consequently, this may induce a shift from short- to long-term trading activity, putting downward pressure on the ON unsecured money market interest rate as well.

The effects on the secured money market are more complex. When repos are collateralized by level 1 assets[15](0% run-off rate), they do not need to be covered by HQLA. If conducted via level 2 assets[16], the collateral receives a haircut of minimum 15% (non LCR eligible collateral repos have 100% run-off rate) (Schmitz (2013, pp. 147-148)). Therefore, using HQLA for repo transactions is preferred. Overall, the secured segment will be more advantageous compared to unsecured transactions and the previous shift to secured transactions will be intensified by the LCR implementation. Further developments of the repo markets are dependent on specific collateral standards and haircut practices. If repo transactions are mainly conducted via domestic high quality collateral, nearly no effect of the implementation of the LCR appears with regard to the secured money market, because the cash and the security are considered as HQLA in the LCR. However, when level 2 assets or non-HQLA are used for repos, haircuts are applied which might be divergent from LCR and repo market perspectives (Market haircuts for level 1 assets are higher and lower for level 2 assets, compared to LCR haircuts.). Therefore, repos are not necessarily LCR neutral and participants might become more selective regarding the quality and currencies of collateral in repo transactions. Divergent interest rate curves for repo transactions with different classes of collateral might be a consequence (Danthine (2013, p. 266)).

[14]For a more detailed explanation of the constitution, implementation and origin of the NSFR and LCR, see Basel Committee on Banking Supervision (2013).

[15]Level 1 assets are characterized by having the highest quality and liquidity on the strength of art. 17b "Banking liquidity act". These are coins, banknotes, CB reserves and claims on sovereigns, CBs, the BIS, the IMF with 0% risk weight under Basel II.

[16]Claims on sovereigns, CBs with 20% risk weight under Basel II, corporate bonds (not issued by financial institutions) and covered bonds (not issued by the bank itself) with high rating.

Another important and often discussed issue is the increased demand to hold HQLA, resulting in a decrease of the supply of such assets for repo transaction purposes. This will potentially reduce the liquidity in the secured money market and increase market volatility. Especially in times of increased counterparty risks in interbank markets, where some banks may be excluded from unsecured money market trading, this effect may experience an even stronger relevance. (Doran et al. (2014, p. 94))

The NSFR is likely to have comparable effects on money markets. It forces banks to fund their assets in the longer term, reducing the demand for short-term funding. Again, the activity in the money markets will be negatively affected. At the current point in time, with money markets beeing freezed at all, it will be difficult for central banks to reactivate trading in this segment and to find the right exit strategy from current monetary policy stances. This will likely be hindered through the new liquidity regulation, discriminating funding in money markets. (Doran et al. (2014, pp. 93-96))

But what are the specific characteristics of the Swiss money market environment? As we saw in the previous sections, the current level of liquidity in the banking system is very high according to the growth of SNB sight deposits, which are also added to the stock of HQLA. The "Erläuterungsbericht zur Revision der Liquiditätsverordnung" of the "Eidgenössisches Finanzdepartement" reveals the scarcity of CHF HQLA in Switzerland apart from CB reserves (Eidgenoessisches Finanzdepartement (2014, p. 37)).[17] About 3/4 of the CHF HQLA stock are SNB sight deposits. When the SNB decides to find back to the traditional liquidity deficit, the decline of reserves will not be able to be compensated by holding Level 1 assets in Swiss francs, depending on the choice of instrument (Danthine (2013, p. 265)).

Bech and Keister (2013*a*,*b*) pick up these considerations and provide a theoretical framework for implementing monetary policy in the presence of LCR requirements. It builds on the work of Poole (1968), where a bank's balance sheet has the following composition.

Assets			Liabilities
Loans	L	*Deposits*	$D-\varepsilon$
Bonds	B	*Net interbank borrowing*	$\Delta_t+\Delta_T$
Reserves	$R+\Delta_t+\Delta_T-\varepsilon+X$	*Central bank borrowing*	X
		Equity	E

[17]The scarcity of HQLA denoted in CHF is important because "a bank should be able to use the stock to generate liquidity in the currency and jurisdiction in which the net cash outflows arise." Basel Committee on Banking Supervision, Basel III: The Liquidity Coverage Ratio and liquidity risk monitoring tools.

Banks can issue deposits D, lend from the CB (X) at rate r_X and raise capital E. Additionally, they are able to borrow in the interbank market where $\Delta_t + \Delta_T$ denote the amount of ON and term loans (maturity $>$ 30 days). Negative values correspond to lending and respective interest rates are r_t and r_T. On the other side, they hold loans L, bonds B and reserves R (the deposit rate is r_R) as assets. There are also liquidity shocks existent. An amount ε is drawn off the deposits and sent to another bank (positive). If it is negative, it means an unexpected inflow of funds. Finally, banks are subject to reserve requirements $R + \Delta_t + \Delta_T - \varepsilon + X \geq K$ and need to fulfill the LCR regulation

$$LCR = \frac{B + R + \Delta_t + \Delta_T - \varepsilon + X + F}{\theta(D - \varepsilon) + \Delta_t} \geq 1,$$

where θ is the run-off rate of deposits and F is a Committed Liquidity Facility (CLF) provided by the CB. Minimizing the amount a bank has to borrow from the CB yields in critical values

$$\varepsilon_K^* = 0, \quad \varepsilon_C^* = \frac{B + F - \theta D}{1 - \theta} \quad and \quad \hat{\varepsilon^*} = -\frac{B + F - \theta D}{\theta},$$

where ε_K^* is the critical value until which reserve requirements are satisfied (minimum reserves are assumed to be zero (Bech and Keister (2013a, p. 195)). Until ε_C^* LCR requirements are satisfied. If $\varepsilon_K^* < \varepsilon_C^*$, borrowing needed to satisfy the reserve requirement also suffices to satisfy the LCR requirements. If $\varepsilon_K^* > \varepsilon_C^*$, the amount borrowed from the CB is determined by the need to meet the LCR until $\hat{\varepsilon^*}$. If $\varepsilon > \hat{\varepsilon^*}$, the amount borrowed from the CB is determined by reserve requirements. If no LCR requirement is implemented ($\theta = 0$), the critical values always satisfy $\varepsilon_C^* \geq \varepsilon_K^*$ and banks only need to manage their reserve requirements. The short-term interest rate is in the mid of the interest channel $\bar{r} = (r_X + r_R)/2$ and the term interest rate is given by $r_T = \bar{r} + \tau$ where τ is a premium for credit and liquidity risk. (Bech and Keister (2013a, p. 195))

$$r_T^* - \tau = r_t^* = \bar{r}$$

Maximizing the expected profit with respect to the interbank borrowing activity yields the interbank interest rates in equilibrium. When the LCR requirement is binding ($\theta > 0$), they satisfy

$$r_t = r_R + (r_X - r_R)(1 - G[max\{\hat{\varepsilon^*}(B), 0\}])$$

and

$$r_T = r_R + (r_X - r_R)(1 - G[min\{\varepsilon_C^*(B), 0\}]) + \tau.$$

$G[\cdot]$ is a common, symmetric distribution with zero mean out of which ε is drawn from. When B is less than $\theta\bar{D}$ (when cash outflows in the stress scenario are not sufficiently covered by HQLA, i.e. HQLA is scarce), then $\varepsilon_C^* < 0$ and $\varepsilon^* > 0$. It becomes clear that the lower the bond holdings, respective the stock of bonds is ($\partial\varepsilon_C^*/\partial B > 0$ and $\partial\hat{\varepsilon^*}/\partial B < 0$), the steeper the yield curve is (a decrease in collateral pushes the ON money market interest rate to the floor). Even in equilibrium, Bech and Keister (2013*b*, p. 198) show that

$$r_T^* - \tau > \bar{r} > r_t^*.$$

Under liquidity regulation, the short-term money market rate is below the mid of the CB corridor and the yield curve becomes steeper. Additionally, when a limited supply of HQLA is present in an economy, a large regulatory liquidity premium might emerge and short-term interest rates are further pushed down to the CB interest rate corridor. However, they provide a solution in order to work against this unappreciated effect of hindered effective steering of interest rates. Introducing a CLF allows to mitigate this effect. F takes the form of a CLF, which means that CBs are able to provide contractual committed liquidity lines for an up-front fee (Bech and Keister (2013*a*, p. 195)). We see that with an increase in F, the critical shocks can be harmonized, such that banks are less confronted with failing to achieve the LCR requirements under HQLA scarcity. According to these considerations, the Basel Committee on Banking Supervision revised the Basel III liquidity rules and added the possibility of a CLF for jurisdictions facing domestic currency HQLA scarcity on January 2014 (Basel Committee on Banking Supervision (2014)).

Regarding the segmentation of the repo market, caused by different haircut applications in the market and for the LCR, the Swiss money market is likely to be affected. About 99% of all repo transactions are concluded against the SNB GC basket and not against specific securities. Additionally, 96% of the collateral in CHF repo transactions is denominated in foreign currencies. In the past, nearly no haircuts were applied in the CHF repo market. However, this is different for the LCR consideration. Transactions against non-CHF assets will have a negative impact on the LCR, leading to the previously explained segmentation of repo transactions. Because participants want to choose specifically which kind of assets to use in order to collateralize transactions and to optimize their coverage of liquidity in the LCR. (Danthine (2013, p. 266-267))

3 A Model to analyse Money Market Interest Rates

In the following section, a model of Berentsen et al. (2013) and Berentsen et al. (2010) will be presented in order to analyse the behaviour of the Swiss money market in recent years. The preceding sections highlighted three main factors, affecting the trading behaviour as well as interest rate movements in the Swiss money market during the crisis. First of all, high losses and a change in counterparty risk influenced liquidity needs in the banking system. Therefore, one can assume an aggregate variance shock in liquidity needs if there appears a turmoil in the money market. Secondly, a large supply of money by the SNB decreased the activity in CHF money markets and has driven down respective interest rates. As it will be presented later on, this shock can also be interpreted as an aggregate collateral shock in this model framework because the money and collateral stock both come up in one variable (In sections 2.3 and 2.4 it became obvious, that this shock is especially important for repo markets, which is the focus of the model). According to recent developments of SNB sight deposits, it will be mainly regarded as an aggregate money supply shock. However, when analysing the money market developments during the Lehman Brothers default and taking the problems on the market for securitized assets into account, it is more meaningful to regard this shock as a decrease in collateral eligible assets. Therefore, a mixture of both effects seems to be the empirically relevant case. Summing up, the hypotheses building on the descriptive analysis from section 2 are:

- *Increased counterparty risk and high losses in the banking system triggered an aggregate variance shock, increasing the liquidity needs in the banking system, driving down money market interest rates and increasing the turnover in the secured money market segment.*
- *The SNB's monetary policy triggered an aggregate money supply shock, driving down money market interest rates and decreasing the money market turnover.*
- *The Lehman Brothers bankruptcy triggered an aggregate collateral shock, driving down money market interest rates and decreasing the money market turnover.*

3.1 Basic Settings

The model of Berentsen et al. (2013) builds on the Lagos-Wright framework introduced by Lagos and Wright (2005). In this kind of model, time is discrete and infinitely lived agents can interact in distinct markets, which open subsequently and are characterized by different forms of frictions. In the version at hand, a time period (one day) consists of three subperiods where three markets open consecutively. Originally, the timing was inspired by the features of the European money market. At the beginning of the day, outstanding loans from interbank and ECB transactions are settled. After that, banks operate in the euro money market from 7 a.m. to 5 p.m. Finally, when the interbank market closes, the ECB provides its standing facilities for additional 30 minutes (Berentsen et al. (2013, p. 4)). This concept can also be transferred to the Swiss money market. Therefore, one period consists of the settlement market (SM), the money market (MM) and the standing facilities market (SFM) which are all assumed to be perfectly competitive. (Berentsen et al. (2013, p. 4))

In the SM, agents are able to settle their claims from the previous day and all agents are able to produce a SM good x by providing labour h, the only factor of production with a constant returns to scale technology. The utility of consumption and the disutility of production are both assumed to be linear (consuming x units yields utility x and producing h units of the good causes disutility -h). New money and new bonds are issued in the SM and trade takes place by direct bilateral barter. Money is delivered for newly issued bonds. (Berentsen et al. (2013, p. 4))

In the money market, agents are able to adapt their money holdings, depending on their preference or need for liquidity. They can borrow or lend money against collateral from other agents. These transactions depend on the money market interest rate i_m which emerges competitively and under market clearing. Accordingly, an agent who borrows one unit of money in the MM repays $(1+i_m)$ in the next SM. In the following, let $\rho_m = 1/(1+i_m)$. When the money market opens, agents are hit by an idiosyncratic preference shock ε, which has a continuous distribution $F(\varepsilon)$. It is iid across agents and serially uncorrelated. The higher the shock is for a buyer, the higher are his liquidity needs. In order to satisfy these needs, agents can participate in the money market, adjusting their money holdings. (Berentsen et al. (2013, p. 5))

However, an agent does only have access to the MM with probability π. With converse probability $(1-\pi)$, an agent is suspended from interbank trading and needs to use the standing facilities provided by the CB in order to adjust money holdings with respect to his preference shock. This happens in the SFM. Agents can trade goods (SFM good q) for money and a CB provides a deposit and lending facility at interest rates $i_d \leq i_l$ where agents can deposit money to earn i_d and borrow money against collateral at i_l. The partial exclusion of banks from the money market is essential in order to generate a need for CB facilities. Because the interest rates for standing facilities build a channel around the money market rate, agents would never pay interest rates $i_l > i_m$, when they have access to the money market. On the other side, they would never deposit money at the CB in order to earn $i_d < i_m$. A clear preference for interbank trading is the consequence. Again let $\rho_d = 1/(1 + i_d)$ and $\rho_l = 1/(1 + i_l)$. Then $\rho_d \geq \rho_l$ illustrates the CB's bid-ask spread. On the one hand, an agent who borrows one unit of money at the lending facility repays $(1+i_l)$ in the SM. On the other hand, if an agent deposits one unit of money at the CB, he receives $(1 + i_l)$ in the SM. (Berentsen et al. (2013, p. 5))

In the MM and SFM, agents can differ in their technologies and preferences, generating a foundation for the existence of money (coincidence of wants problem). If an agent prefers to consume the SFM good q, he is a buyer. If an agent has no preference for consumption, but has the technology to produce, he is a seller. In general, buyers are not able to produce but want to consume and sellers can produce but have no demand for consumption. This is why direct barter between buyers and sellers is ruled out in the MM and SFM. The buyer is not able to reciprocate the seller's wants. Anonymity of agents creates additional frictions. More precisely, the assumption of missing credibility of buyers to repay their debt to sellers in the SM and a missing record keeping or monitoring mechanism makes sellers refuse offerings based on credit arrangements. Therefore, using assets as collateral or directly handing over the assets to the seller for payment is necessary to facilitate trade in the SFM.

The agents are endowed with two kinds of assets, money m and nominal government bonds b ($\rho = 1/(1 + i)$ is the price of bonds in the SM), which have a maturity of one period. Therefore, a bond delivers a payoff in the SM, denoted in one unit of money per bond. Furthermore, they are assumed to be totally illiquid, meaning that they have no purpose of being used as media of exchange. Money is the only means of exchange but government bonds can still serve as collateral in order to be able to borrow money in interbank or CB transactions. The current stock of money is denoted by M and M^+ is the stock of money at the beginning of the next period. The same notation applies for the current and future stock of bonds (B, B^+). Because there are two different goods in the model (SM good x and SFM good q), we also have two different prices. P denotes the price for SM goods and p denotes the price for SFM goods. In the model, assets are claims on all or parts of SM goods. Therefore, when $\phi \equiv 1/P$, ϕm describes the real value of money for example. Finally, the impatience of agents across periods (discount factor) is $\beta = 1/(1 + r)$, where r is the real interest rate. (Berentsen et al. (2013, p. 5))

3.2 Settlement Market

When agents enter the settlement market, they have specific asset holdings from transactions in the previous period. These claims are settled in the market and according to the amount of production and consumption, an agent's problem becomes the following:

$$V_S(m,b,l,d,z) = \max_{h,x,m',b'} x - h + V_M(m',b') \tag{1}$$

$$s.t.\ \ x + \phi m' + \phi\rho b' = h + \phi m + \phi b + \phi d/\rho_d + \phi l/\rho_l - \phi z/\rho_m - \phi\tau M$$

$V_S(\cdot)$ describes the value function of the SM. It is the expected value of entering the market, holding m units of money, b units of bonds, l loans from the CB's lending facility, d deposits on the deposit facility and z, the loans from other banks in the money market. $V_M(\cdot)$ is the expected value from entering the MM with an asset portfolio m' and b'. The budget constraint shows, that consumption x and the real asset holdings brought into the next period (lhs) are financed by the amount of working h, real money and bond holdings from the previous period and the settlement of the CB facilities and interbank loans. The last expression are lumpsum transfers from the CB, by which the stock of money in the economy can be controlled. Assembling the maximization problem and the constraint and differentiation with respect to m' and b' yields the first order conditions (FOCs)

$$V_M^{m'} \leq \phi \quad (= if\ m' > 0)$$

$$V_M^{b'} \leq \phi\rho \quad (= if\ b' > 0),$$

where $-\phi$ and $-\phi\rho$ are the utility costs of acquiring one unit of money or one unit of bonds in the SM. What we learn from the FOCs is that all buyers enter the money market with the same portfolio of money and bonds (Berentsen et al. (2013, p. 7)) and the traceability of the model is guaranteed. The only source of a distribution of money holdings are the liquidity shocks in the MM and SFM. Therefore, discovering the effect of a change in the shock is enabled.

3.3 Money and Standing Facilities Market

In section 2.2, it has been mentioned that the secured CHF repo market is divided into an interbank part and the SNB part, depending on the counterparty a bank trades with. However, they all interact on the same trading platform. The same partition appears in the model. The MM is the interbank part and the SFM is the

SNB part of the secured money market. Therefore, transactions in both submarkets can be compound to one value function. At the beginning of the money market, buyers learn whether they have access to the MM or not and according to their individual preference shock ε, they get an idea about whether they are short or long in liquidity. Therefore, buyers are divided into *active* or *non-active* buyers, depending on having access to the money market or not. Overall, the expected utility of a buyer receiving shock ε is

$$V_M(m, b|\varepsilon) = \pi V_A(m, b|\varepsilon) + (1 - \pi)V_N(m, b|\varepsilon). \tag{2}$$

$V_A(m, b|\varepsilon)$ is the value function of an active buyer and $V_N(m, b|\varepsilon)$ is the non-active buyer's value at the beginning of the money market. With respect to the Swiss money market, we need to adapt a special case of the model. Because the SNB's lending facility (liquidity-shortage financing facility) plays a subordinated role and no interest is paid on deposits, the probability of having access to the money market is set to $\pi = 1$ in this paper. Therefore, the description of active buyers' decision problems is of central importance.

In general, a buyer gets utility $\varepsilon u(q)$ from consuming in the money market, where $u(q) = log(q)$. An active buyer is able to borrow or lend his liquidity at the money market interest rate i_m and is also able to use the standing facilities. With $\rho_m = 1/(1 + i_m)$, an agent, who lends one unit of money to a liquidity demanding agent earns $1/\rho_m$ units of money in the following SM. On the other side, the borrower pays this interest rate and needs to deposit collateral at the counterparty. With regard to the SFM, the role of the CB can be interpreted as being the market maker for standing facilities. $\rho_d = 1/(1+i_d)$ is the ask price and $\rho_l = 1/(1+i_d)$ the appropriate bid price of the bid-ask spread for facilities. Taking this into account, the indirect utility function in the money and facility market of an active ε-buyer becomes

$$V_A(m, b|\varepsilon) = \max_{q_\varepsilon, z_\varepsilon, d_\varepsilon, l_\varepsilon} \varepsilon u(q_\varepsilon) + \beta V_S(m + l_\varepsilon + z_\varepsilon - pq_\varepsilon - d_\varepsilon, b, l_\varepsilon, d_\varepsilon, z_\varepsilon)$$

$$s.t. \;\; m + l_\varepsilon + z_\varepsilon - pq_\varepsilon - d_\varepsilon \geq 0, \;\; \rho_l b - z_\varepsilon - l_\varepsilon \geq 0 \; and \; \rho_m b - z_\varepsilon - l_\varepsilon \geq 0.$$

An active buyer's decision of how much to consume in the money market is constrained to his budget. This is formalized in the first inequality of the constraints. The value of consumption pq_ε and excess money holdings deposited at the CB d_ε cannot exceed the level of initial money holdings m, borrowing from the CB l_ε and the interbank market z_ε. The sign of z_ε depends on whether an agent operates as cash taker or provider in the money market. The other two inequalities are collateral constraints. They restrict borrowing in the MM and SFM. Agents can only

If	amount of goods	borrowing/lending	An active buyer...
$0 \leq \varepsilon < \varepsilon_z$	$q_\varepsilon = \varepsilon\rho_m/\rho_d$	$z_\varepsilon = p(\varepsilon - \varepsilon_z)$	lends money in the money market
$\varepsilon_z < \varepsilon \leq \varepsilon_{\bar{z}}$	$q_\varepsilon = \varepsilon\rho_m/\rho_d$	$z_\varepsilon = p(\varepsilon - \varepsilon_z)$	borrows money and the collateral constraint is non-binding
$\varepsilon_{\bar{z}} \leq \varepsilon$	$q_\varepsilon = \varepsilon_{\bar{z}}\rho_m/\rho_d$	$z_\varepsilon = \rho_m b$	borrows money and the collateral constraint is binding

Table 2: Lemma 2 (source: Berentsen et al. (2013, p. 8))

receive an amount of borrowing, which can be collateralized, being dependant on specific bond holdings which serve as collateral. Because active buyers solely fund their liquidity needs by operating on the money market ($l_\varepsilon = d_\varepsilon = 0$), the FOCs for q_ε and z_ε are (Berentsen et al. (2013, p. 8)):

$$\varepsilon u'(q_\varepsilon) - \beta p \phi^+(1 + \lambda_\varepsilon^A) = 0$$

$$-1/\rho_m + (1 + \lambda_\varepsilon^A) - \lambda_z^A = 0$$

But how will be determined if a buyer in the MM operates as cash taker or cash provider. The answer is the following. First of all, preference shocks ε determine whether an agent is short or long in liquidity. Therefore, we need some critical values for the shock. In a nutshell, if ε exceeds a specific value, the weight on the utility of consumption is high and an agent is more volitional to consume, requiring larger amounts of money. These critical values are summarized in table 2. By using the FOCs, Berentsen et al. (2013, pp. 14-15) show that they solve

$$\varepsilon_z = \beta\phi^+ m/\rho_m \quad and \quad \varepsilon_{\bar{z}} = \beta\phi^+ m/\rho_m + \beta\phi^+ b. \tag{3}$$

If a buyer's liquidity shock is below ε_z, he lends money in the MM, because his preference for consumption is low and thus his need for money holdings. If the shock is above this critical value, the buyer starts to borrow in the MM in order to satisfy his increased preference for consumption (Consumption q_ε increases proportional with ε), but the collateral constraint is not binding yet. This changes from $\varepsilon_{\bar{z}}$ on. The buyer's willingness to consume reaches a level, where his need for liquidity is higher than what he is able to collateralize. He can only fund his consumption in the amount of the discounted value of bond holdings. Hence, the amount of goods is flat for shocks $\varepsilon > \varepsilon_{\bar{z}}$.

The decision by non-active buyers is nearly the same as for active buyers except for the fact that no interbank loans appear in the portfolios, only one collateral constraint for CB funding exists and value maximization is done with respect to consumption and the level of deposits and borrowing from the CB (Berentsen et al. (2013, pp. 14-15)). For the sake of completeness and a better understanding of the following equations and figure 6, you can find the critical values for non-active buyers in the appendix. [18]

3.4 First-best Allocation and Equilibrium

In order to determine the stationary equilibrium, the first-best allocation, where a social planner chooses the welfare maximizing allocation of consumption and production, has to be considered. The weighted average of the expected steady state lifetime utility of households and firms (welfare function) is

$$\begin{aligned}\mathcal{W} = \pi &\left[\int_0^{\varepsilon_{\bar{z}}} [\varepsilon u(q_\varepsilon) - q_\varepsilon] dF(\varepsilon) + \int_{\varepsilon_{\bar{z}}}^{\infty} [\varepsilon u(q_\varepsilon) - q_\varepsilon] dF(\varepsilon)\right] \\ &+ (1-\pi)\Bigg[\int_0^{\varepsilon_d} [\varepsilon u(q_\varepsilon) - q_\varepsilon] dF(\varepsilon) + \int_{\varepsilon_d}^{\varepsilon_l} [\varepsilon u(q_\varepsilon) - q_\varepsilon] dF(\varepsilon) \\ &+ \int_{\varepsilon_l}^{\varepsilon_{\bar{l}}} [\varepsilon u(q_\varepsilon) - q_\varepsilon] dF(\varepsilon) + \int_{\varepsilon_{\bar{l}}}^{\infty} [\varepsilon u(q_\varepsilon) - q_\varepsilon] dF(\varepsilon)\Bigg].\end{aligned} \tag{4}$$

Under the assumption of symmetrically treated sellers and symmetrically treated buyers experiencing the same preference shock, the first best solution satisfies

$$q_\varepsilon^* = \varepsilon \; for \; all \; \varepsilon \tag{5}$$

$$q_s^* = \bar{\varepsilon} \equiv \int_0^{\infty} \varepsilon dF(\varepsilon), \tag{6}$$

where q_ε^* and q_s^* are aggregate consumption and production by buyers and sellers (Berentsen et al. (2013, p. 9)). In order to determine symmetric stationary equilibria, additional assumptions need to be satisfied. Symmetry only has to exist among buyers with the same access shock in the money market. In addition, all markets clear and real quantities are constant over time (i.e. $\phi M = \phi^+ M^+$). Under market

[18] The decision by sellers has been omitted, because it does not play a decisive role for later simulations. It is assumed, that sellers do not carry bonds across periods and will never acquire money in the SM.

clearing, equation (6) holds with equality. Berentsen et al. (2013, pp. 9-10) assume a laissez-faire money market where $\rho_d > 1$ and $\rho_l = 0$ and agents do not use the SFM to fund their liquidity needs. In this case, the supply of money satisfies

$$SM(\rho_m) = \pi \int_0^{\varepsilon_z} p(\varepsilon_z - \varepsilon) dF(\varepsilon) \tag{7}$$

and the demand for money satisfies

$$DM(\rho_m) = \pi \int_{\varepsilon_z}^{\varepsilon_{\bar{z}}} p(\varepsilon - \varepsilon_z) dF(\varepsilon) + \pi \int_{\varepsilon_{\bar{z}}}^{\infty} \rho_m b dF(\varepsilon), \tag{8}$$

where $\varepsilon_z = \varepsilon_d(\rho_d/\rho_m)$ and $\varepsilon_{\bar{z}} = \varepsilon_z(1 + \rho_m \mathcal{B})$.

$\mathcal{B} = B/M$ is the bonds-to-money ratio. It describes the relationship between the stock of collateral and the liquidity in the banking system. The variable will help testing the last two hypotheses described at the beginning of this chapter. If sight deposits (M) increase or the stock of collateral (B) decreases, the critical value $\varepsilon_{\bar{z}}$ decreases, resulting in a higher fraction of collateral constrained borrowers (second term of equation (8)). Overall, the demand for money decreases (less collateral existing for more constrained borrowers; high level of liquidity in the system), whereas the supply stays unaltered in this model, eventually resulting in a decrease of i_m.

Under market clearing, equations (7) and (8) satisfy $SM(\rho_m) = DM(\rho_m)$. One can assume three cases in order to determine the money market rate. If market clearing ends up in $\rho_m > \rho_d$ ($i_d > i_m$) such that $SM(\rho_d) > DM(\rho_d)$, agents prefer to deposit their excess liquidity at the CB. The liquidity supply in the MM decreases until $\rho_m = \rho_d$. Otherwise, if market clearing yields $\rho_m < \rho_l$ ($i_m > i_l$) such that $SM(\rho_l) < DM(\rho_l)$, buyers borrow at the lending facility, resulting in a decrease in the demand for money in the MM until $\rho_m = \rho_l$. Eventually, buyers trade in the MM if $\rho_d > \rho_m > \rho_l$.

A typical pattern of money market interest rates is their fluctuation within the interest rate corridor provided by the respective CB. Although this seems to be very intuitive, the model provides a formulated microfoundation for the phenomenon. As we will see in the simulation, the fluctuation in the channel will be nicely replicated and strongly depending on individual liquidity shocks.

Now, in order to be able to compute the demand for bonds and money, preceiving insights need to be combined. With $\gamma = M^+/M$ describing the constant growth rate of the money stock and $\mathcal{B} = B/M$ denoting the bonds-to-money ratio, Berentsen et al. (2013, pp. 15-17) derive the symmetric stationary equilibrium with a positive demand for money and bonds. It satisfies the following two equations:

$$
\begin{aligned}
\frac{\rho_d \gamma}{\beta} = {} & \pi \left[\int_0^{\varepsilon_{\bar{z}}} \frac{\rho_d}{\rho_m} dF(\varepsilon) + \int_{\varepsilon_{\bar{z}}}^{\infty} \frac{\rho_d}{\rho_m} \frac{\varepsilon}{\varepsilon_{\bar{z}}} dF(\varepsilon) \right] \\
& + (1-\pi) \left[\int_0^{\varepsilon_d} dF(\varepsilon) + \int_{\varepsilon_d}^{\varepsilon_l} \frac{\varepsilon}{\varepsilon_d} dF(\varepsilon) + \int_{\varepsilon_l}^{\varepsilon_{\bar{l}}} \frac{\rho_d}{\rho_l} dF(\varepsilon) \right. \\
& \left. + \int_{\varepsilon_{\bar{l}}}^{\infty} \frac{\rho_d}{\rho_l} \frac{\varepsilon}{\varepsilon_{\bar{l}}} dF(\varepsilon) \right]
\end{aligned} \tag{9}
$$

$$
\begin{aligned}
\frac{\rho \gamma}{\beta} = {} & \pi \left[\int_0^{\varepsilon_{\bar{z}}} dF(\varepsilon) + \int_{\varepsilon_{\bar{z}}}^{\infty} \frac{\varepsilon}{\varepsilon_{\bar{z}}} dF(\varepsilon) \right] \\
& + (1-\pi) \left[\int_{\varepsilon_0}^{\varepsilon_{\bar{l}}} dF(\varepsilon) + \int_{\varepsilon_{\bar{l}}}^{\infty} \frac{\varepsilon}{\varepsilon_{\bar{l}}} dF(\varepsilon) \right]
\end{aligned} \tag{10}
$$

By maximizing the value function (2) and using the optimal selection of money holdings in the SM, equation (9) is derived. Equation (10) arises from the arbitrage condition $\rho V_M^m(m,b) = V_M^b(m,b)$. It guarantees that a strictly positive demand for bonds and money prevails in equilibrium. In chapter 4, the two equations will be used to determine the price for bonds and value of money in equilibrium. Supply and demand in the money market (respective the MM turnover) will be obtained from equations (7) and (8). Additionally, ρ_m emerges out of these two equations in equilibrium. The following critical values emerge from the budget constraints of the buyers:[19]

$$
\begin{aligned}
&\varepsilon_l = \varepsilon_d(\rho_d/\rho_l), \quad \varepsilon_{\bar{l}} = \varepsilon_l(1+\rho_l \mathcal{B}), \\
&\varepsilon_z = \varepsilon_d(\rho_d/\rho_m) \quad and \quad \varepsilon_{\bar{z}} = \varepsilon_z(1+\rho_m \mathcal{B}).
\end{aligned} \tag{11}
$$

Until now, it was possible to see where a change in the bonds-to-money ratio $\mathcal{B}$ affects the demand and supply in the money market and the demand for bonds and money as a whole (by moving the critical values when the collateral constraints are binding). However, it is difficult to analytically evaluate how e.g. an increase in $\mathcal{B}$ affects the money market interest rate or the turnover in general equilibrium. Therefore, it is useful to calibrate and simulate the model to be able to identify the specific effects. Evaluating an increase in the variance of ε is even more difficult. But

[19]See section 3.5 or table 6 in the appendix for the specific meaning and composition of the critical values for non-active buyers.

eventually, it is important to learn on which equations the simulations of chapter 4 are based on and which theoretical background they have.

3.5 First Insights

The model is able to provide an answer on the question of optimal monetary policy in the sense of choosing an optimal interest rate channel ρ_d and ρ_l. Berentsen et al. (2013, p. 11) have been able to show that any value of $\rho_l \leq \rho_d$ yields the first-best allocation. Therefore, running a floor or channel system can be the optimal choice as long as $\rho_d = \beta/\gamma$ and settlement and money market prices satisfy $\rho = \rho_m = \rho_d$ (ρ_l is irrelevant). Under this policy, holding money becomes costless as market participants are compensated for their impatience and for inflation. Consequently, implementing the Friedman rule[20] in the sense of paying interest on deposits constitutes an optimal solution. However, the optimality is constrained to how the interest payments on deposits are financed.[21] If the CB makes a deficit by paying interest, the government needs to transfer funds. One can think of such transfers as a situation where the CB holds sufficient government bonds, such that their interest covers the deposit interest or the CB needs to hold other real assets delivering sufficient revenue. However, if the CB makes a surplus or if it does not receive enough funds, the optimal policy changes. First of all, a strictly positive spread $i_d < i_l$ should be chosen. Additionally, Berentsen et al. (2013, pp. 17-20) show that increasing i_d strictly improves welfare.

Figure 6 illustrates the first best levels of consumption (y-axes) in the MM and SFM for $i_l = i_d$ (Zero corridor) and $i_d < i_l$ (Positive corridor), when the CB is not able to run a sufficient deficit. The 45° line depicts the first best solution for different values of ε (x-axes). The red line plots the consumption level for non-active buyers when the CB chooses to set a zero corridor. With an increase in ε, buyers consume more as they have a stronger preference for consumption. The non-active buyers strictly increase their consumption until $\varepsilon_{\bar{z}}$, where the first-best consumption quantities are receivable. From that point on, the collateral constraint is binding and the maximum level of consumption is achieved. The red curve depicts the consumption quantities for non-active buyers, if the CB implements a positive corridor. Until

[20] Implementing the Friedman rule means setting the nominal interest rate to zero or equivalently $\gamma/\beta < 1$ Nosal and Rocheteau (2011, p. 132)). Consequently, the deposit rate needs to satisfy $i_d > 0$.

[21] Berentsen et al. (2013) implement the budget of the CB and the government budget into the model. However, it is not the focus of this thesis to explain the interaction between the government and the CB. I briefly describe the foundation of the choice of an optimal interest spread in the appendix.

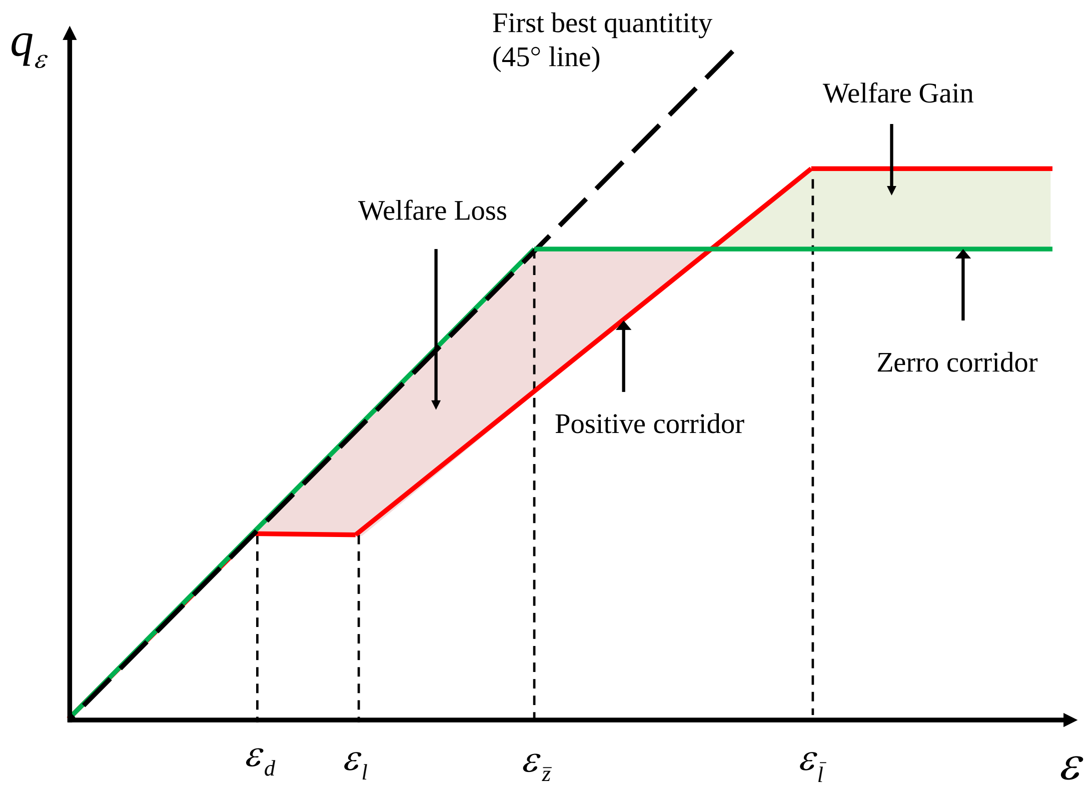

Figure 6: Welfare effects: Positive v.s. Zero corridor (source: Berentsen et al. (2013, p.9))

ε_d, the first-best consumption quantity is consumed and excess money holdings are deposit at the deposit facility. For $\varepsilon_d < \varepsilon < \varepsilon_l$, the buyers spend all their money and consume $q_\varepsilon = \varepsilon_d$. The borrowing at the lending facility begins with $\varepsilon = \varepsilon_l$. Until $\varepsilon_{\bar{l}}$, the borrowing constraint is non-binding. If $\varepsilon > \varepsilon_{\bar{l}}$, the buyers can only borrow in the amount of their bond holdings. By comparing both curves, we see that implementing a positive corridor has positive and negative effects on welfare. For instance, increasing i_l lowers the consumption of medium-ε buyers, but increases consumption of high-ε buyers. However, in their proof, Berentsen et al. (2013) show that the gain in welfare is always higher than the loss.

The Federal Act on the Swiss National Bank does explicitly stipulate a surplus of the SNB, which is used to pay dividends and after that distributed to the confederation and cantons (Art. 29-31). Consequently, the second case (CB is not able to run a deficit) seems to be relevant for the SNB case and running a positive spread is optimal. This is fulfilled for the Swiss monetary policy. However, it seemed to be welfare improving to increase the deposit rate as well. The SNB deviates from this theoretical optimality as it does not pay interest on reserves. In order to make holding money more attractive and with this improving the economic efficiency (Berentsen et al. (2013, p. 12)), the SNB should provide a deposit facility. Similar measures have been realized by the Fed in October 2008 (Goodfriend (2011, p. 5)). In this case, pure welfare improving considerations have been of minor importance. According to the large increase in excess balances, the open market trading desk faced problems in achieving the operating target for the federal funds rate as the high liquidity placed a downward pressure on the ON rate. By paying interest on excess reserves, steering money market rates should be made better achievable.[22] Nevertheless, the Fed explained in a press release on October 6, 2008 (Board of Governors of the Federal Reserve System (2008)):

"Paying interest on required reserve balances should essentially eliminate the opportunity cost of holding required reserves, promoting efficiency in the banking sector."

This statement is in line with the former described welfare improving effects. An additional benefit, which is related to paying interest on deposits, is associated with a potential exit strategy of current stimulating monetary policy. When the market conditions and the economic outlook start to improve, the SNB will be forced to adapt money market interest rates according to the new environment. In order to do so, it is able to put a significant upward pressure on short-term interest rates by increasing the lower bound of the interest rate channel, the deposit rate. Additionally, paying interest on reserves will dampen a potential flow of excess reserves into the economy, which results in a strong increase of inflation when the flood of liquidity will not be absorbed by an increase in macroeconomic activity. Altogether, the provision of a deposit facility on the part of the SNB can generate technical (interest steering) and macroeconomic benefits, which should be taken into account, especially when thinking about an appropriate exit strategy of current expansive monetary policy. By calibrating and simulating the model of Berentsen et al. (2013) in the following section 4, it will be shown that it indeed seems to be welfare improving to pay an interest on reserves and with this, that the interest rate corridor was too wide in the pre-crisis period.

4 Simulating the Swiss Franc Repo Market

In the following sections, the introduced model will be applied to the CHF repo market.[23] As mentioned in section 2, it can be distinguished between different

[22] *http://www.newyorkfed.org/markets/ior_faq.html*

[23] All computations and simulations are done in Mathematica. The code is too long to provide it in the appendix, but extractions will be available on demand.

phases of interest rate movements and changes in the environment of the money market. Therefore, the time series 2005-2011 is split into five periods, which are all characterized by different patterns. *Phase I* (03 Jan 2005 - 07 Aug 2007) is the pre-crisis period, characterized by usual interest rate movements, moderate sight deposits and limited liquidity needs and counterparty risk. It will be used in order to initially calibrate the model and *Phases II-V* will then be compared with regard to the different hypotheses, that have been described at the beginning of section 3. The following chapters will mainly focus on two shocks that come up in the model. The variance of the preference shock ε, describing the change in funding needs and the bonds-to-money ratio B/M, illustrating changes in the sight deposits or a collateral shock (depending on the events of the specific phases).

4.1 Calibrations

The different variables and targets of the model will now be transferred into the environment of the CHF repo market. First of all, the period of the model is one day as initially intended by the authors. Therefore, ON transactions, which are settled on the next day, are the relevant case for this kind of model. According to this, one also has to select the relevant interest rates the model deals with. Despite the fact that the interest rate target of the SNB is the CHF Libor 3M, the SARON is chosen to be the relevant money market interest rate, because the CHF Libor 3M describes unsecured and longer-term transactions whereas the SARON is based on secured ON transactions.

SARON	0.01178
lending rate	0.03168
deposit rate	0.0
Real interest rate	0.01431
Inflation	0.00931
MM access (π)	1

Table 3: Targets

Table 3 summarizes the targets. The average of the annualized daily SARON for *Phase I* is 1.178%. The annualized lending rate, which is based on the SNB's ON Special Rate, is 3.168%. As already mentioned, the SNB does not pay an interest on deposits. Therefore, the deposit rate is at 0.0% for every period. According to estimates of the World Bank[24], the Swiss average real interest in Phase I was around

[24] World Bank (2014): `http://data.worldbank.org/indicator/FR.INR.RINR?page=1`

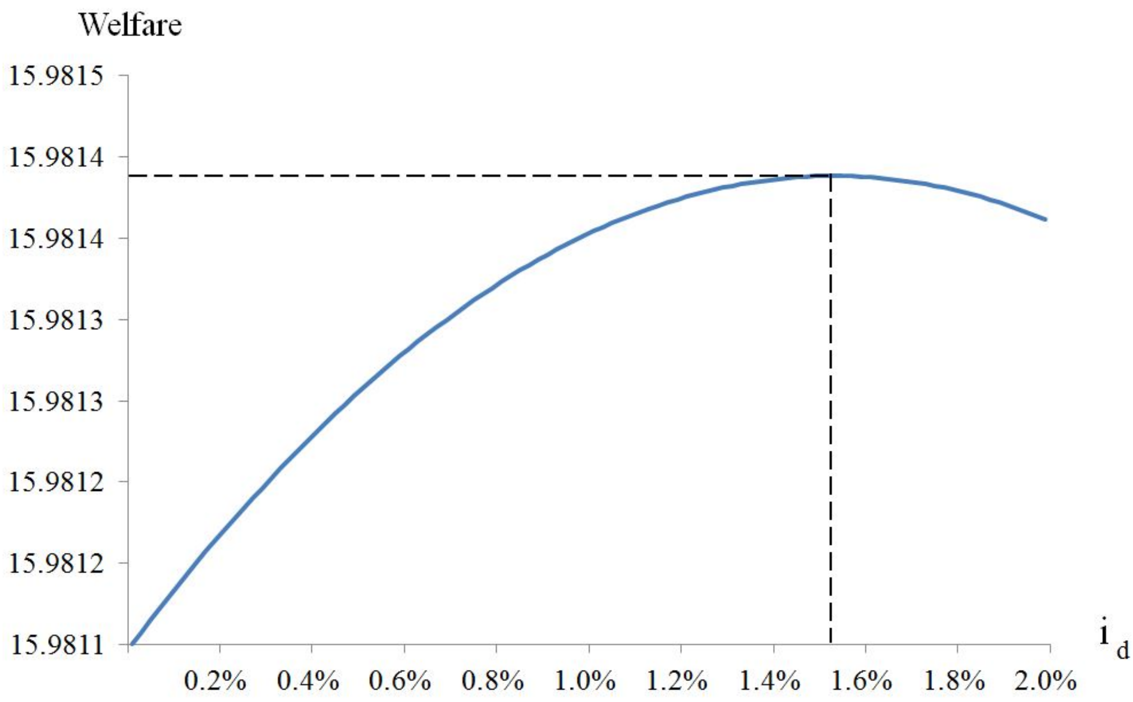

Figure 7: The optimal deposit rate

1.431%. The inflation of consumer prices, calculated as the annual percentage change of the CPI was at 0.931% [25]. And finally, the probability of having access to the interbank money market is set equal to 1 as the liquidity shortage financing facility plays a subordinated role in funding on Swiss money markets.

Now, the parametrization is straightforward. There are three monetary policy variables i_d, i_l and γ. The preceding estimates can directly be used to set $i_d = 0$, $i_l = 0.03168$ and $\gamma = 1.00931$. According to the real interest rate, the discount factor can be set to $\beta = 0.9862$. The utility function for agents in the MM and SFM is assumed to be $u(q) = log(q)$. Liquidity preference shocks ε are assumed to be random draws from a log-normal distribution with parameters $[\mu, \sigma]$. It turned out that the selection of μ and σ does not affect the calibration and simulation results at all. The standard deviation (in the following labelled as variance of the idiosyncratic liquidity needs) of the distribution is set to $\sigma = 2$. $\mathcal{B}$ is chosen such that the deviation of the simulated money market rate from the SARON target is minimized. Unfortunately, a second accurate target to pin down $\mathcal{B}$ in *Phase I* did not exist for the model (Berentsen et al. (2010) used the ratio of deposits to lending which are not existing for the SNB case), but minimizing the interest rate deviation yields in $\mathcal{B} = 21.48$ and the initial parametrization for *Phase I* is done.

[25] SNB (2014): `http://www.snb.ch/de/iabout/stat/statpub/statmon/stats/statmon/statmon_01_1`

A first answer can now be provided to the question: Did the SNB choose an appropriate size of the facility corridor? By using the preceding values and taking equation (4) for the lifetime utility of a representative agent, the monetary policy stance of the SNB during *Phase I* can be evaluated. Taking the value of i_l as given and calculating the welfare for different levels of the deposit rate i_d, it becomes clear, that, as already pointed out in section 4.5, it would be welfare enhancing to provide a deposit facility, according to the mentioned aspects. Additionally, it can be shown that the spread of facility interest rates was too wide during the pre-crisis period. Figure 6 illustrates the combination of an increase in the deposit rate and the appropriate level of welfare. The maximum in welfare is achieved by choosing a deposit rate of 1.559%. Despite the increase in welfare seems to be moderate, the essential message becomes clear. Providing a deposit facility has welfare improving effects. As already mentioned, other effects, not explicitly modelled in this framework may additionally be beneficial. Enhanced steering of money market interest rates may be one of these.

4.2 Comparative Statics and Simulations

Before simulating the model, it is computed such that all shocks from the continuous log-normal distribution appear simultaneously. In this ideal type of situation, one is able to receive some first insights on how the movements of the money market rate and the turnover in the CHF repo market may have taken place and especially which explanations the model provides. Comparative statics are used to allow for interdependencies in equilibrium. Equations (7) and (8) serve to determine the money market rate. This is done by assuming (7) - (8) = 0 and solving for the money market clearing i_m. However, it is still depending on the value of money, which itself is depending on exogenous variables. Solving equation (9) for $\phi^+ m$ and plugging it into (7) and (8) yields the general equilibrium money market rate. The turnover in the money market also results from equations (7) and (8). Idiosyncratic liquidity shocks determine the demand and supply of money, trades are matched and the market clearing money market interest rate forms. Finally, a potential excess demand or supply in the money market is cut off (If $SM(\rho_d) > DM(\rho_d)$ or $SM(\rho_l) < DM(\rho_l)$).

The figures 8 - 11 [26] depict money market interest rate movements for changes in different exogenous variables. From figure 8, the effect of a change in money market access π can be observed. First of all, an increase in the probability of

[26] Red line = i_l, Green line = i_d, Blue line = i_m, Black line = i

having access to the money market decreases the money market interest rate and slightly increases the price for bonds until the two rates converge at $\pi = 1$, where $i_m = 0.01178$, which is the average money market interest rate of *Phase I*. The economic content is the following: As agents always satisfy their liquidity needs in the money market when they have access, a clear preference for interbank funding emerges. Therefore, one can speak of an access premium, which pushes up the money market interest rate. With a decrease in the probability of having money market access, the premium starts to increase, being contributory to an increase in i_m. This observation was empirically confirmed by Kraenzlin and Nellen (2012), who discovered an economically significant access premium for the CHF unsecured money market. The decrease in bond prices with a decrease in the access probability can be explained with the loss in value of bonds, according to lower collateralization purposes. In the following graphs, MM access is $\pi = 1$ and i_m and the price of bonds have the same course.

Figure 9 shows the effect of moving the borrowing facility interest rate i_l. At this point, one is able to recognize an unforeseen effect. Changing the upper bound of the interest rate corridor does not affect the money market interest rate as long as it reaches its current level. By further decreasing the borrowing rate, i_m begins to move just on the upper bound of the channel. Steering the money market rate by changing the borrowing rate, when the deposit rate is equal to zero, is therefore not being explained in the model. However, when it comes to simulating the model later on, a different pattern emerges and moving the borrowing rate has a significant effect, which is mainly emerging from technical considerations.

Matter of the following inspection are the comparative statics of the two shocks σ and $\mathcal{B}$, which should help testing the hypotheses developed in the preceding sections. Figure 10 illustrates the effect of altering $\mathcal{B} = B/M$ (keeping $\sigma = 2$ constant). Clearly, a decrease in this ratio may push the money market rate to the floor of the corridor. In the Swiss money market case, $\mathcal{B} = 15$ already suffices to achieve $i_m = 0$. Regarding the former hypotheses, the desired effects are present. An increase in the money stock M (increase in sight deposits) or a decrease in the collateral eligible bond stock B (i.e. larger haircuts for collateral or a downsizing of the collateral basket) decrease the money market rate. Consequently, the expected effect of a high level of reserves in the banking system or an aggregate collateral crisis are confirmed. The influence of an increase in the aggregate variance of the liquidity shock is illustrated in figure 11. The sensitivity of i_m with respect to changes in the variance seems to be high and small changes in this variable need to be precisely considered later on. Overall, all three hypotheses with respect to the effect on the

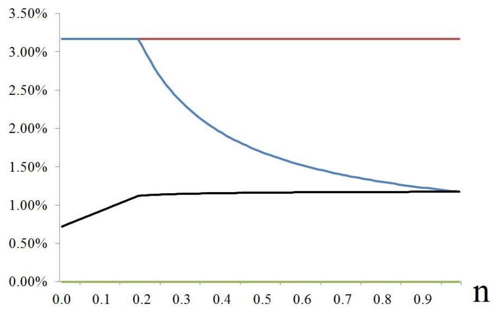

Figure 8: MM access effects

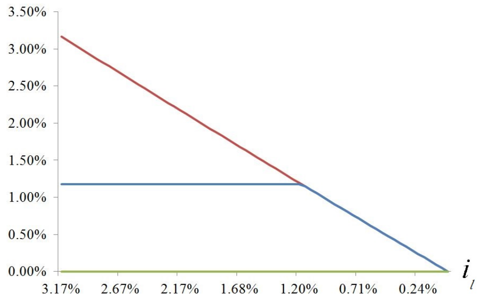

Figure 9: Liquidity facility

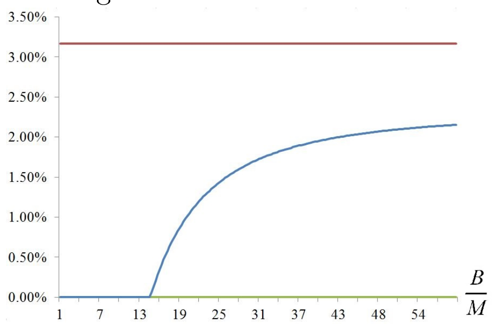

Figure 10: Bonds-to-Money ratio

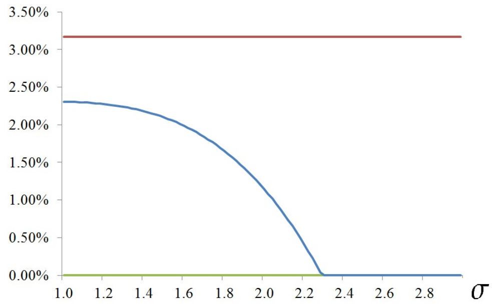

Figure 11: Variance of liquidity shock

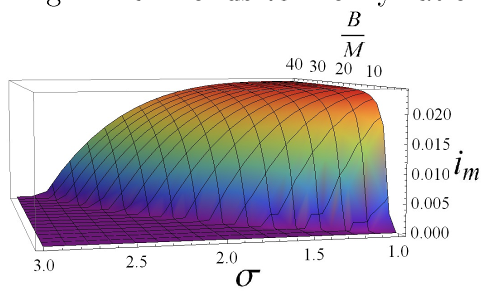

Figure 12: Combination of shocks and i_m

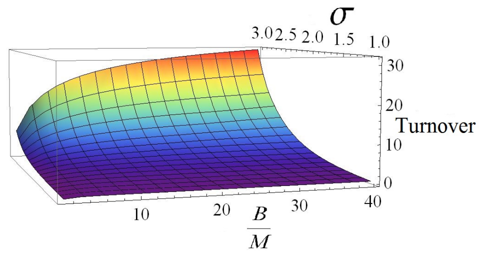

Figure 13: Combination of shocks and turnover

money market interest rate are confirmed by the model framework.

The combination of both shocks is depicted in figure 12. It becomes obvious that a decrease in σ dampens the effect of a decrease in $\mathcal{B}$ on i_m. Intuitively, the lower the variance of liquidity needs is, the lower is the demand for money and, i.e. a collateral crisis does not affect MM activities as most agents are already satisfied in liquidity. Figure 13 depicts changes in the money market turnover, which arise from the two shocks. An increase in the variance results in an increased money market turnover. Additionally, a decrease in $\mathcal{B}$ leads to less repo market activity. These effects are close to what has been observed in the past. When the aggregate variance of liquidity needs increases, banks tend to lend more in the secured ON segment of the money market. Finally, the liquidity provision by the CBs resulted in reduced repo market activity. Consequently, all the hypotheses are covered by the model.

The two figures 12 and 13 [27] are essential for later simulation purposes. The best replicating combination of the two shocks will be selected by simultaneously minimizing the deviation of the simulated and empirical money market interest rate (for every phase) and the deviation of the simulated and empirical turnover increase from *Phase I* to *Phase II - V*. We see that there exists an infinite combination of shocks, which yield in a money market interest rate of 1.17% (i.e.), but additionally considering turnover changes will help to overcome this problem.

By simulating the model, the movements of the money market rate and turnover developments in recent years will be explained in the following. Figure 14 illustrates the simulation of the money market rate in the course of time. The daily values of the ON special rate are used and equations (7)-(9) (with appropriate critical values $\varepsilon_{z,t}$) are solved for $i_{m,t}$ for each t. The green line represents the simulation with 100 draws of the log-normal distribution $F(\varepsilon)$. It becomes clear that the simulation often fails to track the path of the SARON in many ways. In 2005, $i_{m,t}$ fluctuates around the average money market rate of *Phase I*. When the ON special rate starts to increase, $i_{m,t}$ rises as well, but not sufficiently. Most importantly, the drop of the money market rate in the end of 2008 is not covered by the initial calibration of the model. Hence, aggregate shocks regarding the two variables σ and $\mathcal{B}$ need to be considered, in order to better track the movements. The orange path depicts the money market rate, when all shocks in the log-normal distribution $F(\varepsilon)$ appear at the same time. Obviously, the more draws are chosen, the more the simulated money market rate converges to the orange line and the less the interest rate movements are tracked. This emerges from pure technical aspects. By analysing the composition of the average simulated money market rate (the average simulated money market rate consists of money market rates for each iteration in the simulation process), it becomes clear that choosing a small amount of draws makes the money market rate fluctuating just in the middle of the interest rate corridor, because the single interest rate observations highly start to appear just on the border of the standing facilities interest rate channel. Kraenzlin and von Scarpatetti (2012, p. 7) discovered that the number of participants in the interbank repo market averaged around 110 - 150 banks between 2005 - 2007. Resulting from this observation, the amount of draws from the log-normal distribution of liquidity shocks should be related to this number. Hence, because a lower amount of liquidity shocks increases the ability to track interest rate movements in the course of time and because it is more linked to the number of operating banks, the following simulations are executed with 100 draws. In order to improve the consistency, the simulations of the turnover and the

[27] Exemplary simulated versions for *Phase I* can be found in the appendix.

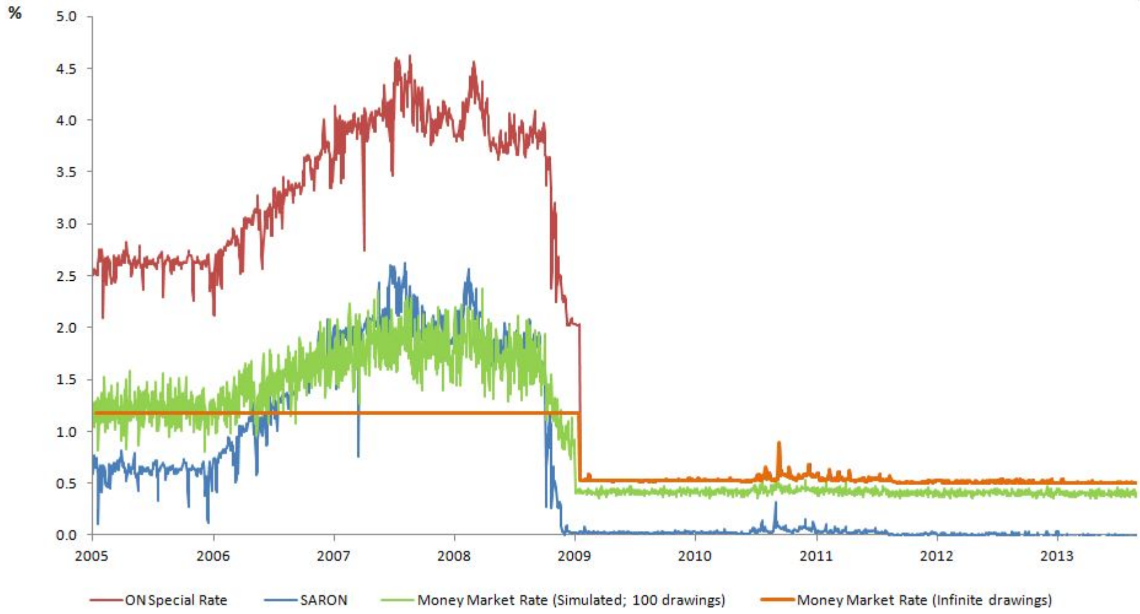

Figure 14: The simulated money market rate over time

interest rate are iterated 100 times. Nevertheless, the simulation has been conducted by choosing 5,000 draws either, according to the following drawbacks.

When choosing 100 draws, the simulated money market rate seems to be inaccurate. Figures 15 and 16 in the appendix show, which effect a change in the number of drawings has on the quality of the simulation. If there are little liquidity shocks, the effect of a change in the variance or in the bond-to-money ratio becomes inaccurate and precise conclusions can not be made at all. When choosing 5,000 draws, the simulated effects converge to a more applicable alternative. Therefore, the sensitivity of the model according to the number of draws from the log-normal distribution can be recognized. However, it turned out, that when simulating the single phases, nearly no change in the conclusions of the simulation outcomes appeared.

In table 4, the average empirical and simulated SARON and interbank money market turnovers for the different phases are listed. The model is simulated for 100 and 5,000 liquidity shocks, in order to account for possible deviations, stemming from the amount of draws. Already in *Phase I*, the model is not able to track the average money market rate, as expected according to figure 14. But the more draws are chosen, the closer the simulation gets to the empirical data with respect to the mentioned technical aspects. In the following periods, the initial calibration fails to explain the SARON movements even more. Similar to figure 14, the money market rate does not increase strong enough in *Phase II*. Additionally, the basic calibration does not account for the massive SARON decrease in the following phases, where movements close to the bottom of the corridor could be observed. The initial simulation provides interest rate movements on top of the channel. Likewise divergent are the simulated money market turnovers.[28] Empirically, a significant increase in *Phase II* and *III* (compared to *Phase I*) and a decrease in the following periods occurred. In contrast, using the initial calibration, the simulated money market turnovers subsequently decrease in every period. These solutions seem to be disappointing at the first sight, but the opposite is the case. On the framework of the presented model, it is possible to draw the conclusion, that aggregate shocks appeared in the subsequent periods, which are directly linked to the hypotheses of section 2. It is now up to investigate, which shocks might have taken place, explained by the model framework. The simulated money market rate and the changes in turnovers are now matched to the empirical counterparts by finding the combinations of σ and $\mathcal{B}$, which best replicate the SARON and CHF repo market turnover (ON) developments in the different phases. Because π is set equal to one, the overall turnover in the repo market was chosen to be the relevant data. But this might result in drawbacks according to the outcome and conclusions emerging from the simulation. In the following, the meaning of this difficulty will become clear.

	Phase I	Phase II	Phase III	Phase IV	Phase V
empirical					
$SARON^{emp}$	0.01178	0.0197	0.0037	0.0002	0.0004
$Turnover^{emp\ a}$	3.25	5.62	5.36	3.73	4,03
$Turn.Ratio^{emp}$	-	1.73	1.64	1.15	1.24
100 draws					
$SARON^{sim}$	0.01439	0.0179	0.0089	0.0042	0.0043
$Turnover^{sim\ b}$	3.13	3.21	2.92	2.52	2.49
$Turn.Ratio^{sim}$	-	1.02	0.93	0.80	0.80
5000 draws					
$SARON^{sim}$	0.01388	0.01587	0.00988	0.00524	0.00549
$Turnover^{sim}$	3.70	3.70	3.27	2.63	2.66
$Turn.Ratio^{sim}$	-	1.00	0.88	0.71	0.72

Table 4: Empirical and simulated SARON and Turnovers (initial calibration)

[a] in CHF bn

[b] Figures do not necessarily represent empirical values.

The squared minimum of the distance between empirical and simulated turnover changes from *Phase I* to *Phase II-V* serves as a fixing point for detecting the most

[28] They do not necessary represent the empirical values. Therefore, in order to pin down the two shocks in *Phases II-V*, I use the ratio $turnover_t/turnover_1$ in order to be able to track the turnover movements compared to *Phase I*. A comparison of absolute empirical and simulated values is not possible.

realistic combination of σ and $\mathcal{B}$. Additionally, the squared distance of the empirical and simulated money market rate is minimized.[29] According to this, the determination of the optimal combination takes the form

$$\min_{\sigma,\mathcal{B}} \ \omega[i_{m,t}^{emp} - i_{m,t}^{sim}]^2 + (1-\omega)\left[\frac{turn_t}{turn_1}^{emp} - \frac{turn_t}{turn_1}^{sim}\right]^2.$$

By assigning a weight ω to each term, the minimization problem allows for considering a different importance on aiming to simulate the correct money market rate or turnover ratio. In the following, both terms is assigned an equal weight. In addition, $\omega = 0.5$ results in well replicating solutions. But the selection of the weight turns out not to have a significant effect on the simulations, if it lies in an intermediate rang $(0 < \omega < 1)$.

Subsequently, aggregate shocks to σ and $\mathcal{B}$, which might explain the movements of the money market rate and the behaviour of the turnover in the repo market will be considered. The outcomes are summarized in table 5. First of all, with a slight deviation from the initial calibration $[\sigma = 2; \mathcal{B} = 21.48] \rightarrow [\sigma = 2.02\ (2.02); \mathcal{B} = 24.87\ (18.51)]$, the money market interest rate in *Phase I* is replicated. [30]

Now, the movements in *Phase II* are analysed. As previously recognized, it is characterized by an increase in the money market rate ($0.01178 \rightarrow 0.0197$), as well as an increase of the repo turnover by the factor 1.73, which are both not fully explained by the initial calibrations. By increasing the standard deviation of the idiosyncratic liquidity shocks to $\sigma = 2.27\ (2.24)$ and choosing an increased bonds-to-money ratio $\mathcal{B} = 33.70\ (34.61)$, the replication of the pattern of the second phase can be improved. Clearly, the simulated money market rate and the change in turnover are now closer to the data (deviations are higher for 5,000 draws). But do these aggregate shocks stick to what has been empirically observed in this time? As presented in section 2.2 and 2.3 (table 1), *Phase II* is characterized by an increase in the collateral stock (widening of the SNB GC Basket to more eligible currencies), whereas the sight deposits were left unchanged. Therefore, an increase in the relation of the stock of collateral to the money stock can be confirmed. According to figure 4, it is also possible to observe an increase in interbank counterparty risk/liquidity needs. However, the results of the comparative statics indicate, that an increase in σ is accompanied by a decrease in the money market interest rate. Hence, a closer look at the outcomes is required. First of all, only the average SARON of the period is simulated. Figure 1 illustrates, that at the beginning of *Phase II*, the

[29] Values are normalized to their maximum in order to be comparable.
[30] Figures in brackets belong to 5,000 draws.

SARON essentially starts to decrease, but compared to *Phase I*, the average level is still higher. In addition, the evolution of the turnover needs to be considered as well. The main origin of an increase in money market turnovers is an increase in σ, whereas changes in $\mathcal{B}$ can insufficiently explain turnover increases (See figure 13; a significant effect of $\mathcal{B}$ on the turnover is only apparent for lower/decreasing values. If $\mathcal{B}$ sufficiently decreases, the money market dries up.). Eventually, these considerations provide additional insights. First of all, an increase in available collateral accounts for an upward pressure of the SARON on an average level. But deeper examining the phase reveals, that the main driving force of the SARON drop since August 2007 was an increase in liquidity needs, which also accounts for an increase in the secured money market turnover. Something not explicitly picked up in the model is the shift from the unsecured to the secured money market segment and from long-term to short-term funding. But from an empirical point of view, this is the story behind the simulation.

	Phase I	Phase II	Phase III	Phase IV	Phase V
empirical					
$SARON^{emp}$	0.01178	0.0197	0.0037	0.0002	0.0004
$Turnover^{emp}$ [a]	3.25	5.62	5.36	3.73	4,03
$Turn.Ratio^{emp}$	-	1.73	1.64	1.15	1.24
100 draws					
$SARON^{sim}$	0.01178	0.01966	0.00367	0.00021	0.00041
$Turnover^{sim}$ [b]	3.13	5.41	5.13	3.48	4.00
$Turn.Ratio^{sim}$	-	1.73	1.64	1.11	1.27
$\mathcal{B}$	24.87	33.70	31.73	10.06	12.82
σ	2.02	2.27	2.33	2.07	2.11
5000 draws					
$SARON^{sim}$	0.01177	0.01887	0.00435	0.00029	0.00018
$Turnover^{sim}$	3.70	6.51	6.49	4.83	4.93
$Turn.Ratio^{sim}$	-	1.76	1.75	1.30	1.33
$\mathcal{B}$	18.51	34.61	21.17	17.13	17.14
σ	2.02	2.24	2.31	2.17	2.17

Table 5: Empirical and simulated SARON and Turnovers (under aggregate shocks)

[a] in CHF bn

[b] Figures do not necessarily represent empirical values.

Phase III starts with the Lehman Brothers default and is fundamentally characterized by the aftermath, which means an explosion in counterparty risk perception, very high liquidity needs and a shock to the recognizability of securitized assets, infecting the market for collateral. At the end of the phase, the SNB already started to provide high amounts of liquidity. These incidents were accompanied by the abrupt and strong decrease in the SARON ($0.0197 \rightarrow 0.0037$) as well as a still high level of the ON repo market turnover compared to *Phase I*. The simulation provides choosing $\mathcal{B} = 31.73$ (21.17) and $\sigma = 2.33$ (2.31) and mirrors a phase of high uncertainty in aggregate liquidity needs in the banking system. For 100 and 5,000 draws, the liquidity needs variance is even higher than in the preceding period. With regard to a collateral crisis, section 2.3 described that the robustness of the secured CHF money market is based on the high quality of collateral, on which no haircuts have been applied historically (Danthine (2013, p. 267)). That is why the decrease in $\mathcal{B}$ should be solely contributed to the liquidity provision of the SNB at the end of 2008. Altogether, the simulation indicates, that the still relative high level of money market turnovers and the drop of the SARON stem from the high variance of liquidity needs. In the end of the phase, the liquidity provision put an additional downward pressure on the interest rate and led to decreasing turnover rates.

In *Phase IV*, the SARON decreased to its lowest level in the time span (0.0002). Again, the strong movement is insufficiently covered by the initial calibration of the model. Additionally, the turnover in the ON repo market decreased compared to the former two phases. The most important characteristic of the period March 2009 - May 2010 was been the huge extension of the sight deposits, also leading to lower aggregate liquidity needs in the banking system (figure 15). From the mid of 2008 to the mid of 2009, the reserves at the SNB increased by a factor of 10. Ceteris paribus, a strong decrease in the bonds-to-money ratio might be expected in order to replicate the decrease in repo market turnovers and the stronger downward pressure on the SARON. Liquidity needs should also vanish according to the flood of money. The simulation results in $\mathcal{B} = 10.06$ (17.13), which indeed goes into the expected direction. However, the figure does not seem to be the empirical relevant case as the large increase in the money stock would require a bonds-to-money ratio of around 2. The liquidity variance decreases either ($\sigma = 2.07$ (2.17)), but still lies above the level of the basic calibration. This seems to be unfounded, with regard to the structural liquidity position of the banking system (figure 15).

Compared to the preceding phase, *Phase V* is characterized by a slight decrease in sight deposits. Additionally, according to figure 4 and 15, the high level of counterparty risk and liquidity needs seemed to entirely vanish since May 2010. The low level of the SARON is still unaltered and the turnover in the repo market only slightly increased compared to *Phase IV*. According to these developments, a slight increase in the bonds-to-money ratio (decrease in sight deposits) and a further decrease in the liquidity shock seem to be reasonable. The first shock is covered by $\mathcal{B}$ $= 12.82$ (17.14), but the standard deviation is still high at $\sigma = 2.11$ (2.17). At this point, a critical note needs to be done. According to the high level of liquidity in the banking system, the variance of liquidity needs should fall below pre-crisis levels, which is not the case. The reason is that the turnover movements in the overall ON repo market (still not dried up completely) prevent σ from strongly decreasing. The drawback of selecting the overall turnover in the ON repo market becomes clear now. In section 2.3, the even stronger decrease of interbank transactions in *Phase IV - V* was mentioned and choosing these turnovers might result in expected outcomes. Simulating the model with respect to estimated interbank turnovers (outcomes are listed in the appendix) mirrors the expected effect. The variance of idiosyncratic liquidity needs rests below the level of the basic calibration ($\sigma = 1.96$ (1.97)) and the negative shock to $\mathcal{B}$ is even stronger ($\mathcal{B} = 8.88$ (13.10)). However, the interbank repo turnovers only build on estimates according to Kraenzlin and von Scarpatetti (2012, pp. 79-81), which is why the outcomes still should be regarded as inaccurate.[31]

Therefore, an additional phase has been added in order to check whether it is possible to observe a different pattern in times where the secured money market nearly freezed all in all. In order to do so, the time series will now be extend until the end of 2013. Since September 2011, the SNB's monetary policy is completely aiming at defending the 1.20 CHF/EUR currency peg (This phase was primarily excluded from the simulations, because steering interest rates and ensuring proper functioning of the money market became irrelevant for implementing monetary policy). In order to prevent the Swiss franc from appreciating, the SNB started a tremendous liquidity provision (see chapter 2.1 and figure 2) and gave up its mandate to steer money market interest rates or stimulating the financial markets. Consequently, the sight deposits exploded, liquidity needs completely vanished and the activities in the repo market strongly decreased (The turnover ratio is 0.23, which depicts a decrease in turnover of nearly 80 % compared to *Phase I*). With these strong movements of the target variables, even stronger effects of the two aggregate shocks are recognizable. By setting $\mathcal{B} = 2.97$ (4.44) and $\sigma = 1.30$ (1.29), the decrease in turnover and the even stronger pressure on the SARON can be explained.

At the end, the final conclusions concerning the preceding simulations have to be mentioned. *Phases II - III* were mainly characterized by an increase in σ, representing the main driver of interest rate movements and a still high level of money market turnovers. Since the increase of sight deposits in 2008, changes in $\mathcal{B}$ start to dominate the downward pressure on the money market rate. A strong negative shock to this variable accounted for a freeze up of the money market later on. In

[31] From 2005 - February 2009, the interbank turnover is assigned an average portion of 65%. With the onset of the liquidity provision, the interbank portion decreases to 50% in 2010.

comparison to Berentsen et al. (2010), the aggregate variance of idiosyncratic liquidity shocks also has a significant effect on the interest rate in the money market, which makes it difficult to fully relate the simulated interest rate to a change in the bonds-to-money ratio. However, the model is able to track the movements of the turnover and the money market rate and the provided shocks also fit to what could be empirically observed. Overall, two of the three hypotheses developed in this work could all be confirmed. In phases of an increased liquidity needs variance, interest rates are pushed down and the turnover in the secured ON money market increases. High liquidity provision of the SNB further pushes down money market interest rates and leads to a freeze up of money markets. A collateral crisis could not be confirmed, which stemmed from the high quality of collateral in CHF repo markets.

5 Discussion

The Swiss repo market turned out to be a comparatively robust source of funding for the Swiss banking system, stemming from rather restrictive collateral practices. However, the financial crisis affected the trading pattern in this financial market segment as well. A shift from unsecured to secured money market activity was mainly caused by a loss in counterparty confidence. A resulting increase in liquidity needs additionally strengthened the high turnover in the ON repo market. But the increase in sight deposits, satisfying the liquidity needs, reduced the money market activity in general and forced money market interest rates to drop to the floor.

Berentsen et al. (2010, 2013) have built a model in the framework of Lagos and Wright (2005), which captures the environment and sequence of trading in the European money market. It has been applied to the Swiss money market environment in order to replicate the developments and movements of the CHF ON repo market turnover and interest rate in the phase of 2005 - 2013. Beforehand, it was possible to show, that the interest rate corridor of the SNB was too wide before the crisis started. More precisely, by evaluating the model for different levels of the deposit rate, the outcome was such that paying interest on reserves would have been welfare enhancing. Later on, by choosing aggregate variance shocks in idiosyncratic liquidity needs of banks and aggregate money supply shocks, the model was able to track the behaviour of the money market interest rate and the volumes of trade in repo transactions. Also the intensity of the shocks in the course of time mirror the empirical findings from section 2.

The most important adaptions and some important drawbacks, limiting the explanatory power of the model, have to be mentioned in the following. First of all, the basic theoretical framework was initially modelled in order to replicate the European money market, which is different to the Swiss money market in several ways. Primariliy, these differences refer to a divergent monetary policy implementation of the ECB and SNB. The ECB aims at keeping ON interest rates close to the interest rate target, whereas the SNB steers the CHF Libor 3M. The SARON turned out to be the relevant interest rate, fitting to secured ON transactions, which the model framework aims to cover. Therefore, a discrepancy between monetary policy implementation and the movement of the SARON appears, possibly hindering the transferability of the model. Most importantly, the SNB does not provide standing facilities like the ECB does. Whereas the ECB uses a fixed deposit and lending facility, which build the interest rate corridor, the SNB only provides a lending facility. The so called liquidity-shortage financing facility is based on the SARON plus an interest premium. Consequently, an inverse dependence between the lending facility and the ON money market rate exists. The lending facility does not put downward pressure on the SARON or does not represent an upper bound for it. It rather is determined by the SARON movements. However, the theoretical intention of a lending facility, being the last resort of satisfying a bank's liquidity needs is still existing and the liquidity-shortage financing facility still functions as a ceiling for ON interest rates in the interbank money market. At least from an inner day perspective. A deposit facility does not exist for the Swiss money market case either. A deposit rate of 0% needed to be chosen for the whole simulation period, as the SNB does not pay any interest on reserves. Hereby, there have been no symmetric changes of the interest rate corridor, making the simulation of the SARON in the course of time difficult.

A few points with regard to interest rate movements in the secured and unsecured segments have been mentioned in section 2.1. Since 2011, there are phases of negative interest rates in the secured money market, according to Figure 1. In general, lending money at negative interest rates always builds on a high level of uncertainty. The shift from unsecured to the secured segment was the first indication of an increased search for safer investments. Negative interest rates in the secured segment are the continuation of these developments. But there exists another puzzling fact. The average interest rate for secured transactions also lies below the "deposit rate". From a theoretical point of view, this seems to be absolutely counter intuitive. When money market participants are still able to deposit their excess liquidity at the CB at an interest rate of zero percent, why should they accept a negative interest in interbank transactions? Bech and Klee (2011) contribute this puzzle to a limited access of some participants[32] to the deposit facility of central banks and additionally, to an unequal distribution of the bargaining power of money market participants. Therefore, if disadvanteged participants with no access to CB facilities face strong liquidity excess and if arbitrage is hindered through divergent bargaining power, the cash taking counterparty may pay a rate below the interest rate on CB reserves. This is a characteristic which is not included in the theoretical model, because the money market interest rate can never lie outside the interest rate corridor (This is another reason why I initially excluded this last phase from the simulations). By assigning a limited accessibility to standing facilities in the model, one might allow for interest rates moving outside of the corridor.

Another issue is, that trading in the money market is assumed to be competitive and no uneven distribution of the bargaining power is considered. However, the CHF repo market is transparent and non-anonymous. Kraenzlin and von Scarpatetti (2011) found evidence, that some trading partners have bargaining power and indeed use it for price differentiation. Their analysis shows, that if cash providers have a higher bargaining power than the cash takers, they are able to enforce a higher repo rate (0.8 bps). On the other side, cash takers with a higher bargaining power were able to reduce the repo rate by 0.5 bps. By implementing Kalai or Nash bargaining into the trading process in the MM, one could be able to assign a higher bargaining power to the cash takers or providers in the model. Kraenzlin and von Scarpatetti (2011) additionally show, that the aggregate bargaining power in the CHF repo market shifted from cash takers to cash providers during the crisis. We thus might get an additional interesting shock, accounting for money market interest rate movements. A bargaining shock building under the label "cash became king" (Kraenzlin and von Scarpatetti (2011, p. 13)).

Overall, with the help of the analysis of the Swiss money market, this thesis shed light on important factors influencing the developments in recent years. The conclusions can help to evaluate the funding situations of the banking system in the future and provide additional aspects for monetary policy implementation in times of money market stress.

[32] Such participants might be money market funds or other shadow banks operating in the market.

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6 Appendix

From liquidity deficit to surplus

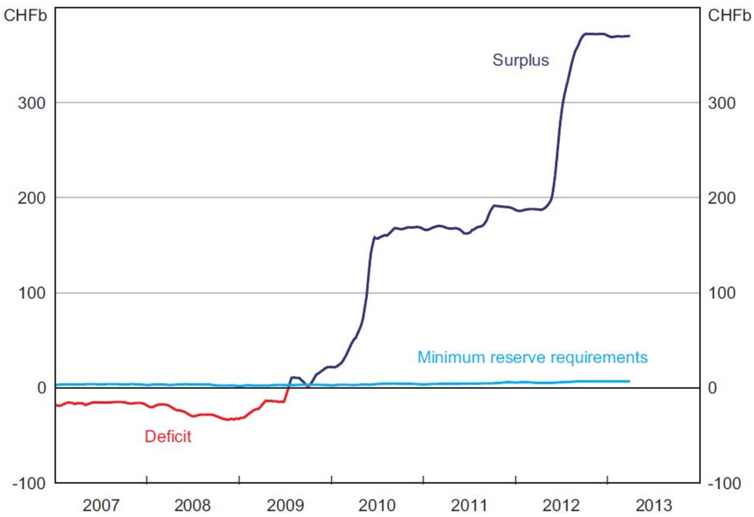

Figure 15: Structural Liquidity Position of the Banking System versus SNB (source: Danthine (2013, p. 265), Swiss National Bank)

Consumption quantities, borrowing/lending and critical values for non-active buyers problems

If	amount of goods	deposits	borrowing	A non-active buyer...
$0 \leq \varepsilon \leq \varepsilon_d$	$q_\varepsilon = \varepsilon$	$d_\varepsilon = p(\varepsilon_z - \varepsilon)$	$l_\varepsilon = 0$	deposits money at the deposit facility
$\varepsilon_d \leq \varepsilon \leq \varepsilon_l$	$q_\varepsilon = \varepsilon_d$	$d_\varepsilon = 0$	$l_\varepsilon = 0$	does not use the standing facilities
$\varepsilon_l \leq \varepsilon \leq \varepsilon_{\bar{l}}$	$q_\varepsilon = \varepsilon \rho_l / \rho_d$	$d_\varepsilon = 0$	$l_\varepsilon = p(\varepsilon \rho_l / \rho_d - \varepsilon_d)$	borrows money at the standing facility
$\varepsilon_{\bar{l}} \leq \varepsilon$	$q_\varepsilon = \varepsilon_{\bar{l}} \rho_l / \rho_d$	$d_\varepsilon = 0$	$l_\varepsilon = \rho_l b$	borrows money at the standing facility / collateral constraint is binding

Table 6: Lemma 1 (source: Berentsen et al. (2013, p. 8))

The appropriate critical values are

$$\varepsilon_d = \beta\phi^+ m/\rho_d, \quad \varepsilon_l = \beta\phi^+ m/\rho_l, \; and \;\; \varepsilon_{\bar{l}} = \varepsilon_l + \beta\phi^+ b$$

Financing the payment of deposits and the optimal interest rate spread

The central bank surplus is

$$\mathcal{S} = M^+ - M + (1/\rho_l - 1)L - (1/\rho_d - 1)D.$$

Under an optimal policy, holding money is costless, because by paying $\rho_d^* = \beta/\gamma$ agents are compensated for their impatience and inflation. They always hold sufficient money to achieve the optimal quantity of consumption. Consequently, agents do not borrow at the borrowing facility ($L = 0$). Therefore $M = D$ (Corollary 1) and the surplus is

$$\mathcal{S}^* = M^+ - M/\rho_d.$$

In steady state, $M^+/M = \gamma$ and the surplus becomes

$$\mathcal{S}^* = (\gamma/\beta)(\beta - 1)M < 0.$$

Obviously, the central bank needs to run a deficit in order to implement the optimal policy. Consequently, the government (which needs to run a surplus) needs to transfer funds to the CB in each period.

If the CB is not able to run a deficit or if it does not receive enough funds, this means

$$\mathcal{S}^* < \mathcal{S}.$$

One can reform the optimal CB deficit such that

$$\mathcal{S}^* = (\gamma - 1/\rho_d^*)M.$$

This implies, if $\mathcal{S}^* < \mathcal{S}$, any other floor system ($i_d = i_l$) yields $\rho_d = \rho_l > \rho_d^*$.

Finally Berentsen et al. (2013, pp. 18 - 20) show that for a floor system $\rho_d = \rho_l > \rho_d^*$, an increase in the borrowing rate i_l (i.e.) is increasing by calculating $\frac{d\mathcal{W}}{d\rho_l}$ at $\rho_d = \rho_m = \rho_l$ such that

$$\left.\frac{d\mathcal{W}}{d\rho_l}\right|_{\rho_d=\rho_m=\rho_l} < 0$$

Choosing different amounts of liquidity shocks - The effect of σ on i_m

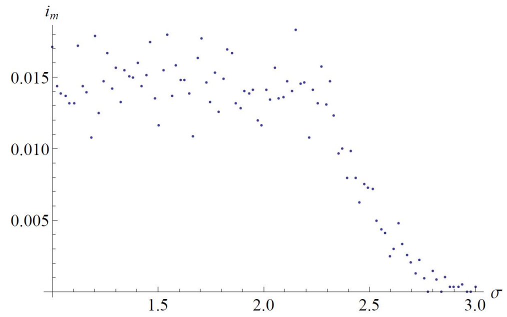

Figure 16: Simulated effect of an increase in σ (100 draws)

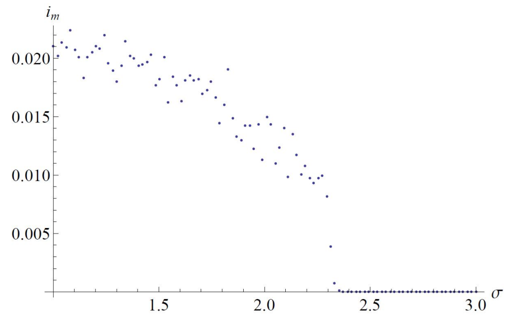

Figure 17: Simulated effect of an increase in σ (5,000 draws)

Exemplary simulation of i_m and money market turnover

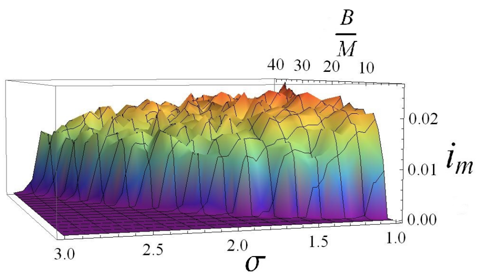

Figure 18: Simulated money market rate (*Phase I*; 5,000 draws)

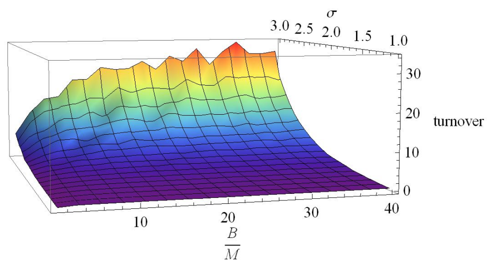

Figure 19: Simulated money market turnover (*Phase I*; 5,000 draws)

Simulating the model for estimated interbank repo market turnovers

	Phase I	Phase II	Phase III	Phase IV	Phase V
empirical					
$SARON^{emp}$	0.01178	0.0197	0.0037	0.0002	0.0004
$Turnover^{emp}$	2.11	3.66	3.35	1.87	2.02
$Turn.Ratio^{emp}$	-	1.73	1.59	0.89	0.96
100 draws					
$SARON^{sim}$	0.01439	0.0179	0.0089	0.0042	0.0043
$Turnover^{sim}$	3.13	3.21	2.92	2.52	2.49
$Turn.Ratio^{sim}$	-	1.02	0.93	0.80	0.80
5000 draws					
$SARON^{sim}$	0.01388	0.01587	0.00988	0.00524	0.00549
$Turnover^{sim}$	3.70	3.70	3.27	2.63	2.66
$Turn.Ratio^{sim}$	-	1.00	0.88	0.71	0.72

Table 7: Empirical and simulated SARON and Turnovers (initial calibration; estimated interbank turnover)

	Phase I	Phase II	Phase III	Phase IV	Phase V
empirical					
$SARON^{emp}$	0.01178	0.0197	0.0037	0.0002	0.0004
$Turnover^{emp}$	2.11	3.66	3.35	1.87	2.02
$Turn.Ratio^{emp}$	-	1.73	1.59	0.89	0.96
100 draws					
$SARON^{sim}$	0.01178	0.01966	0.00363	0.00026	0.0004
$Turnover^{sim}$	3.13	5.41	4.87	2.77	3.07
$Turn.Ratio^{sim}$	-	1.73	1.561	0.88	0.98
$\mathcal{B}$	24.87	33.70	17.15	8.88	10.45
σ	2.02	2.27	2.25	1.95	2.01
5000 draws					
$SARON^{sim}$	0.01177	0.01887	0.004	0.00023	0.00021
$Turnover^{sim}$	3.70	6.51	6.49	3.15	3.22
$Turn.Ratio^{sim}$	-	1.75	1.75	0.85	0.87
$\mathcal{B}$	18.51	34.62	21.17	13.10	13.10
σ	2.02	2.24	2.31	1.96	1.97

Table 8: Empirical and simulated SARON and Turnovers (under aggregate shocks; estimated interbank turnover)

Plagiatserklärung

Ich bezeuge mit meiner Unterschrift, dass meine Angaben über die bei der Abfassung meiner Arbeit benutzten Hilfsmittel sowie über die mir zuteil gewordene Hilfe in jeder Hinsicht der Wahrheit entsprechen und vollständig sind.
Ich habe das Merkblatt zu Plagiat und Betrug vom 22. Februar 2011 gelesen und bin mir der Konsequenzen eines solchen Handelns bewusst.

Basel, 11. Juni 2014 Maximilian Ossonich