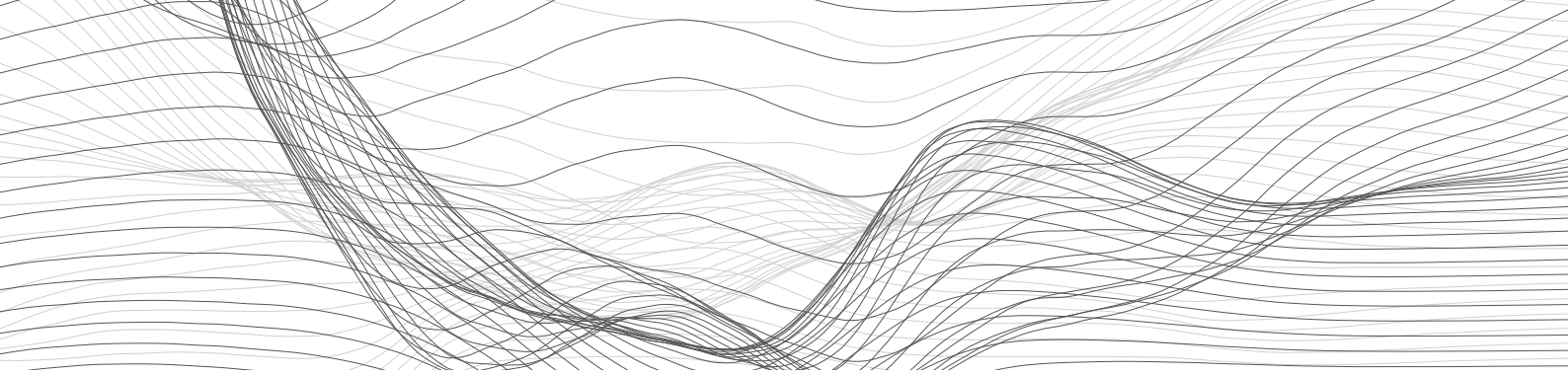

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Liquidity in the Repo Market*

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Abstract

This paper examines liquidity in the Swiss franc repurchase (repo) market and assesses its determinants using a proprietary dataset ranging from 2006 to 2016. I find that repo market liquidity has a distinct intraday pattern, with low liquidity in early and late trading hours. Moreover, repo market liquidity is negatively affected by stress in the global financial system and the end of the minimum reserve requirement period if central bank reserves are scarce. Furthermore, I show that with excess central bank reserves in the financial system, quoted volumes in the interbank market get imbalanced towards more cash provider relative to cash taker quotes and the trading volume declines. By estimating liquidity in an interbank repo market and explaining its drivers, this paper contributes to the ongoing debate on repo market functioning.

JEL Classification: G01, G12, G21
Keywords: Repo market, liquidity, central bank reserves, Switzerland.

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1 Introduction

Banks commonly use repurchase (repo) markets to smooth liquidity shocks. Although these markets are of great importance for the financial system (Fecht, Nyborg and Rocholl, 2011), little is known about the underlying liquidity (in the financial economics sense of the word) of those markets. As in the repo market, central bank reserves (reserves), often called liquidity, is exchanged against collateral, the repo market can be considered liquid if a bank can borrow or lend reserves at any time, at a low cost, and without moving interest rates (see, for instance, Black (1971) and Kyle (1985)).

This paper contributes to the economic literature by describing liquidity and identifying its key determinants in the Swiss franc (CHF) overnight repo market where reserves are exchanged against the collateral basket, which is also used by the Swiss National Bank (SNB) in its monetary policy operations.[1] The analysis I conduct is unique, as it is based on the entire quote book as well as all trades from the prevailing electronic trading platform for CHF repo transactions ranging from 2006 to 2016. Consequently, it allows an intraday analysis of market liquidity prior to, during, and after the financial crisis as well as in a positive and a negative interest rate environment. Moreover, by analyzing how reserves exceeding banks' minimum reserve requirements (excess reserves) affect liquidity in the interbank market, the paper contributes to a better understanding of how accommodative monetary policy affects interbank markets.

I capture liquidity in the CHF repo market by studying standard measures of transaction costs and price impacts. On the one hand, transaction costs are measured by the quoted bid-offer spread as well as the effective spread which is based on actual transactions. On the other hand, price impacts are approximated by changes in quoted mid-rates following a repo trade and the volatility of repo trade rates. Furthermore, to describe the more general market activity, I calculate the size of the cash taker quote volume, the cash provider quoted volume, and the trade volume. The key stylized facts of repo market liquidity can be summarized as follows. First, I show that repo market liquidity has a distinct intraday pattern, with low liquidity in the early and late trading hours. Second, the measures reveal that at the peak of the financial crisis, liquidity in the CHF repo market was subdued. For example, in October 2008 the bid-offer spread reached levels of up to 100 basis points (bps; about 50% of the interest rate level at that time) compared to an average bid-offer spread of about 7 bps prior to the financial crisis. Third, with the extraordinary liquidity injections by the SNB in the months after of the financial crisis, liquidity indicators returned back to pre-crisis levels relatively quickly. Fourth, with excess reserves in the financial system after the financial crisis, the structure of the interbank market changed considerably. Quoted volumes became imbalanced towards more cash providers and the trade volume declined substantially. This is due to the fact, that with excess reserves, banks have no or little need to trade reserves in the interbank market anymore. Along with this, fewer market liquidity indicators can be calculated as only few banks act as cash takers in the repo market.

To identify the key determinants of market liquidity, I run different regression specifications using market liquidity indicators on a daily and an intraday frequency. The regression results indicate that market liquidity indicators are affected by the SNB's monetary policy framework. In this regard, I find that market liquidity is reduced at the end of the minimum reserve requirement period before the financial crisis, i.e. in the period where reserves are scarce. Moreover, when interest rates trade close to the SNB's deposit rate, price impact indicators are low as there is little uncertainty about overnight repo rates.

[1] Studying the liquidity characteristics of repo markets is of particular interest in the overnight maturity, as banks satisfy their short-run liquidity needs predominantly in this maturity. Banks with excess reserves (e.g., from client inflows) typically lend, whereas banks with a need for liquidity (e.g., from client outflows) typically borrow reserves.

This is due to the fact, that all market participants in the CHF repo market have a sight deposit account at the SNB and that depositing excess reserves at the central bank is an available outside option for all banks. Moreover, I find that when the SNB fully allot all bids submitted by banks in daily fixed-rate repo auctions during and after the financial crisis (i.e., fixed-rate full allotment policy), transaction costs and price impact indicators were reduced, indicating that the SNB's policy not only ensured banks access to central bank money but also improved market liquidity in the interbank market. Additionally, a negative risk sentiment in the global financial system affects liquidity in the CHF repo market negatively. If market participants are more risk-averse, they place fewer and more conservative quotes in the interbank market, and market liquidity declines.

Monitoring and understanding the determinants of repo market liquidity is important for central banks and regulators for the following reasons. First, decreasing liquidity in repo markets deteriorates banks' funding conditions. This, in turn may trigger illiquidity in other financial market segments (see Nyborg and Östberg (2014) and Rupprecht, Ranaldo and Wrampelmeyer (2016)) and ultimately affects the real economy. Consequently, liquidity in repo markets signals vulnerabilities in the financial system, and liquidity measures can be used as indicators for financial stability risks (Committee on the Global Financial System (2017)).[2] Second, repo rates are of importance for the transmission of monetary policy and the determination of the yield curve. When liquidity in repo markets evaporates, banks' insurance against sudden liquidity shocks becomes costlier and interbank repo rates increase ("liquidity premium"; see Amihud and Mendelson (1986)). Consequently, the liquidity premium in repo markets affects the transmission of monetary policy and central banks may need to take this premium into account to establish the desired monetary conditions. Third, my analysis shows that for the definition and the design of robust benchmark interest rates, regulators need to consider that trading activity is subdued and cash taker quotes are rather rare in an environment with excess reserves. Thus, it is important to consider all available quoted repo rates and trades for the calculation of reliable benchmarks and not to apply quote and trade filters that are too strict.

The remainder of this paper is structured as follows. Section 2 gives an overview on the literature while Section 3 describes the institutional framework of the CHF repo market. Section 4 defines the liquidity measures and provides descriptive statistics thereof. The determinants of market liquidity are empirically analyzed in Section 5. Finally, Section 6 concludes.

2 Literature

This paper can be incorporated into the literature that analyzes liquidity in money markets, the more general literature on the role and the importance of money markets, and the theoretical and empirical literature on liquidity in equity, fixed income, and foreign exchange markets.

2.1 Market liquidity in money markets

Repo markets are used by banks to exchange liquidity on a secured basis and are an important segment of money markets.[3] Though repo markets are of great importance for the financial system, up to now relatively little is known about the underlying liquidity in those markets. In particular, to the best of my

[2] Deteriorating repo market liquidity is considered a financial stability risk by the Bank of England (2015).
[3] See, for instance, Euro money market survey, September 2015.

knowledge, repo market liquidity has been analyzed only by one paper, and few studies exist on liquidity in unsecured markets.

Dunne, Fleming and Zholos (2011) provide an in-depth description of different market liquidity indicators for the euro (EUR) repo market between 2006 and 2009 using trade and quote data from the BrokerTec trading platform. The authors illustrate that bid-offer spreads increased dramatically with the outbreak of the financial crisis, but returned to pre-crisis levels relatively shortly afterwards. Moreover, Dunne, Fleming and Zholos (2011) examine how changes in European Central Bank (ECB) open market operations during the financial crisis affected the efficiency and reliability of the repo market (measured by market liquidity indicators) as secondary market for reserves.[4] Most importantly, they find that the conditions in the interbank market mirror the outcomes in ECB operations and liquidity in the interbank market improves after more favorable ECB auction outcomes.

Based on trade and quote data from the e-Mid trading platform, Brunetti, Di Filippo and Harris (2011), Beaupain and Durré (2013), and Beaupain and Durré (2016) analyze liquidity in the unsecured market for EUR liquidity. Brunetti, Di Filippo and Harris (2011) illustrate that the main refinancing operations by the ECB positively affected liquidity prior to the financial crisis but negatively affected liquidity during the financial crisis. The authors conclude that these operations failed to reduce asymmetric information problems prevalent in the unsecured money market and were hence unable to improve liquidity. Moreover, Brunetti, Di Filippo and Harris (2011) show that the extraordinary refinancing operations of the ECB increased uncertainty in financial markets and reduced the supply of reserves in the interbank market. Beaupain and Durré (2013) analyze liquidity in the same market but focus on the general determinants of market liquidity. They find that market liquidity depends on the amount of reserves in the financial system, the general market activity, and on the so-called operational framework of the ECB. In particular, they illustrate that the adjustment of the ECB's operational framework in 2004 significantly improved market liquidity.[5] More recently, Beaupain and Durré (2016) assess the impact of the ECB's fixed-rate full allotment policy on the unsecured interbank market and find that in this period liquidity in the money market depends on the level of excess reserves.

2.2 Role of money markets

With regard to the more general literature on money markets, most relevant for my paper is the analysis by Bindseil, Nyborg and Strebulaev (2009), where the structure and imperfections of the market for reserves in the euro area are studied on the basis of banks' bidding behavior in ECB repo auctions. On the one hand, the authors show that banks' bidding behavior is affected by the allocation of reserves, i.e., they find evidence that the allocation of reserves in repo auctions matters. Thereby, they also show that liquidity in the interbank market is not perfect. On the other hand, Bindseil, Nyborg and Strebulaev (2009) find that private information about future short-term rates does not play a central role in banks' bidding behavior and infer that the market is informationally efficient. Following this argument, Fecht, Nyborg and Rocholl (2011) analyze the determinants of interest rates that banks pay in central bank repo

[4] Central bank operations can be understood as the primary market, while the interbank market as the secondary market for reserves (Bindseil, Nyborg and Strebulaev, 2009). In this regard, two different views exist. On the one hand, there is a strain of literature building on Goodfriend and King (1988), which argues that interbank markets allocate liquidity efficiently. On the other hand, there is the literature building on Bhattacharya and Gale (1987), which argues that market liquidity in interbank markets might not be resilient during times of crisis; thus the allocation of reserves is prone to be inadequate.

[5] As of May 2004, the ECB aligned the reserve maintenance period to the Governing Council meetings and reduced the maturity of the main refinancing operations from two weeks to one week.

operations using bank characteristics and market conditions as explanatory variables. They find that the price for liquidity is higher if the distribution of reserves is more imbalanced and thereby confirm that the amount and the allocation of reserves matters.

Moreover, my analysis is also related to empirical papers, which describe the behavior of repo markets during the financial crisis. For the bilateral repo market in the US, Gorton and Metrick (2012) document that haircuts increased dramatically and repo volumes declined during the recent financial crisis, i.e. there was a "run on repo". Copeland, Martin and Walker (2014) and Krishnamurthy, Nagel and Orlov (2014) analyze the US tri-party repo market and show that repo volumes in this market also declined; however, haircuts remained stable as relatively high quality collateral was used. Thus, the authors provide evidence that no system-wide run on repo occurred. Similarly, Mancini, Ranaldo and Wrampelmeyer (2016) showed that the central counterparty European repo market serves as a shock-absorber and ensures a resilient money market even during periods of stress.

2.3 Market liquidity theory and empiricism

This paper is also related to the theoretical and empirical literature on liquidity in equity, fixed income and foreign exchange markets. Theoretical studies in the tradition of Demsetz (1968) associate market illiquidity with the asynchronous arrival of buyers and sellers with immediate trading interest. In those frameworks, transaction costs represent the price for providing immediacy and is determined by the costs of market makers, which quote bid and offer prices at the same time, as well as the degree of competition between market makers (see, for example, Foucault, Pagano and Röell (2013)). In particular, the costs of market making is analyzed in detail and depends on the costs of holding inventories (see, for example, Garman (1976) and Stoll (1978)) as well as private information about the true value of the assets (see, for example, Copeland and Galai (1983), Amihud and Mendelson (1980), and Kyle (1985)). More recently, Duffie, Gârleanu and Pedersen (2005) study how imperfect competition among market makers affects market liquidity. In their framework, market illiquidity is the margin, which market makers are able to extract from their clients and thus reflects the degree of imperfect competition. Apart from these theoretical papers, liquidity has been extensively analyzed in equity markets.[6] In fixed income markets, for instance, Fleming and Sarkar (1999), and Fleming (2003) describe liquidity in the U.S. treasury market, whereas Mancini, Ranaldo and Wrampelmeyer (2012) and Karnaukh, Ranaldo and Söderlind (2015) provide empirical evidence on liquidity in major foreign exchange markets.

3 Institutional background

Next to the institutional setup of the interbank market, monetary policy implementation by the SNB may crucially influence liquidity in the repo market. Hence, the following subsections discuss the institutional setup of the interbank market and SNB's monetary policy framework.

3.1 Characteristics of the CHF repo market

Trading in the CHF repo market takes predominantly place on an electronic trading platform that was launched in 1999 (Kraenzlin and von Scarpatetti, 2011) and was operated by Eurex Repo Ltd. up to 2

[6] See, for example, Chordia, Roll and Subrahmanyam (2000), Chordia, Roll and Subrahmanyam (2001), Hasbrouck and Seppi (2001), and Chordia, Sarkar and Subrahmanyam (2005).

May 2014 and by SIX Repo Ltd. afterwards.[7] The trading platform is set up as a non-anonymous market with bilateral trade relationships. Quote-based trading is predominant[8] for the overnight maturity and works in a fairly simple way: market participants who enter quotes (similar to "limit orders" in equity markets) must specify the following information: maturity, bid/offer indicator, cash amount, repo rate, and collateral basket.[9] To execute a trade, market participants can hit a quote via a click.

Pre- and post-trade transparency is high in the CHF repo market. Quotes are collected in a so-called quote book (similar to a "limit order book" in equity markets), which is displayed for all market participants in the market overview section of the trading platform. The quote book shows all bid and offer quotes ordered by maturity, bid/offer indicator, and repo rate. Thus, market participants can immediately identify the best quoted repo rates, the bid-offer spread, and the quoted volumes for a given maturity. Moreover, the terms of trade (repo rate, volume, maturity, and collateral basket) of all concluded repo transactions are instantaneously visible to all market participants in a public trade list. Therefore, all market participants have the same information set, and current market conditions are common knowledge at all times.

As of 2015, the trading platform has about 150 eligible market participants. Market participants are predominantly banks as well as a few insurance companies domiciled in Switzerland (two-thirds) and banks domiciled abroad (one-third).[10] All market participants have a sight deposit account at the SNB, and most market participants are an eligible counterparty of the SNB in its open market operations.

3.2 Collateral standards[11]

The CHF repo market is highly standardized. Almost all repo transactions (i.e., more than 99%) are traded against a collateral basket and approximately 95% of the outstanding volume is secured with the collateral basket used, defined and maintained by the SNB, the so-called SNB GC basket. Compared to other central banks, the SNB has a relatively strict collateral framework with regard to the collateral quality but a relatively liberal framework concerning the eligible currencies.[12] SNB eligible securities can be denominated in CHF as well as EUR, US Dollars, Pound Sterling, Danish Krone, Swedish Krona and Norwegian Krone. All eligible securities must be marketable and traded on a recognized stock exchange or a representative market that publishes price data on a regular basis. Moreover, the volume at issuance must at least be CHF 1 billion (bn) for securities denominated in foreign currencies and CHF 100 million (mn) for securities denominated in CHF. To ensure collateral quality, SNB eligible securities must have a minimum long-term rating of AA- (where the second-best rating of Standard & Poor's, Moody's and Fitch is decisive). The list of SNB eligible securities is subject to daily modifications due to new issues, redemptions, and exclusions. At the end of 2015, the total volume of collateral eligible for SNB repos amounted to roughly CHF 9,200 bn. Overall, the relatively high quality of the securities accepted in the SNB GC basket ensures that interbank transactions can be considered as nearly free of counterparty risks

[7] Note that all technical functionalities, such as the trading interface, were identical on the two trading platforms. As of 2 May 2014, the vast majority of market participants had access to the new trading environment and trades are conducted predominantly on the SIX repo trading platform.

[8] The share of quoted-based trades is more than 90% in the overnight maturity.

[9] Note that further specifications, such as substitutions and early termination rights, as well as collateral haircuts, are predefined by default but adjustable by market participants.

[10] Since 2006, the number of market participants increased from about 125 to 150. This was mainly due to new participants after the financial crisis, when foreign banks in particular requested access to the market.

[11] This subsection is based on the SNB's instruction sheet on collateral eligible for SNB repos (see Swiss National Bank (2016), Swiss National Bank (2004), and Fuhrer, Müller and Steiner (2017)).

[12] For a detailed discussion of the importance of central banks' collateral framework see Nyborg (2016).

(Kraenzlin, 2008). In interbank repo transactions against the SNB GC basket no haircuts are applied (as defined in the collateral framework of the SNB), the right for collateral substitution is usually not granted, and re-use of collateral is possible (Fuhrer, Guggenheim and Schumacher, 2016).

3.3 Infrastructure

The trading platform is directly linked to the central securities depository (called SECOM) and the real-time gross settlement payment system (called Swiss Interbank Clearing, SIC). Together, these systems constitute an infrastructure that allows for the complete electronic integration of trading, clearing and settlement, the so-called Swiss value chain. The Swiss Master Agreement for repo transactions and the Global Master Repurchase Agreement (GMRA) with Swiss Annex form the legal basis for any repo transaction in the Swiss repo market (SIX Repo, 2016). Interbank repo transactions are settled in central bank money, the settlement is done as delivery versus payment, and no daily "unwinding" of positions occurs (which has proven to be problematic in the United States (Copeland, Martin and Walker, 2010)). To obtain access to the CHF repo system, market participants must have a sight deposit account at the SNB (Swiss National Bank, 2010). In particular, the SNB requires candidates for a sight deposit account to make a "significant contribution to the fulfilment of the SNB's mandate and do not bring with them any major risks" (Swiss National Bank (2010). Therefore, the access policy of the SNB determines the number of market participants in the CHF repo system (Kraenzlin and Nellen, 2015) and ensures that only market participants with a sufficient credit rating are eligible.

3.4 Monetary policy environment

The SNB's operational framework for the implementation of monetary policy can be differentiated into three periods: a liquidity-neutral period lasting from the beginning of the sample period until 14 September 2008, an excess liquidity period lasting from 15 September 2008 to 21 January 2015, and a negative interest rate period with excess reserves from 22 January 2015 onwards.

Liquidity-neutral period: Prior to the financial crisis, the SNB implemented monetary policy in structural liquidity deficit (Berentsen, Kraenzlin and Müller, 2015). In this environment, the SNB provided the financial system with enough reserves so that banks could fulfill the minimum reserve requirements in aggregate, i.e., a so-called liquidity-neutral policy. By requiring banks to hold minimum reserves, the SNB ensures banks' demand for reserves and aims to stabilize money market rates. Minimum reserves must be held at an average level over the reporting period, which lasts from the 20th of the current month until the 19th of the following month.[13] The aggregate minimum reserve requirement of the banking system was about CHF 8 bn in 2006 and increased slightly to roughly CHF 11 bn in 2015 (see Figure 5 Panel B).

The provision of reserves in the liquidity-neutral period was predominantly done via daily open market operations (i.e. fixed-rate repo auctions), normally with a one-week maturity, and the amount of reserves in the financial system was kept constant (see Figure 5 Panel B).[14] In this period, the SNB did not remunerate reserves (i.e., the deposit rate was zero) and the pricing of the standing facility lending

[13] Minimum reserve requirements are calculated as a fraction of banks' short-term liabilities (see National Bank Act, arts. 17 et seq. and National Bank Ordinance, arts. 12 et seq.). Banks can use CHF coins, banknotes and reserves to fulfill minimum reserves requirements.

[14] For more details on SNB repo auctions, see Kraenzlin and Schlegel (2012).

rate was calculated as the average overnight rate (midday fixing) plus 200 bps. Thus, the SNB operated a so-called corridor system and steered money market interest rates via the conditions offered in open market operations (see, e.g. Jordan and Kugler (2004) and Berentsen, Marchesiani and Waller (2014)).

Excess liquidity period: Following the Lehman Brothers collapse on 15 September 2008, the SNB started to provide the banking system with additional reserves via exceptional liquidity-providing operations (see Figure 1). Specifically, the SNB increased the allotment volume in regular repo auctions, conducted longer-term repo operations, and even went over (from 29 October 2008 onwards) to a fixed-rate full allotment policy. Moreover, the SNB cooperated with foreign central banks to indirectly distribute CHF liquidity to foreign banks with CHF funding needs (see, e.g. Auer and Kraenzlin (2011)). Additionally, the SNB started to purchase foreign currencies to combat deflationary risks up from March 2009 (see Figure 1, Swiss National Bank (2009)). The FX purchases led to a structural liquidity surplus with reserves in the financial system exceeding the minimum requirement by a multiple (factor 27 as of January 2015). For this reason, after the financial crisis, minimum reserve requirements are no longer binding for the banking system and the SNB stopped liquidity-providing repo auctions on 12 May 2010 (see Figure 5 Panel B).[15] In the excess liquidity period, the SNB did not remunerate reserves (i.e., the deposit rate was zero), the add-on for the pricing of the standing facility lending rate was reduced from 200 to 50 bps as of January 2009 and interbank rates traded closely to the SNB's deposit rate. Consequently, the SNB operated effectively a floor system of monetary policy implementation.

Negative interest rate period: In December 2014 the SNB announced a tiered remuneration system for reserves with negative interest rates of -0.25%, effective as of 22 January 2015 (Swiss National Bank, 2014). On the 15 January 2015, the SNB discontinued the EURCHF minimum exchange rate and at the same time announced to lower negative interest rates by 0.5 percentage points to -0.75%, effective as of 22 January 2015 (Swiss National Bank, 2015). In the tiered remuneration system, reserve holdings that exceed an individually defined threshold are remunerated at -0.75%, while reserves below this threshold are remunerated at 0%. The individually defined thresholds correspond to a multiple of a banks' minimum reserve requirement (As of 2015, factor 20) or a fixed exemption threshold of at least CHF 10 mn for banks without minimum reserve requirement. With the tiered remuneration system, only banks that hold reserves exceeding the exemption threshold are affected by negative interest rates. In the interbank market, the introduction of the tiered remuneration system with negative interest rates created a new trading motivation. Banks holding fewer reserves than their exemption threshold are willing to borrow reserves at a negative rate and deposit it at the SNB at an interest rate of 0%, whereas banks that hold reserves exceeding their exemption threshold are willing to lend reserves at a negative rates as long as it is higher than the negative deposit rate of the SNB which is -0.75% (see, e.g. Moser (2016) and Bech and Malkhozov (2016)).

[15] The SNB is only operating its so-called "liquidity-shortage financing facility", which has hardly been used in recent years (see SNB accountability reports). Between 5 July 2010 and 2 August 2011, the SNB absorbed excess liquidity from the financial system via the issuance of own debt register claims and liquidity-absorbing repo auctions while from 24 August 2011 to 24 May 2012, the SNB provided the interbank market reserves at a negative rate by placing repo quotes in the interbank market.

3.5 SARON

Overnight repo trades and quotes are used for the calculation of SARON, i.e. the secured CHF money market reference rate. The reference rate has been developed by the SNB in cooperation with SIX Swiss Exchange Ltd in 2009. SARON can be used as a benchmark interest rate by financial market participants for a variety of purposes (SIX Swiss Exchange, 2016). For example, SARON is planned to replace the TOIS fixing (panel based reference rate for unsecured tomorrow next liquidity) as a benchmark interest rate in CHF overnight index swaps (National Working Group on CHF Reference Interest Rates, 2017).

For the calculation of SARON a trade and quote filter is used which intends to limit the possibilities for manipulations (SIX Swiss Exchange, 2016). For example, the filter considers quoted volumes only if the bid-offer spread is not wider than 6 bps at a specific point in time (SIX Swiss Exchange, 2012). To ensure the continuous calculation of SARON also in periods of subdued trading and quoting activity, five major market participants have signed a Memorandum of Understanding (MoU) for active quoting in October 2013, which encourages market participants to place cash provider and cash taker quotes with a bid-offer spread not exceeding 5 bps.[16] Thus, liquidity in the CHF repo market may also be affected by market participants' efforts to strengthen the continuous calculation of SARON.

4 Measuring liquidity

This section describes measures of liquidity in the CHF repo market. First, the dataset used is described, followed by the definition of the market liquidity indicators used. Afterwards, stylized facts about liquidity is provided.

4.1 Dataset

The proprietary dataset used in this paper includes all quotes and trades from the CHF overnight repo market against the SNB GC basket. The sample covers the period from 3 April 2006 to 26 February 2016, which spans ten years with 2,496 trading days, over 120 minimum reserve requirement periods. Detailed information about the 83,198 trades (day, time, repo rate, and volume) as well as the 262,247 quote entries (day, start-time, end-time, quote type, repo rate, volume, and buy/sell indicator) is available.[17]

4.2 Definition of indicators

To identify liquidity in the CHF repo market, I use standard measures of market liquidity, capturing transaction costs and price impacts. Transaction cost indicators are the quoted bid-offer spread as well as the effective spread which is based on actual trades. If spreads are low, executing a trade is associated with low costs and the market can be considered as liquid. Price impact indicators are the volatility of repo trade rates and the change in repo mid-rates following a repo trade. Price impact measures describe a market's ability to absorb "large" transactions without affecting repo rates. If trades have no or little impact on subsequent repo mid-rates as well as trade rates, market liquidity is considered high. Furthermore, to describe the more general market activity, I calculate the size of the cash taker quote

[16] See: www.six-repo.com/de/home/saron.html

[17] Extreme outliers are removed from the dataset if the volume is $\geq$ CHF 10 bn or the interest rate is $\geq$ 10%. The volume (interest rate) condition identifies 22 (4) erroneous quotes and zero erroneous trades.

volume, the cash provider quoted volume, and the trade volume.[18] The following paragraphs define the measures in detail and rely on Goyenko, Holden and Trzcinka (2009).

Transaction costs: The simplest form of a transaction cost indicator is the quoted bid-offer spread (BOS_t). The bid-offer spread measures the distance between the best quoted offer rate (p_t^{bo}) and the best quoted bid rate (p_t^{bb}) at time t.

$$BOS_t = p_t^{bo} - p_t^{bb} \tag{1}$$

As trades are not always executed at the best quoted repo rates, the bid-offer spread might over- or underestimate real transaction costs.[19] The effective spread (EFS_t) controls for this fact, as it measures transaction costs using actual trades. The effective spread is computed as twice the absolute difference between a repo trade rate (p_t^{tr}) and the quoted mid-rate (p_t^m) prevailing at the time of the trade (Goyenko, Holden and Trzcinka, 2009). Thus, it is twice the difference between the effective execution rate and the ideal mid-rate.

$$EFS_t = 2 \cdot \mid p_t^{tr} - p_t^m \mid \tag{2}$$

Price impact: To approximate the price impact of a repo trade, I calculate the 5-minute ($5'$) price impact (PIM_t) for every repo trade. The price impact is calculated as the absolute difference between the quoted mid-rate (p_t^m) prevailing at the time of the trade (t) and the quoted mid-rate ($p_{t+5'}^m$) at time $t + 5'$ (Goyenko, Holden and Trzcinka, 2009).

$$PIM_t = \mid p_t^m - p_{t+5'}^m \mid \tag{3}$$

The price impact of repo trades can also be approximated by the realized volatility of repo trade rates (Jankowitsch, Nashikkar and Subrahmanyam (2011)). If the volatility of repo trade rates (VOL_t) is high, market liquidity tends to be low. Therefore, I calculate the standard deviation (σ) of repo rates ($p_{t,i}^{tr}$) for all trades i conducted in the time interval t to $t + \Delta t$.

$$VOL_t = \sqrt{\frac{1}{I}\sum_{i}^{I}(p_{t,i}^{tr} - \mu_t)^2} \tag{4}$$

Quote and trade volumes: In addition to the market liquidity indicators described above, I calculate the size of the cash provider quote volume, the cash taker quote volume, and the trade volume. The size of the cash provider quote volume (QCP_t) at time t is the sum of the quote volume ($q_{t,i}^{CP}$) of all available cash provider quotes (i) at time t, while the size of the cash taker quote volume (QCT_t) at time t is the sum of the quote volume ($q_{t,i}^{CT}$) of all available cash taker quotes (i) at time t.

[18] It should be noted that measures of trade and quote volumes are not used as market liquidity indicators since their relationship with market liquidity is ambiguous. See, for example, Mancini, Ranaldo and Wrampelmeyer (2012).

[19] In the CHF repo market trades may not be executed at the best prices for several reasons. For example, if the quoted volume at the best rate is small (compared to the intended trade volume) banks may hit the second-best quote to execute the total volume at one price with one counterparty. Moreover, as the CHF repo market is set-up as a market with bilateral trade relationships, banks may also deviate from the best quoted rates as they do not have a trade relationship with the corresponding counterparty. Finally, banks may also execute quotes at a better price directly when new quotes are entered.

$$QCP_t = \sum_{i=1}^{I} q_{t,i}^{CP} \tag{5}$$

$$QCT_t = \sum_{i=1}^{I} q_{t,i}^{CT} \tag{6}$$

The trade volume (TRV_t) is defined as the sum of the transaction volume (v_t) conducted within the time interval t to $t + \Delta t$.

$$TRV_t = \sum_{t}^{t+\Delta t} v_t \tag{7}$$

4.3 Sampling frequency

Liquidity in the CHF overnight repo market can be analyzed between the market opening at 7:00 a.m. and the end of business at 3:55 p.m.[20] To assess the optimal sampling frequency for the calculation of the market liquidity indicators, the trading and quoting frequency in the CHF repo market is analyzed and the optimality principles to separate microstructure noise from volatility proposed by Bandi and Russell (2006) are applied. Table 1 provides descriptive statistics of trade and quote frequencies. On average, a repo trade occurs every 8.5 minutes and quotes remain active for 56 minutes. Moreover, there are on average 34 repo trades per day and 70 repo quotes. Thus, compared to many other markets, the trading and quoting frequency in the CHF repo market is relatively low. This is also indicated by the optimal sampling frequency, which is approximately 55 minutes according to Bandi and Russell (2006). Based on these findings and to have evenly spaced intervals, I compute market liquidity indicators every 53.5 minutes, resulting in 10 observations per business day, starting at 07:53:30 and ending at 15:55:00.[21] To make this more concrete: the quoted bid-offer spread is calculated at these specific points of the day, the effective spread and the price impact measures are calculated for every repo trade and averaged over the time interval (i.e. over the 53.5 minutes), while the volatility of repo trade rates is calculated using all repo trades within this time interval.[22]

4.4 Stylized facts

Table 3 reports descriptive statistics of market liquidity indicators over the total sample period and the three sub-periods, while Figure 2 depicts the development of market liquidity indicators graphically.

Development of market liquidity: For the overall sample period, the quoted bid-offer spread is 6.8 bps on average. While it is 7.8 bps in the liquidity-neutral period, it is slightly lower in the excess liquidity and the negative interest rate period with an average of 6.8 bps and 4.8 bps, respectively. The effective spread which is based on actual transactions is 6.3 bps for the overall sample period and thus slightly lower than the bid-offer spread. Figure 2 Panel A illustrates that the bid-offer spread and the effective spread behave very similarly for the overall sample period, indicating that repo trades are predominantly

[20] The official trading hours for all maturities, except the overnight maturity, are from 7 a.m. to 6 p.m. The cut-off time for overnight transactions is 3:55 p.m., as the end-of-day processing starts at around 4.15 p.m.

[21] Note that in the regression analysis, I also use market liquidity indicators on a daily frequency.

[22] Note that the quoted bid-offer spread cannot be calculated at the last intraday observation point (i.e. when the market closes) at 15:55:00. Thus, for the bid-offer spread only 9 observations per business day are calculated.

executed at the best available quotes. Moreover, the figure shows that at the peak of the financial crisis bid-offer spreads spiked substantially, reaching levels of up to 100 bps; i.e., more than 50% of the interest level at that time. This spike was temporary, however, as spread indicators fell down to pre-crisis levels when the SNB started exceptional liquidity providing operations after October 2008. In August and September 2011 as well as in January 2015, spread indicators increased significantly at a time when the SNB took unconventional monetary policy actions, i.e., the introduction and the discontinuation of the EURCHF minimum exchange rate as well as the introduction of negative interest rates. In the years 2012 and 2013, trading activity was subdued due to the increase of the CHF reserves injected by the SNB (see discussion below) and bid-offer as well as effective spreads were on average approximately 10 bps, revealing reduced market liquidity. With market participants implementing the MoU to ensure the calculation of the SARON, spread indicators decreased in late 2013 back to few bps. Finally, it is worth noting that the bid-offer as well as the effective spread do not change after January 2015, when a tiered remuneration system for reserves with negative interest rates was introduced.

The development of price impact indicators is illustrated in Figure 2 Panel B. On average, the 5-minute price impact of a repo trade is 0.8 bps for the overall sample period and slightly higher in the liquidity-neutral period with 1.3 bps. The volatility of repo trade rates indicator shows a similar picture as the 5-minute price impact measure. On average, the volatility of repo trade rates is 1.7 bps for the overall sample period and 3.2 bps in the liquidity-neutral period. For the excess liquidity period, the volatility of repo trade rates is lower, with 1.1 bps on average. Overall, it is important to note that both price impact measures develop quite similarly as transaction costs indicators. Thus, they peaked during the financial crisis and at the time when the SNB introduced negative interest rates and the EURCHF minimum exchange rate. However, they remained at low levels during the period with subdued trading activity in 2012 and 2013, while transaction cost indicators increased.

Quote and trade volumes: The size of the quote book, measured by the cash provider quote volume and the cash taker quote volume, is illustrated in Figure 4. The quoted volumes were approximately symmetric prior to the financial crisis and increased slightly over time. As shown, the quoted volumes changed only to some extent during the peak of the financial crisis. During the excess liquidity period, the cash provider volume almost doubled, while at the same time, the cash taker quote volume declined due to excess reserves in the system. Over time, the quoted volumes became even more imbalanced, as the cash provider quote volume increased while the cash taker quote volume remained very low, which goes along with a considerable increase in excess reserves (see Figure 5 Panel B). Consequently, the quoted volumes indicate a structural change in the repo market. Whereas in the liquidity-neutral period the market was balanced with trading interest on both sides, is the trading interest completely asymmetric in the excess liquidity period.

The development of the trade volume is depicted in Figure 5 Panel A. The average trading volume between 2006 and 2016 is about CHF 3.0 bn. At the beginning of the sample period, trading activity was substantially livelier with a daily trade volume reaching a maximum of CHF 9.7 bn, while in the period with excess reserves, trading activity was subdued with an average daily trade volume of CHF 1.5 bn. In the negative interest rate period, the trade volume increased again to an average of CHF 2.9 bn, even though the amount of excess reserves increased further. This is due to the fact, that the introduction of the tiered remuneration system with negative interest rates created a new trading motivation and banks trade reserves to reduce the costs induced by negative interest rates.

Intraday pattern: Table 4 provides evidence that market liquidity indicators display distinct intraday patterns, which are particularly pronounced in the liquidity neutral period. Market liquidity tends to be low at the beginning and the end of a trading day, whereas it is relatively high during the day. For example, the average bid-offer spread at the market opening (closing) is around 12 (9) bps whereas it as about 6 bps during the trading day. In line with this, the size of the quote book is typically small in the early trading hours then increases relatively quickly reaching its peak at around 11 a.m. and declines gradually afterwards before collapsing shortly before the end of the business day. For the excess liquidity and the negative interest rate period, intraday patterns are also present but of a slightly lower magnitude.

Intra-month pattern: Table 5 shows the intra-month pattern of market liquidity indicators. The table provides evidence that liquidity is affected by minimum reserve requirements set by the SNB. In the liquidity-neutral period, the fulfillment of the minimum reserve requirement was binding for banks and the last days of the minimum reserve requirement period (day of month: 16, 17, 18, and 19) are associated with higher transaction costs and price impacts. While spread indicators reveal 2-5 bps wider transaction costs, price impact indictors show more volatile repo rates by up to 2 bps on those dates. In the excess liquidity and the negative interest rate period, banks easily fulfill minimum reserves, and the minimum reserve requirement pattern no longer exits. Additionally, Table 5 reveals that market liquidity is typically also reduced at the end of the month, which is potentially due to bank's window dressing activities.

Correlations: Table 6 shows pairwise correlation coefficients between various liquidity measures. The correlation coefficients are positive across all market liquidity indicators. In particular, the correlation between the bid-offer spread and the effective spread is high with a correlation coefficient of approximately 0.7. Moreover, the correlation coefficients between the different groups of market liquidity indicators are also positive (correlation coefficients between 0.3 and 0.5) and indicate that transaction costs are positively related to price impact measures. Additionally, it is important to note that the correlation coefficients for quoted as well as traded volumes with transaction cost and price impact indicators are close to zero or even negative, which is in line with the findings in the related literature (see, e.g., Mancini, Ranaldo and Wrampelmeyer (2012)).

Availability of indicators: Not every market liquidity indicator can be calculated for every observation point. For example, to measure the bid-offer spread a cash provider quote and a cash taker quote is required. If one of the two is missing, the bid-offer spread cannot be calculated and appears as a missing observation in the dataset. Table 3 Column 7 indicates that this is the case for roughly 20% of all potential observation points. On the one hand, these missing observations occur during the beginning of the trading day (see Table 7). Especially, market liquidity indicators for the first observation of a business day (timestamp 07:53:30) can often not be calculated. On the other hand, Table 7 reveals that fewer market liquidity indicators can be calculated in the excess liquidity period. During this period, trading activity is reduced and cash taker quotes are rather scarce, reducing the availability of market liquidity indicators.

5 Determinants of liquidity

This section identifies the determinants of market liquidity. First, I motivate my hypotheses. Second, I define the estimated regressions and discuss the results. Finally, I subject my findings to several robustness checks.

5.1 Hypothesis

Positioning of interest rates in corridor: When the central bank increases the amount of reserves in the financial system the positioning of interest rates in the interest rate corridor of the central bank lowers towards the deposit rate (see e.g., Bech and Monnet (2015)). Consequently, the spread between the interbank rate and the rate at which banks can deposit reserves at the central bank is low. In a market where all participants have access to the central banks' deposit facility, this reduces market liquidity indicators as all banks can deposit their excess reserves at the central bank and do not have to lend them in the interbank market at a market interest rate. Thus, I expect market liquidity indicators to be low, if the spread between the interbank rate and the SNB's deposit rate is low.

Hypothesis 1: Market liquidity indicators are positively related with the spread between the interbank rate and the SNB's deposit rate.

Minimum reserve requirements: The literature suggests that repo markets show distinct seasonal patterns due to minimum reserve requirements set by central banks.[23] Typically, calendar-based regularities due to minimum reserve requirements occur at the end of the maintenance period (Fecht, Nyborg and Rocholl, 2008). As the SNB requires banks to hold minimum reserves, market liquidity might also be affected by minimum reserve requirements, if the allocation of reserves matters. Consequently, I test whether market liquidity is reduced on the last days of the maintenance period (day of month: 16, 17, 18, and 19) using dummy variables (called MiRe). I expect market liquidity indicators to increase on those days in the liquidity-neutral period. As banks easily fulfill minimum reserve requirements in the excess liquidity period, minimum reserve requirements no longer matter for banks; hence, market liquidity should be unaffected at the end of the maintenance period.

Hypothesis 2: Market liquidity is reduced at the end of the minimum reserve requirement period in the liquidity-neutral period but unaffected in the excess liquidity period.

Risks: Market liquidity might be affected by the general risk sentiment in the financial system (Borio, 2000). Theoretical models predict that banks reduce lending in times of elevated aggregate risk, uncertainty, and asymmetric information (see e.g. Allen, Carletti and Gale (2009), Caballero and Krishnamurthy (2008), and Stiglitz and Weiss (1981)). These risks may also affect liquidity in the repo market. Consequently, I expect a negative risk sentiment in the global financial system to cause larger transactions costs and price impact indicators. As a measure of the global financial market's risk sentiment, I use the Chicago Board Options Exchange Volatility Index (VIX) as an explanatory variable.

Hypothesis 3: Market liquidity deteriorates with a negative risk sentiment.

[23] See, for example, Fecht, Nyborg and Rocholl (2008), Hamilton (1996), and Bartolini, Bertola and Prati (2001).

Fixed-rate full allotment: The SNB used the fixed-rate full allotment auction procedure from 28 October 2009 to 12 May 2010 to counter tensions in money markets during and after the financial crisis. As the SNB follows an open access policy and the majority of banks active on the trading platform can participate in SNB's open market operations (Kraenzlin and Nellen, 2015), the fixed-rate full allotment auction procedure ensured banks access to reserves in the primary market. Hence, with the fixed-rate full allotment auction procedure, there was no need for banks to reallocated reserves in the interbank market anymore and as a consequence, the trade volume in the interbank market declined substantially. Therefore, I expect the fixed-rate full allotment auction to improve market liquidity indicators.

Hypothesis 4: The fixed-rate full allotment auction procedure improved market liquidity.

Calendar-based regularities and MoU: Calendar-based regularities might not only occur at the end of the minimum reserve requirement period but also on specific disclosure dates, such as the month-, quarter-, and year-end due to banks' window dressing (see, e.g. Feldberg (2015)). Hence, I include dummy variables (called Ultimo) for the year-, quarter-, and month-end in the regression analysis. Moreover, I include a dummy variable (called MoU) for the period after 1 October 2013, when five major market participants in the CHF repo market signed the MoU to place cash provider and taker quotes with a bid-offer spread not exceeding 5 bps to facilitate the calculation of the SARON (see discussion in Section 3.5).

Control variables: First, I use day-of-the-week dummy variables (i.e. a dummy for every weekday), a dummy variable for the day of a monetary policy announcement as well as a dummy variable for the day before a national holiday. Second, I control for the amount of reserves in the financial system. Third, I account for (i) the exceptional liquidity measures implemented by the SNB between 3 August and 10 September 2011 and (ii) the period when the SNB conducted liquidity-providing repo transactions at negative rates (24 August 2011 until 24 May 2012) using two dummy variables.

5.2 Regression analysis

To assess the determinants of market liquidity indicators I run two ordinary least squares (OLS) regression specifications.[24] First, I assess the determinants of liquidity on a daily basis. By analyzing liquidity on a daily basis, I account for the fact that during the excess liquidity period market activity was subdued. Second, I run a regression analysis using all available intraday observations of market liquidity indicators. By analyzing liquidity on an intraday basis, I am able to control for possible intraday patterns in market liquidity indicators.

5.2.1 Data

For both regress specifications, the dataset described in Section 4 is slightly adjusted. First, to control for the change in the platform provider as of 2 May 2014, the sample period is reduced to the period from 3 April 2006 to 2 May 2014 (see discussion in Section 3.1). Second, I apply the natural logarithm for volumes. Third, I define the positioning of repo rates in relative terms as the width of the SNB's interest rate corridor changed over time (see Equation 8).

[24]Note that estimating a vector autoregression model would also be a possibility. However, as in the market under consideration, reserves are exchanged on an overnight basis, most effects are only prevalent for one time period. Moreover, most independent variables are dummy variables. Thus, I focus on an OLS regression.

$$\text{Positioning in corridor}_t = \frac{i_t^{\text{IB}} - i_t^{\text{SNB deposit}}}{i_t^{\text{SNB lending}} - i_t^{\text{SNB deposit}}} \tag{8}$$

Fourth, for the regression analysis using daily data market liquidity indicators are adjusted as follows: For the quoted bid-offer spread, the effective spread and the price impact indicator, simple averages of all available intraday observations are calculated. For the volatility of repo trade rates, the daily series is generated by calculating the daily standard deviation of repo rates.

5.2.2 Analysis of daily data

For the analysis of market liquidity indicators on a daily basis, I run the following OLS regression:

$$MLI_t = \alpha + \sum_{n=1}^{N} \beta_n \, \mathrm{x}_{t,n} + \epsilon_t \tag{9}$$

The dependent variable, market liquidity indicator (MLI_t), is the bid-offer spread, the effective spread, the price impact of repo trades, and the volatility of repo trade rates. Explanatory variables ($x_{t,n}$) used are stated in Subsection 5.1 and described in Table 2. To eliminate endogeneity issues all independent variables apart from dummy variables are lagged, as current independent variables are not influenced by future dependent variables. Finally, I use heteroskedasticity and autocorrelation robust standard errors to control for a potential correlation of the error terms, using the Newey and West (1987) correction.

The regression results are reported in Table 8. With respect to Hypotheses 1, the regression results reveal that the relative positioning of interest rates affects price impact and transaction costs measures. The positive regression coefficients for price impact measures indicate that when interest rates are close to the SNB's deposit rate, the uncertainty about repo rates declines and price impact measures show low values. Moreover, also transaction cost indicators are positive and statistically significant, indicating that transaction costs are low when interest rates are close to the SNB's deposit rate. In terms of economic magnitude, a reduction of interbank rates from the middle of the interest rate corridor to the deposit rate decreases spread indicators by around 13 bps, the volatility of repo rates by about 6 bps and the 5-minute price impact indicator by about 1.3 bps.

The coefficients for end of minimum reserve requirement period dummy variables are positive and statistically significant in the first sample period. The economic and statistical magnitude is predominantly increasing towards the end of the maintenance period, indicating elevated tensions towards the end of the minimum reserve requirement period. For example, the volatility of repo trade rates on the last day of the minimum reserve requirement period is, ceteris paribus, 5.5 bps higher than on any other business day, whereas the corresponding regression coefficient for the second last day indicates a value of 3.3 bps. With excess reserves, the allocation of reserves at the end of the maintenance period no longer plays a role, because banks easily fulfill the minimum reserve requirements. Therefore, the corresponding regression coefficients lack statistical and economic significance in the excess liquidity period. Overall, these results confirm Hypothesis 2.

There is strong evidence that the risk sentiment in the global financial system affects liquidity in the CHF repo market negatively, supporting Hypothesis 3. For all market liquidity indicators, the regression coefficient is statistically significant and positive. Hence, an increase in the VIX is associated with higher transaction costs as well as price impact indicators. In terms of economic magnitude, a one standard deviation increase in the VIX increases the bid-offer spread as well as the effective spread by approximately

2.4 bps, the price impact of a repo trade by about 0.4 bps and the daily volatility of repo trade rates by about 1.8 bps, respectively.

In the period when the SNB conducted the fixed-rate full allotment auction procedure, the quoted bid-offer spreads was 6.2 bps and the effective spread 6.7 bps lower (Hypothesis 4). Also the coefficients for the price impact as well as the volatility of repo trade rates measure are statistically significant and negative. Thus, the regression results provide evidence that the SNB policy ensured banks' access to central bank money in the primary market and thereby also improved interbank market conditions.

The regression results also provide evidence that market participants indeed followed the MoU to place cash provider and taker quotes with a bid-offer spread not exceeding 5 bps. The corresponding regression coefficient is statistically and economically highly significant for the quoted bid-offer spread as well as the effective spread with around 7 bps. Moreover, the regression coefficients for the year-end is economically significant for transaction costs, however, statistically not significant while price impact measures indicate no reduced market liquidity at those dates. Consequently, there is some evidence that market participants place their quotes more carefully on the year-end, but price changes after repo trades are not more pronounced compared to other business days.

5.2.3 Analysis of intraday data

The determinants of liquidity can also be analyzed using all available intraday data by running the following OLS regression:

$$MLI_t = \alpha + \sum_{n=1}^{N} \beta_n \, \mathrm{x}_{t,n} + \sum_{i=1}^{I} \gamma_i \, \mathrm{FE}_{t,i} + \epsilon_t \tag{10}$$

As before, the dependent variable, market liquidity indicator (MLI_t), is the bid-offer spread, the effective spread, the price impact of repo trades, and the volatility of repo trade rates. In addition to the explanatory variables used in the analysis of daily data, I use time-of-day (indexed by i) dummy variables (FE) to account for intraday patterns in market liquidity and an unbalanced number of observations across the day. Moreover, I use standard errors clustered by business day to control for a potential correlation of the error terms.

The regression results for the OLS regression analysis using all available intraday data are reported in Table 9. The regression results using intraday data turn out to be very similar compared to the regression analysis using daily data. Hence, the findings for Hypotheses 1–4 can also be confirmed using intraday data. Between the two regression specifications, the most notable differences are that the regression coefficients for the year-end and the month-end disclosure date are statistically significant on a 5% and on a 10% significance level for the bid-offer spread. Moreover, the regression results indicate that during the period when market participants followed the MoU the volatility of repo trade rates was elevated while spread coefficients are still negative and statistically significant. Additionally, this regression specification also shows the intraday pattern of market liquidity indicators. The dummy variables provide strong evidence that market liquidity is low at the beginning and the end of a trading day, whereas market liquidity is relatively high during the trading day.

5.3 Robustness

Risk variable: Table 10 shows the regression analysis with daily data using the volatility index of the Swiss Market Index (VSMI) instead of the VIX, while in Table 11 the CHF Libor-OIS spread is used as a measure for the risk sentiment. The regression coefficients for both risk variables are positive and statistically significant for all market liquidity indicators, as in the baseline analysis. Thus, Hypothesis 3 can also be confirmed using the VSMI or the CHF Libor-OIS spread instead of the VIX.

Lagged dependent variable: Table 12 shows the OLS regression results with daily data using a lagged dependent variable as an explanatory variable. For all market liquidity indicators, the lagged dependent variable is positive and statistically significant, suggesting that market liquidity indicators have a moving component. Compared to the baseline analysis, the most notable difference in this regression specification is that the dummy variables at the end of the minimum reserve requirement period have less statistical significance. However, also with this regression specification, the findings with regard to Hypotheses 1–4 remain valid.

Sample periods: Table 13 and 14 show the OLS regression results with daily data for the liquidity neutral and the excess liquidity period separately. Compared to the baseline analysis, the most important change is that in the liquidity neutral period, the coefficients for the positioning of interest rates in the interest rate corridor are mostly positive, however, statistically not significant. This changes in the excess liquidity period, for which the coefficients are statistically and economically significant for all market liquidity indicators.

Availability of intraday market liquidity indicators: As seen in Section 4.4, intraday market liquidity indicators are not always available. With a probit regression, I assess whether a market liquidity indicator's availability can be explained. To do so, a binary dependent variable is generated (MLI_t^{av}), which takes the value one if a market liquidity indicator is available at time t and zero otherwise.

$$Prob(MLI_t^{av} = 1) = \Phi(\sum_{n=1}^{N} \beta_n \ \mathrm{x}_{t,n} + \sum_{i=1}^{I} \gamma_i \mathrm{FE}_{t,i}) \tag{11}$$

In addition to the independent variables used in the OLS regressions, the probit regression contains the cash provider quote volume, the cash taker quote volume, and the trade volume as explanatory variables.[25] Table 15 provides the probit regression results.[26] Most importantly, the table reveals that the availability of market liquidity indicators can be explained to a considerable extent (pseudo R-squared between 0.4 and 0.6). Moreover, the regression results indicate that the probability to observe a market liquidity indicator is positively and statistically significantly related with the cash provider quote volume and the cash taker quote volume, which intuitively makes sense. This illustrates that with higher excess reserves in the financial system fewer market liquidity indicators can be calculated, as only few cash taker quotes are available. Moreover, market liquidity indicators are also positive and statistically significantly related with the trade volume, expect the bid-offer spread which is negative and significantly related.

[25] To eliminate endogeneity issues, these variables are lagged as before.

[26] Note that the sign of the coefficient in a probit regression gives the sign of the according marginal effect (Cameron and Trivedi, 2005). Hence, the interpretation of the probit regression results focuses on the sign and the significance of the coefficient, which determines the direction of the corresponding marginal effect.

Finally, it is worth noting that the end of the minimum reserve requirement period affects the availability of market liquidity indicators in the liquidity neutral period negatively. Thus, on the last days of the minimum reserve requirement period market liquidity indicators are not only lager but also less likely to be observed.

Sample selection model: As the availability of intraday market liquidity indicators can be explained, an OLS analysis of all available intraday market liquidity indicators may contain a sample selection problem. To control for this, I apply a Heckman selection model to validate the findings from the intraday OLS regression. In a first step the Heckman selection model combines a selection mechanism to predict the availability of a market liquidity indicator and in a second step assesses the determinants of market liquidity. In the Heckman selection model, the selection equation is

$$m_t^* = \boldsymbol{\gamma} \boldsymbol{w}_t + \mu_t \tag{12}$$

and the regression model

$$MLI_t = \boldsymbol{\beta} \boldsymbol{x}_t + \epsilon_t \tag{13}$$

where the error terms ϵ_t and μ_t are assumed to be bivariate normal [0,0,1,τ_ϵ, ρ] and m_t^* is not observed. The probability of observing a market liquidity indicator ($m_t = 1$) is Prob($m_t = 1$) = $\Phi(\gamma^{'} w_t)$ while the probability of not observing a market liquidity indicator is Prob($m_t = 0$) = 1-$\Phi(\gamma^{'} w_t)$, where Φ is the standardized normal cumulative distribution function. In the selected sample, the following equation applies:

$$E[MLI_t \mid m_t = 1]_t = \boldsymbol{\beta} \boldsymbol{x}_t + \tau_\epsilon \rho \lambda(\gamma^{'} w_t) \tag{14}$$

In the selection equation, I use the cash provider quote volume, the cash taker quote volume, and the trade volume as additional variables explaining the availability of market liquidity indicators.[27] The Heckman regression is estimated using the two-step procedure, which provides efficient estimates of the parameters (see Cameron and Trivedi (2005)) and standard errors are calculated based on the two-step variance estimator derived by Heckman. The regression results are reported in Table 16. The signs of the coefficients in the selection equation are in line with the findings in the probit regression. Moreover, the regression coefficients in the main equation are generally in line with the findings from the intraday OLS regression. Compared to the OLS regression, the most notable differences are that the Heckman regression provides more statistical evidence of reduced market liquidity at the end of the minimum reserve requirement period as well as at specific disclosure dates.

[27] As shown in the probit model, these variables explain the availability of a market liquidity indicator quite good.

6 Conclusion

This paper estimates and analyses liquidity in the CHF overnight repo market. Based on standard measures of transaction costs and price impacts, repo market liquidity is characterized prior to, during, and after the financial crisis, as well as in a positive and a negative interest rate environment.

The key stylized facts of repo market liquidity can be summarized as follows: Frist, I document that liquidity in the CHF overnight repo market disappeared during the financial crisis. Second, market liquidity indicators have distinct intraday patterns, with low liquidity in the early and late trading hours. Third, I find that with excess reserves in the financial system after the financial crisis, the market structure of the interbank market changed considerably. Quoted volumes in the interbank market became imbalanced towards more cash providers relative to cash takers and the trade volume declined substantially. Along with this, fewer market liquidity indicators can be calculated as only few banks act as cash takers in the repo market. Additionally, the regression results indicate that market liquidity is affected by the SNB's monetary policy framework. In this regard, I find that market liquidity is reduced at the end of the minimum reserve requirement period before the financial crisis. Moreover, when interest rates trade close to the SNB's deposit rate, price impact indicators are low as there is little uncertainty about repo rates. This is due to the fact, that all market participants in the CHF repo market have a sight deposit account at the SNB and that depositing excess reserves at the central bank is an available outside option for all banks. Furthermore, I find evidence that a negative risk sentiment in the global financial system affects liquidity in the CHF repo market negatively.

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A Appendix

A.1 Figures

Figure 1: SNB's open market operations

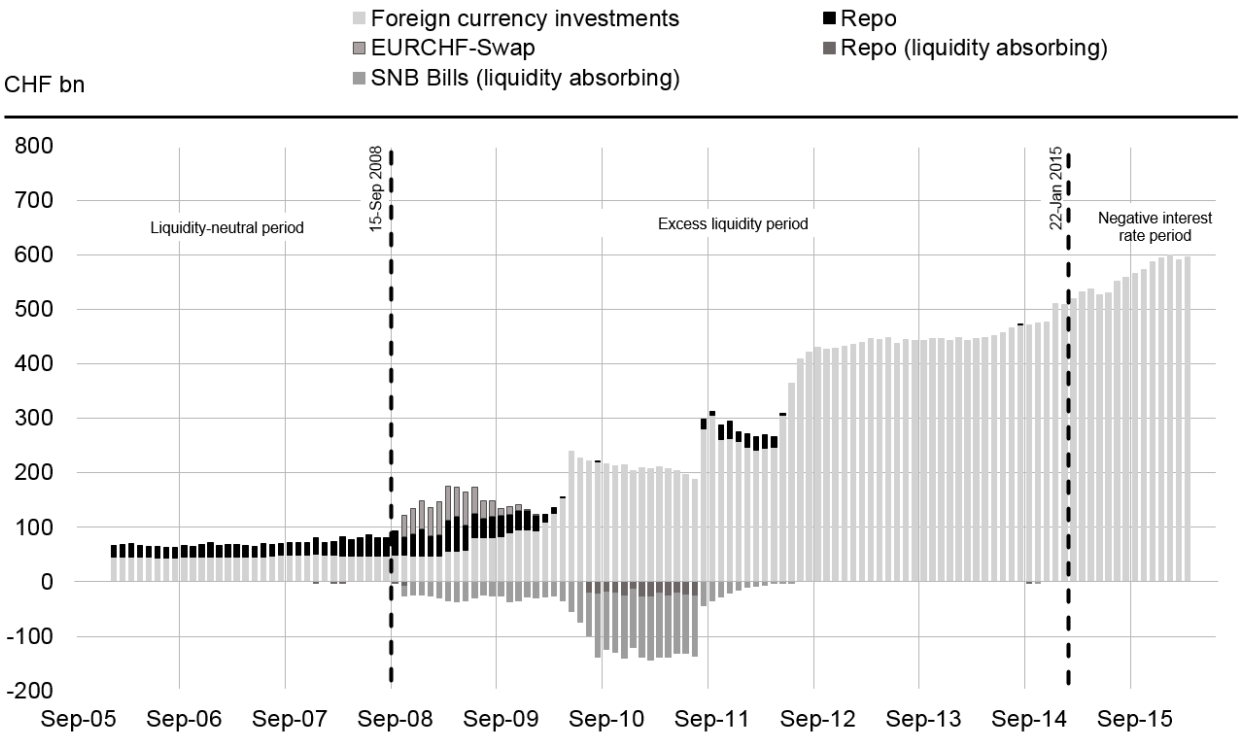

Figure 1 illustrates selected balance sheet positions of the SNB. Source: Data portal of the SNB.

Figure 2: Market liquidity indicators

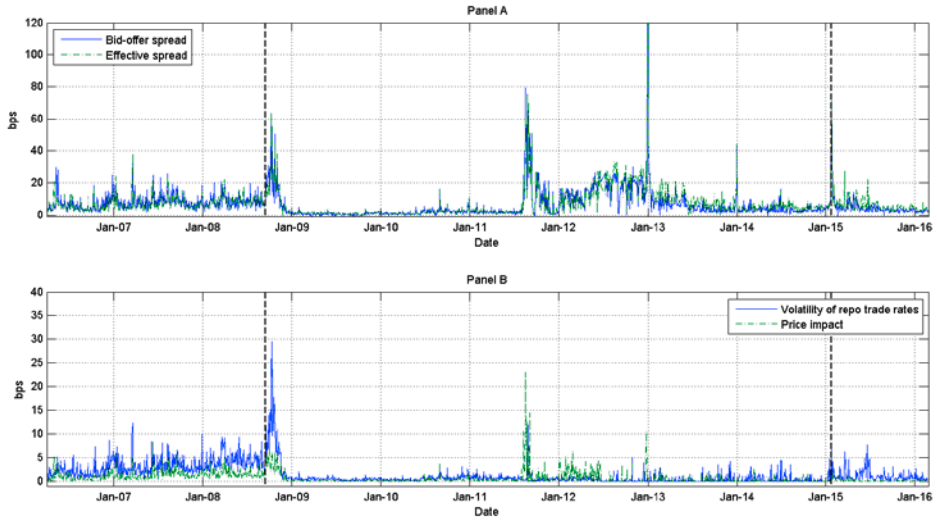

Figure 2 illustrates market liquidity indicators over the sample period. Panel A shows the bid-offer spread and the effective spread. Panel B depicts the volatility of repo trade rates as well as the 5-minute price impact of repo trades. Daily averages are illustrated. The vertical line indicates the different phases of monetary policy implementation. The liquidity-neutral period lasts from 3 April 2006 to 14 September 2008, the excess liquidity period from 15 September 2008 to 21 January 2015, and the negative interest rate period from 22 January 2015 to 26 February 2016. The specification of market liquidity indicators is given in Section 4.2.

Figure 3: State variables I

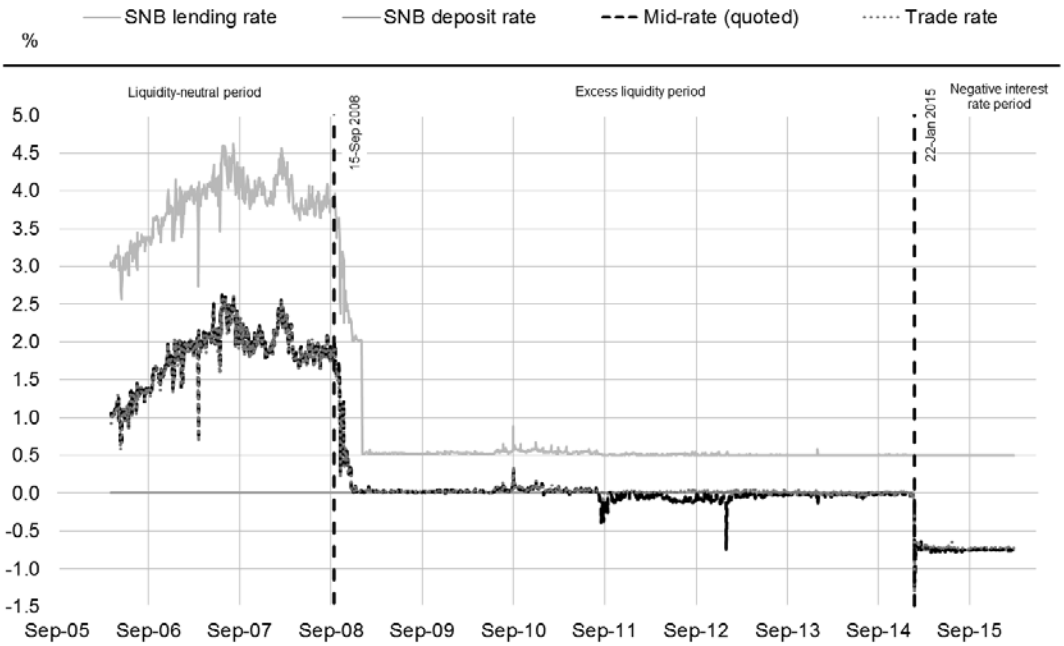

Figure 3 illustrates the development of repo rates (quoted mid-rates as well as trade rates) and the SNB's standing facility rates. Daily averages are illustrated. The vertical line indicates the different phases of monetary policy implementation. The liquidity-neutral period lasts from 3 April 2006 to 14 September 2008, the excess liquidity period from 15 September 2008 to 21 January 2015, and the negative interest rate period from 22 January 2015 to 26 February 2016.

Figure 4: State variables II

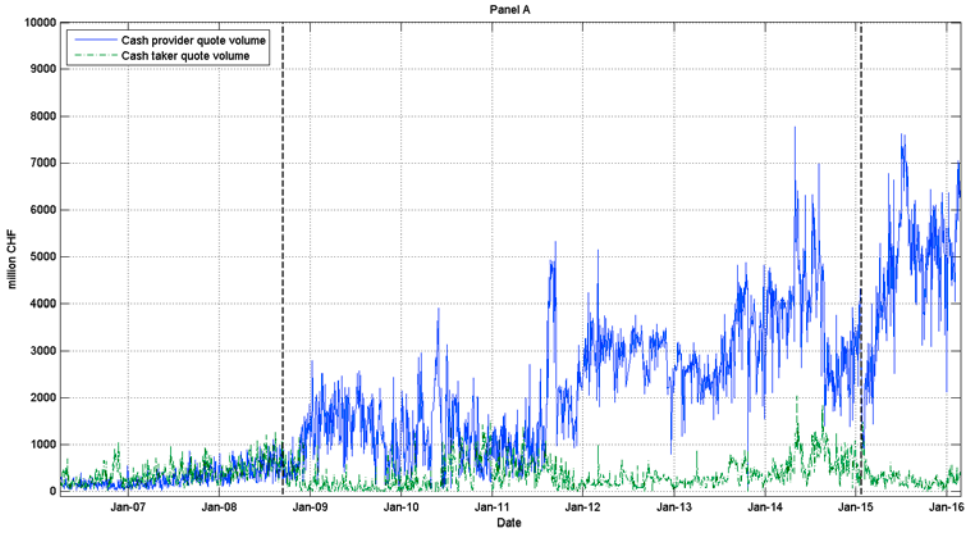

Figure 4 shows the cash provider quote volume and the cash taker quote volume. Daily averages are illustrated. The vertical line indicates the different phases of monetary policy implementation. The liquidity-neutral period lasts from 3 April 2006 to 14 September 2008, the excess liquidity period from 15 September 2008 to 21 January 2015, and the negative interest rate period from 22 January 2015 to 26 February 2016.

Figure 5: State variables III

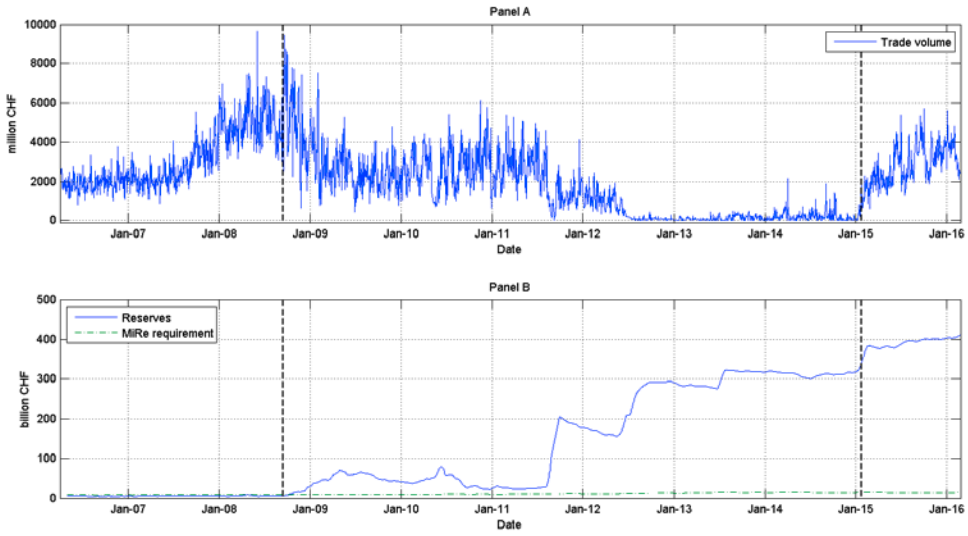

Figure 5 Panel A illustrates the daily trade volume in the overnight repo market. Panel B shows the level of reserves (20-day moving average) and the minimum reserve requirements. The vertical line indicates the different phases of monetary policy implementation. The liquidity-neutral period lasts from 3 April 2006 to 14 September 2008, the excess liquidity period from 15 September 2008 to 21 January 2015, and the negative interest rate period from 22 January 2015 to 26 February 2016.

A.2 Tables

Table 1: Trade and quote frequencies

	mean	median	sd	min	max	count
Time between trades (in minutes)	8.5	2.7	17.8	0.0	429.2	83'198
Number of trades per day	33.5	34.0	25.4	1.0	135.0	2'496
Quote active time (in minutes)	55.7	10.0	106.8	0.0	614.6	262'247
Number of quotes per day	69.6	64.0	45.2	1.0	256.0	2'496

Table 1 provides descriptive statistics of trade and quote frequencies. The sample period ranges from 3 April 2006 to 26 February 2016.

Table 2: Description of variables

Abbreviation	Unit	Variable name
Market liquidity indicators		
BOS	basis points	Bid-offer spread
EFS	basis points	Effective spread
PMI	basis points	Price impact of repo trades
VOL	basis points	Volatility of repo trade rates
Independent variables and market characteristics		
QCP	mn CHF	Cash provider quote volume
QCT	mn CHF	Cash taker quote volume
TRV	mn CHF	Trade volume
VIX	percentage points	Chicago Board Options Exchange Volatility Index
VSMI	percentage points	Volatility Index of the Swiss Market Index (SMI)
Libor-OIS	percentage points	Libor-OIS spread (three-month maturity)
MiRe (1d)	dummy	One if last day of minimum reserve requirement period
MiRe (2d)	dummy	One if second-last day of minimum reserve requirement period
MiRe (3d)	dummy	One if third-last day of minimum reserve requirement period
MiRe (4d)	dummy	One if fourth-last day of minimum reserve requirement period
Fixed-rate full allotment	dummy	One for period 29 October 2008 – 12 May 2010
Control variables		
Month-end	dummy	One if month-end
Quarter-end (add-on)	dummy	One if quarter-end
Year-end (add-on)	dummy	One if year-end
MoU	dummy	One for period 1 October 2013 – end of dataset
Exceptional liquidity measures	dummy	One for period 3 August 2011 – 10 September 2011
SNB quotes negative	dummy	One for period 24 August 2011 – 24 May 2012
Pre-holiday	dummy	One if the following day is a holiday
MPA	dummy	One if day of monetary policy announcement

Table 3: Descriptive statistics

	mean	p50	min	max	count	NaN	N
Panel A: Overall sample period							
Bid-offer spread (bps)	6.78	3.50	-140.00	160.00	17722	21.1%	22464
Effective spread (bps)	6.33	3.65	0.00	157	14693	34.6%	22464
Price Impact (bps)	0.82	0.17	0.00	63.00	13934	44.2%	24960
Volatility (bps)	1.70	0.58	0.00	60.83	16157	35.5%	24960
Cash provider quote volume (mn CHF)	2029.56	1600.00	0.00	12809.00	24960	0.0%	24960
Cash taker quote volume (mn CHF)	359.66	250.00	0.00	2885.00	24960	0.0%	24960
Trade volume (mn CHF)	206.74	88.00	0.00	3516.00	24960	0.0%	24960
Trade rate (%)	0.52	0.03	-1.72	2.69	16157	35.3%	24960
Panel B: Liquidity neutral period							
Bid-offer spread (bps)	7.78	5.00	-10.00	120.00	4618	16.6%	5535
Effective spread (bps)	7.13	5.20	0.00	102.33	5014	9.4%	5535
Price Impact (bps)	1.31	0.75	0.00	39.17	4924	19.9%	6150
Volatility (bps)	3.20	2.29	0.00	49.20	5158	16.1%	6150
Cash provider quote volume (mn CHF)	295.85	205.50	0.00	1900.00	6150	0.0%	6150
Cash taker quote volume (mn CHF)	396.82	315.00	0.00	2385.00	6150	0.0%	6150
Trade volume (mn CHF)	308.50	200.00	0.00	3516.00	6150	0.0%	6150
Trade rate (%)	1.81	1.88	0.00	2.69	5158	16.1%	6150
Panel C: Excess liquidity period							
Bid-offer spread (bps)	6.79	3.00	-40.00	160.00	10896	24.4%	14418
Effective spread (bps)	5.88	2.00	0.00	156.00	7599	47.3%	14418
Price Impact (bps)	0.68	0.00	0.00	63.00	6941	56.7%	16020
Volatility (bps)	0.98	0.35	0.00	60.83	8752	45.4%	16020
Cash provider quote volume (mn CHF)	2232.23	2185.00	0.00	8049.00	16020	0.0%	16020
Cash taker quote volume (mn CHF)	360.77	250.00	0.00	2885.00	16020	0.0%	16020
Trade volume (mn CHF)	154.06	15.00	0.00	3340.00	16020	0.0%	16020
Trade rate (%)	0.07	0.02	-0.75	2.12	8752	45.4%	16020
Panel D: Negative interest rate period							
Bid-offer spread (bps)	4.76	3.00	-140.00	98.00	2208	12.1%	2511
Effective spread (bps)	6.03	4.17	0.00	157	2080	17.2%	2511
Price Impact (bps)	0.16	0.00	0.00	12.50	2069	25.8%	2790
Volatility (bps)	1.06	0.38	0.00	43.30	2247	19.5%	2790
Cash provider quote volume (mn CHF)	4687.43	4900.50	0.00	12809.00	2790	0.0%	2790
Cash taker quote volume (mn CHF)	271.33	250.00	0.00	1850.00	2790	0.0%	2790
Trade volume (mn CHF)	284.89	200.00	0.00	2165.00	2790	0.0%	2790
Trade rate (%)	-0.72	-0.72	-1.72	0.02	2247	19.5%	2790

Table 3 provides descriptive statistics of market liquidity indicators and general market characteristics. The specification of market liquidity indicators is given in Section 4.2. The overall sample (Panel A) ranges from 3 April 2006 to 26 February 2016. The liquidity-neutral period lasts from 3 April 2006 to 14 September 2008 (Panel B), the period with excess reserves ranges from 15 September 2008 to 21 January 2015 (Panel C), and the period with negative interest rates ranges from 22 January 2015 to 26 February 2016 (Panel D).

Table 4: Intraday pattern

Panel A: Liquidity neutral period	07:53:30	08:47:00	09:40:30	10:34:00	11:27:30	12:21:00	13:14:30	14:08:00	15:01:30	15:55:00
Bid-offer spread	11.7	7.5	5.9	6.0	6.0	7.3	7.3	6.5	9.4	-
Effective spread	12.5	8.6	6.4	5.9	5.7	5.7	6.8	6.3	6.4	12.3
Volatility	2.8	2.2	2.9	2.5	2.3	1.9	1.9	2.9	4.3	7.2
Price impact	0.0	1.4	1.0	0.8	0.8	0.9	0.7	1.1	2.0	3.2
Cash provider quote volume	11.8	367.1	414.7	393.5	382.8	346.5	323.6	337.4	281.9	99.3
Cash taker quote volume	9.6	547.5	595.2	576.9	528.5	468.4	454.9	442.3	292.9	52.1
Panel B: Excess liquidity period	07:53:30	08:47:00	09:40:30	10:34:00	11:27:30	12:21:00	13:14:30	14:08:00	15:01:30	15:55:00
Bid-offer spread	7.4	6.7	6.2	6.0	6.1	6.1	6.5	6.7	7.4	-
Effective spread	1.8	6.0	5.7	6.8	6.2	5.3	5.2	5.5	5.4	6.8
Volatility	0.1	0.8	1.0	0.9	0.9	0.9	0.9	0.9	1.1	1.7
Price impact	0.2	0.8	0.6	0.5	0.5	0.4	0.7	0.7	0.9	1.5
Cash provider quote volume	321.7	2'406.6	2'625.5	2'624.2	2'582.6	2'424.8	2'397.5	2'410.7	2'387.1	2'141.6
Cash taker quote volume	44.9	478.9	502.7	467.7	437.3	393.1	380.9	361.4	310.3	230.3
Panel C: Negative interest rate period	07:53:30	08:47:00	09:40:30	10:34:00	11:27:30	12:21:00	13:14:30	14:08:00	15:01:30	15:55:00
Bid-offer spread	7.9	4.9	3.9	4.0	4.2	4.3	4.7	3.9	4.8	-
Effective spread	3.8	6.5	6.7	7.2	6.5	5.4	5.6	5.1	5.2	6.3
Volatility	0.2	1.0	2.0	1.6	1.3	0.6	0.6	0.7	0.8	0.9
Price impact	0.1	0.2	0.2	0.1	0.2	0.1	0.1	0.1	0.2	0.2
Cash provider quote volume	2'501.6	5'320.5	5'564.6	5'511.1	5'390.1	4'976.8	4'741.8	4'715.2	4'474.7	3'678.0
Cash taker quote volume	85.2	327.3	340.8	328.8	309.2	293.1	279.6	282.5	267.8	199.0

Table 4 shows the intraday pattern of different market liquidity indicators. Quoted volumes are in mn CHF. All other variables are in bps. Simple averages of available observations are reported. The liquidity-neutral period lasts from 3 April 2006 to 14 September 2008 (Panel A), the period with excess reserves ranges from 15 September 2008 to 21 January 2015 (Panel B), and the period with negative interest rates ranges from 22 January 2015 to 26 February 2016 (Panel C). The specification of market liquidity indicators is given in Section 4.2.

Table 5: Intra-month pattern

	(1) BOS	(2) EFS	(3) PIM	(4) VOL	(5) BOS	(6) EFS	(7) PIM	(8) VOL	(9) BOS	(10) EFS	(11) PIM	(12) VOL
day 2	0.33	0.84	0.22	-0.29	-0.90	0.28	-0.11	-0.00	1.51	2.04*	-0.06	0.01
day 3	-0.07	0.01	0.14	-0.01	-0.29	0.76	0.21	0.05	1.33	1.96**	-0.11	-0.39
day 4	0.50	0.11	0.04	-0.26	-1.61	-0.45	-0.20	-0.36	1.22	0.72	-0.12	-0.52*
day 5	0.12	1.09	0.15	0.11	-1.13	0.19	0.15	-0.13	1.24	1.02	-0.15	-0.03
day 6	0.33	1.52	0.27	0.03	-0.54	0.61	-0.01	-0.05	1.91*	1.68	-0.07	-0.51**
day 7	0.17	0.18	0.01	-0.38	-0.52	0.66	-0.04	-0.07	2.10	2.50*	-0.17	-0.27
day 8	0.61	0.38	0.22	-0.15	-0.55	1.28	-0.01	0.24	1.90	2.38*	-0.10	-0.21
day 9	0.38	0.78	0.46	-0.23	-0.67	0.91	0.02	0.12	0.97	1.84*	-0.07	-0.41
day 10	1.20	1.84	0.35	-0.02	-1.06	1.22	0.21	0.53	1.11	1.41	-0.09	-0.29
day 11	1.10	0.97	0.43	0.30	-1.59	-0.20	-0.11	-0.21	0.20	0.99	-0.13	-0.61**
day 12	2.53*	2.36*	0.39	0.07	-0.46	0.48	-0.06	-0.26	0.39	0.80	-0.11	-0.24
day 13	1.97*	2.51*	0.53	0.39	0.03	0.65	-0.06	0.10	0.11	0.31	-0.06	-0.67**
day 14	1.32	1.67	0.40	0.63	-0.79	0.18	-0.09	-0.12	0.46	0.63	-0.15	-0.63**
day 15	1.40	1.58	0.82**	0.73	-1.23	0.08	-0.00	-0.03	1.29**	1.30	-0.01	-0.44
day 16	1.72	2.42**	0.68*	0.54	-0.59	0.57	-0.04	-0.18	1.04	1.05	-0.06	-0.70***
day 17	2.22*	2.73**	0.42	0.67	-0.66	0.99	0.27	0.38	0.62	1.18*	-0.01	-0.09
day 18	4.58***	3.01***	0.69**	0.92	-0.63	1.74	0.55	-0.02	-1.48	2.36	-0.09	0.20
day 19	2.75*	4.20**	1.02**	1.80**	-0.56	0.80	0.37	-0.14	0.15	1.14	-0.08	0.27
day 20	-0.08	0.49	0.13	-0.17	-1.55	-0.23	-0.05	-0.02	0.66	0.60	0.04	-0.40
day 21	-1.05	-0.59	0.10	-0.66	-1.02	0.23	-0.14	-0.14	0.29	0.65	-0.13	-0.52
day 22	-1.10	-0.86	-0.25	-0.54	0.13	2.77	0.01	0.06	7.02	8.44	0.11	-0.20
day 23	-0.40	-0.47	0.11	-0.50	0.79	1.29	0.02	0.10	6.30	4.86	-0.00	-0.09
day 24	-0.34	-0.35	0.22	-0.76	0.51	1.28	0.31	0.09	1.19	0.48	-0.02	-0.47
day 25	-0.55	-0.45	-0.00	-0.55	-1.18	0.76	0.19	-0.24	1.07*	1.27	-0.08	-0.14
day 26	0.63	0.45	0.19	-0.41	2.08	2.26	-0.04	-0.01	8.28	6.18	0.03	0.17
day 27	1.06	1.23	0.34	0.02	-0.21	0.37	-0.03	-0.19	4.50	3.73	-0.07	-0.06
day 28	1.53	1.78	0.26	-0.03	0.51	0.69	0.05	-0.08	3.77	2.17	-0.18	-0.33
day 29	1.43	1.89	0.37	0.54	-0.38	0.62	0.10	0.06	2.04	1.51	0.05	0.05
day 30	0.90	1.69	0.09	0.44	0.65	0.86	0.23	0.41	1.28*	0.33	0.06	-0.35
day 31	2.92*	3.16*	0.63	0.93	6.46**	5.45**	0.74*	0.17	3.76*	2.54	0.05	-0.14
Constant	11.14***	12.79	-0.12	2.69	8.01***	1.91*	0.06	0.05	6.41***	2.24***	0.13	0.40
Observations	4618	5014	4924	5158	13104	9679	9010	10999	2208	2080	2069	2247
Adjusted R^2	0.068	0.129	0.142	0.208	0.015	0.008	0.009	0.006	0.061	0.029	0.000	0.013
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 5 shows the intra-month (rows) pattern of different market liquidity indicators (columns). Market liquidity indicators are in bps. Column 1–4 show market liquidity indicators for the liquidity neutral period (lasting from 3 April 2006 to 14 September 2008), Column 5–8 show market liquidity indicators for the excess liquidity period (lasting from 15 September 2008 to 21 January 2015), and Column 9–12 show market liquidity indicators for the negative interest rate period (lasting from 22 January 2015 to 26 February 2016). The following abbreviations are used: bid-offer spread (BOS), effective spread (EFS), price impact (PIM), and volatility of repo trade rates (VOL). The specification of market liquidity indicators is given in Section 4.2. Time-of-day fixed effects are not reported. Standard errors are clustered by business day. ***, **, and * denote statistical significance (two-tailed) at the 1%, 5%, and 10% significance level, respectively.

Table 6: Correlations

	BOS	EFS	PIM	VOL	QCP	QCT	TRV
BOS	1.000						
EFS	0.686	1.000					
PIM	0.404	0.297	1.000				
VOL	0.280	0.462	0.399	1.000			
QCP	-0.016	0.030	-0.143	-0.234	1.000		
QCT	-0.127	-0.019	-0.055	0.013	0.074	1.000	
TRV	-0.043	-0.055	0.118	0.200	-0.168	0.114	1.000
Observations	24960						

Table 6 shows correlation coefficients between different market liquidity indicators. The following abbreviations are used: bid-offer spread (BOS), effective spread (EFS), price impact (PIM), volatility of repo trade rates (VOL), quoted volume cash provider (QCP), quoted volume cash taker (QCT), and trade volume (TRV). The sample period ranges from 3 April 2006 to 26 February 2016. The specification of market liquidity indicators is given in Section 4.2.

Table 7: Availability of market liquidity indicators

Panel A: Liquidity neutral period	07:53:30	08:47:00	09:40:30	10:34:00	11:27:30	12:21:00	13:14:30	14:08:00	15:01:30	15:55:00
Bid-offer spread	5.0%	94.5%	97.4%	94.8%	95.4%	92.5%	92.5%	92.8%	85.9%	-
Effective spread	0.3%	76.3%	98.2%	94.3%	93.7%	86.0%	74.1%	95.9%	99.7%	96.7%
Volatility	1.1%	81.0%	98.9%	96.4%	95.9%	88.6%	77.7%	99.2%	99.8%	100.0%
Price impact	0.3%	75.6%	97.6%	93.8%	92.5%	84.7%	72.8%	94.6%	98.7%	89.9%
Panel B: Excess liquidity period	07:53:30	08:47:00	09:40:30	10:34:00	11:27:30	12:21:00	13:14:30	14:08:00	15:01:30	15:55:00
Bid-offer spread	15.7%	85.3%	86.5%	86.4%	84.7%	81.7%	82.1%	81.1%	76.7%	-
Effective spread	1.8%	59.8%	70.3%	68.1%	56.2%	46.6%	34.4%	46.4%	55.6%	35.2%
Volatility	6.7%	67.7%	75.1%	74.6%	63.7%	54.6%	39.5%	53.9%	61.4%	49.1%
Price impact	1.2%	53.9%	66.4%	65.0%	53.7%	43.7%	31.5%	41.8%	48.6%	27.5%
Panel C: Negative interest rate period	07:53:30	08:47:00	09:40:30	10:34:00	11:27:30	12:21:00	13:14:30	14:08:00	15:01:30	15:55:00
Bid-offer spread	43.0%	92.1%	94.6%	97.1%	95.0%	93.5%	92.8%	92.5%	90.7%	-
Effective spread	9.0%	74.2%	87.8%	83.2%	84.2%	71.7%	63.1%	88.2%	91.8%	92.5%
Volatility	16.8%	85.7%	93.9%	86.7%	87.5%	74.9%	68.5%	93.5%	98.2%	99.6%
Price impact	9.0%	73.1%	87.8%	83.2%	84.2%	71.7%	62.7%	87.5%	91.0%	91.4%

Table 7 illustrates the availability of market liquidity indicators (in %) by intraday observations and sample periods. The liquidity-neutral period lasts from 3 April 2006 to 14 September 2008 (Panel A), the period with excess reserves ranges from 15 September 2008 to 21 January 2015 (Panel B), and the period with negative interest rates ranges from 22 January 2015 to 26 February 2016 (Panel C). The specification of market liquidity indicators is given in Section 4.2.

Table 8: OLS regression – daily data

	(1) BOS	(2) EFS	(3) PIM	(4) VOL
Positioning in corridor (lag 1 day)	25.32***	27.93***	2.56***	12.02***
	(9.26)	(10.84)	(7.21)	(6.72)
MiRe 1d - liquidity neutral period	2.16	4.42***	0.62*	5.52**
	(1.29)	(2.63)	(1.85)	(2.12)
MiRe 2d - liquidity neutral period	3.82***	2.58***	0.30	3.25***
	(2.84)	(3.60)	(1.40)	(3.18)
MiRe 3d - liquidity neutral period	2.37**	2.49**	0.16	2.25**
	(2.00)	(2.35)	(0.97)	(2.18)
MiRe 4d - liquidity neutral period	1.40	2.16**	0.38	5.75*
	(1.15)	(2.20)	(1.56)	(1.73)
MiRe 1d - excess liquidity period	-0.17	-0.23	0.34	-0.06
	(-0.19)	(-0.23)	(1.30)	(-0.19)
MiRe 2d - excess liquidity period	1.04	0.75	0.47	-0.17
	(0.80)	(0.77)	(1.18)	(-0.51)
MiRe 3d - excess liquidity period	-0.23	-0.31	0.12	-0.10
	(-0.23)	(-0.33)	(0.59)	(-0.25)
MiRe 4d - excess liquidity period	-0.74	-0.65	-0.17	-0.21
	(-0.84)	(-0.73)	(-1.46)	(-0.55)
VIX (lag 1 day)	0.23***	0.25***	0.04***	0.17***
	(4.53)	(4.46)	(5.39)	(3.92)
Fixed-rate full allotment policy	-6.23***	-6.70***	-0.57***	-3.58***
	(-6.24)	(-6.16)	(-5.32)	(-4.68)
Ultimo: month-end	0.83	0.95	0.17	0.27
	(1.13)	(1.17)	(1.14)	(0.61)
Ultimo: quarter-end (add-on)	0.55	-0.39	0.35	0.63
	(0.41)	(-0.29)	(1.32)	(0.72)
Ultimo: year-end (add-on)	31.52	31.60	-0.33	0.67
	(1.59)	(1.57)	(-0.70)	(0.45)
MoU active quoting	-6.23***	-7.47***	-0.02	0.13
	(-5.84)	(-6.61)	(-0.26)	(0.47)
Constant	-14.06***	-18.45***	-0.51*	-0.91
	(-6.59)	(-9.09)	(-1.84)	(-0.71)
Observations	1948	1948	1948	1948
Adjusted R^2	0.35	0.37	0.33	0.38
Controls	Yes	Yes	Yes	Yes
Error specification	Newey West	Newey West	Newey West	Newey West

Table 8 shows the OLS regression analysis using daily data. Coefficients are in bps. The following dependent variables (see definition in Section 4.2) are used: bid-offer spread (BOS), effective spread (EFS), price impact (PIM), and volatility of repo trade rates (VOL). Independent variables are described in Table 2. The sample period ranges from 3 April 2006 to 26 February 2014. Control variables are not reported. Heteroskedasticity and autocorrelation robust t-statistics are presented in parentheses, using the Newey and West (1987) correction. ***, **, and * denote statistical significance (two-tailed) at the 1%, 5%, and 10% significance level, respectively.

Table 9: OLS regression – intraday data

	(1) BOS	(2) EFS	(3) PIM	(4) VOL
Positioning in corridor (lag 1 day)	21.84***	23.25***	2.73***	5.16***
	(15.70)	(15.85)	(10.05)	(10.95)
MiRe 1d - liquidity neutral period	3.06*	4.13***	0.78**	1.79***
	(1.94)	(2.61)	(2.21)	(3.69)
MiRe 2d - liquidity neutral period	4.32***	2.24***	0.33*	0.61**
	(3.93)	(3.59)	(1.70)	(2.24)
MiRe 3d - liquidity neutral period	2.24**	2.29**	0.15	0.50
	(2.19)	(2.34)	(0.99)	(1.30)
MiRe 4d - liquidity neutral period	1.67	1.99**	0.42*	0.46
	(1.43)	(2.06)	(1.75)	(1.01)
MiRe 1d - excess liquidity period	0.15	0.20	0.54	-0.06
	(0.13)	(0.18)	(1.42)	(-0.34)
MiRe 2d - excess liquidity period	0.80	1.24	0.77	-0.01
	(0.69)	(1.17)	(1.34)	(-0.03)
MiRe 3d - excess liquidity period	0.11	0.26	0.24	0.21
	(0.11)	(0.29)	(0.83)	(0.58)
MiRe 4d - excess liquidity period	-0.88	-0.81	-0.17	-0.09
	(-0.94)	(-1.05)	(-1.43)	(-0.48)
VIX (lag 1 day)	0.24***	0.27***	0.04***	0.11***
	(8.35)	(9.31)	(11.32)	(8.62)
Fixed-rate full allotment policy	-6.09***	-6.18***	-0.62***	-1.43***
	(-10.53)	(-10.62)	(-8.89)	(-6.76)
Ultimo: month-end	1.63*	1.46	0.25	0.35
	(1.95)	(1.55)	(1.53)	(1.56)
Ultimo: quarter-end (add-on)	-0.02	0.07	0.40	0.52
	(-0.02)	(0.05)	(1.20)	(1.01)
Ultimo: year-end (add-on)	22.19**	8.02	0.29	1.10
	(2.22)	(1.55)	(0.59)	(0.92)
MoU active quoting	-5.90***	-4.18***	0.12	0.97***
	(-12.44)	(-6.59)	(1.23)	(7.88)
time FE: 07:53:30	1.52***	-0.66	0.15	-0.24
	(2.60)	(-0.68)	(0.99)	(-1.27)
time FE: 08:47:00	0.98***	0.52*	0.42***	-0.13**
	(5.12)	(1.90)	(5.66)	(-2.02)
time FE: 09:40:30	0.09	-0.40*	0.18***	0.25***
	(0.74)	(-1.70)	(2.60)	(4.41)
time FE: 11:27:30	0.07	-0.38*	0.03	-0.14**
	(0.47)	(-1.88)	(0.41)	(-2.40)
time FE: 12:21:00	0.44**	-0.82***	-0.03	-0.37***
	(2.56)	(-3.54)	(-0.40)	(-5.38)
time FE: 13:14:30	0.72***	-0.35	-0.01	-0.55***
	(3.85)	(-1.45)	(-0.11)	(-6.08)
time FE: 14:08:00	0.52***	-0.45*	0.18**	0.05
	(2.77)	(-1.88)	(2.49)	(0.78)
time FE: 15:01:30	1.80***	-0.45**	0.76***	0.74***
	(7.09)	(-2.09)	(9.53)	(9.02)
time FE: 15:55:00		3.30***	1.69***	2.35***
		(10.18)	(13.50)	(15.81)
Constant	-14.17***	-14.82***	-1.22***	-1.04***
	(-13.97)	(-13.54)	(-5.36)	(-3.18)
Observations	14017	12202	11455	13496
Adjusted R^2	0.245	0.251	0.155	0.304
Controls	Yes	Yes	Yes	Yes
Error specification	clust. date	clust. date	clust. date	clust. date

Table 9 shows the OLS regression results using intraday market liquidity indicators. Coefficients are in bps. The following dependent variables (see definition in Section 4.2) are used: bid-offer spread (BOS), effective spread (EFS), price impact (PIM), and volatility of repo trade rates (VOL). Independent variables are described in Table 2. The sample period ranges from 3 April 2006 to 2 May 2014. Control variables are not reported. Standard errors are clustered by business day. Note that the time fixed effect (FE) 10:34:00 is captured by the constant and that the quoted bid-offer spread cannot be calculated at the last intraday observation point (i.e. when the market closes) at 15:55:00. ***, **, and * denote statistical significance (two-tailed) at the 1%, 5%, and 10% significance level, respectively. t-statistics are in parentheses below the coefficients.

Table 10: OLS regression – VSMI index

	(1) BOS	(2) EFS	(3) PIM	(4) VOL
Positioning in corridor (lag 1 day)	22.86***	25.28***	2.19***	10.21***
	(7.95)	(9.12)	(6.18)	(5.37)
MiRe 1d - liquidity neutral period	1.84	4.08**	0.57*	5.29**
	(1.10)	(2.42)	(1.70)	(2.03)
MiRe 2d - liquidity neutral period	3.81***	2.58***	0.30	3.24***
	(2.81)	(3.40)	(1.39)	(3.13)
MiRe 3d - liquidity neutral period	2.31*	2.42**	0.15	2.20**
	(1.92)	(2.28)	(0.89)	(2.12)
MiRe 4d - liquidity neutral period	1.29	2.05**	0.36	5.67*
	(1.06)	(2.17)	(1.50)	(1.72)
MiRe 1d - excess liquidity period	-0.25	-0.33	0.33	-0.13
	(-0.28)	(-0.33)	(1.24)	(-0.39)
MiRe 2d - excess liquidity period	1.11	0.83	0.49	-0.12
	(0.85)	(0.84)	(1.20)	(-0.35)
MiRe 3d - excess liquidity period	-0.16	-0.25	0.13	-0.06
	(-0.16)	(-0.26)	(0.64)	(-0.14)
MiRe 4d - excess liquidity period	-0.60	-0.50	-0.15	-0.10
	(-0.67)	(-0.55)	(-1.27)	(-0.26)
VSMI (lag 1 day)	0.25***	0.29***	0.04***	0.19***
	(4.72)	(4.99)	(5.87)	(4.35)
Fixed-rate full allotment policy	-6.01***	-6.60***	-0.55***	-3.47***
	(-6.67)	(-6.82)	(-5.79)	(-5.02)
Ultimo: month-end	0.74	0.84	0.15	0.20
	(1.02)	(1.07)	(1.05)	(0.45)
Ultimo: quarter-end (add-on)	0.79	-0.10	0.39	0.82
	(0.59)	(-0.08)	(1.42)	(0.93)
Ultimo: year-end (add-on)	31.39	31.43	-0.36	0.56
	(1.57)	(1.54)	(-0.75)	(0.37)
MoU active quoting	-6.51***	-7.78***	-0.06	-0.08
	(-5.89)	(-6.68)	(-0.79)	(-0.28)
Constant	-13.14***	-17.78***	-0.41	-0.36
	(-6.24)	(-8.99)	(-1.58)	(-0.31)
Observations	1948	1948	1948	1948
Adjusted R^2	0.35	0.37	0.33	0.38
Controls	Yes	Yes	Yes	Yes
Error specification	Newey West	Newey West	Newey West	Newey West

Table 10 shows the OLS regression results with daily data using the VSMI index instead of the VIX as independent variable for the risk environment. Coefficients are in bps. The following dependent variables (see definition in Section 4.2) are used: bid-offer spread (BOS), effective spread (EFS), price impact (PIM), and volatility of repo trade rates (VOL). Independent variables are described in Table 2. The sample period ranges from 3 April 2006 to 2 May 2014. Control variables are not reported. Heteroskedasticity and autocorrelation robust t-statistics are presented in parentheses, using the Newey and West (1987) correction. ***, **, and * denote statistical significance (two-tailed) at the 1%, 5%, and 10% significance level, respectively.

Table 11: OLS regression – CHF Libor-OIS spread

	(1) BOS	(2) EFS	(3) PIM	(4) VOL
Positioning in corridor (lag 1 day)	19.00***	20.77***	1.56***	7.42***
	(6.55)	(7.56)	(4.54)	(3.56)
MiRe 1d - liquidity neutral period	2.09	4.38**	0.61*	5.44**
	(1.15)	(2.41)	(1.78)	(2.03)
MiRe 2d - liquidity neutral period	4.04***	2.86***	0.34	3.38***
	(2.62)	(3.01)	(1.42)	(3.04)
MiRe 3d - liquidity neutral period	2.19	2.29*	0.13	2.11*
	(1.60)	(1.88)	(0.67)	(1.91)
MiRe 4d - liquidity neutral period	1.51	2.32**	0.40	5.80*
	(1.13)	(2.04)	(1.53)	(1.71)
MiRe 1d - excess liquidity period	-0.39	-0.50	0.30	-0.22
	(-0.47)	(-0.53)	(1.20)	(-0.75)
MiRe 2d - excess liquidity period	1.00	0.69	0.47	-0.19
	(0.79)	(0.77)	(1.18)	(-0.69)
MiRe 3d - excess liquidity period	-0.22	-0.32	0.12	-0.08
	(-0.23)	(-0.37)	(0.60)	(-0.22)
MiRe 4d - excess liquidity period	-0.48	-0.37	-0.13	-0.02
	(-0.58)	(-0.44)	(-1.13)	(-0.06)
Libor-OIS (lag 1 day)	11.40***	13.32***	1.86***	8.04***
	(6.10)	(6.98)	(8.06)	(4.58)
Fixed-rate full allotment policy	-6.55***	-7.25***	-0.65***	-3.69***
	(-7.81)	(-8.50)	(-7.68)	(-5.48)
Ultimo: month-end	0.81	0.92	0.16	0.26
	(1.19)	(1.28)	(1.17)	(0.64)
Ultimo: quarter-end (add-on)	0.79	-0.10	0.39	0.81
	(0.66)	(-0.09)	(1.50)	(0.97)
Ultimo: year-end (add-on)	31.38	31.42	-0.36	0.58
	(1.58)	(1.55)	(-0.80)	(0.42)
MoU active quoting	-6.78***	-8.10***	-0.11	-0.27
	(-6.51)	(-7.49)	(-1.38)	(-1.13)
Constant	-9.89***	-14.05***	0.11	2.34**
	(-5.03)	(-7.53)	(0.46)	(2.13)
Observations	1948	1948	1948	1948
Adjusted R^2	0.38	0.41	0.36	0.41
Controls	Yes	Yes	Yes	Yes
Error specification	Newey West	Newey West	Newey West	Newey West

Table 11 shows the OLS regression results with daily data using the CHF Libor-OIS spread instead of the VIX as independent variable for the risk environment. Coefficients are in bps. The following dependent variables (see definition in Section 4.2) are used: bid-offer spread (BOS), effective spread (EFS), price impact (PIM), and volatility of repo trade rates (VOL). Independent variables are described in Table 2. The sample period ranges from 3 April 2006 to 2 May 2014. Control variables are not reported. Heteroskedasticity and autocorrelation robust t-statistics are presented in parentheses, using the Newey and West (1987) correction. ***, **, and * denote statistical significance (two-tailed) at the 1%, 5%, and 10% significance level, respectively.

Table 12: OLS regression – lagged dependent variable

	(1) BOS	(2) EFS	(3) PIM	(4) VOL
Positioning in corridor (lag 1 day)	11.56***	11.17***	1.64***	7.09***
	(4.97)	(4.92)	(6.17)	(6.04)
MiRe 1d - liquidity neutral period	-0.21	2.38	0.47	2.42
	(-0.12)	(1.57)	(1.48)	(1.54)
MiRe 2d - liquidity neutral period	3.10***	1.66***	0.27	2.40***
	(2.67)	(2.96)	(1.45)	(2.67)
MiRe 3d - liquidity neutral period	1.26	1.35	-0.05	0.04
	(1.23)	(1.58)	(-0.32)	(0.05)
MiRe 4d - liquidity neutral period	0.21	1.38*	0.18	3.96
	(0.21)	(1.95)	(0.70)	(1.19)
MiRe 1d - excess liquidity period	-0.56	-0.51	0.15	0.00
	(-0.92)	(-0.81)	(1.00)	(0.01)
MiRe 2d - excess liquidity period	0.88	0.88	0.39	0.08
	(0.99)	(1.35)	(1.18)	(0.25)
MiRe 3d - excess liquidity period	0.29	0.27	0.19	0.10
	(0.35)	(0.40)	(0.83)	(0.39)
MiRe 4d - excess liquidity period	0.08	-0.19	-0.10	0.22
	(0.13)	(-0.37)	(-0.99)	(0.87)
VIX (lag 1 day)	0.10***	0.10***	0.02***	0.07***
	(3.19)	(3.22)	(4.08)	(4.25)
Fixed-rate full allotment policy	-2.66***	-2.66***	-0.34***	-1.19***
	(-3.79)	(-3.85)	(-3.85)	(-4.79)
Ultimo: month-end	0.36	0.87	0.19	0.44
	(0.42)	(1.02)	(1.31)	(1.16)
Ultimo: quarter-end (add-on)	1.46	-0.04	0.31	0.10
	(1.28)	(-0.04)	(1.38)	(0.13)
Ultimo: year-end (add-on)	26.37	28.16	-0.69	-0.57
	(1.36)	(1.49)	(-1.30)	(-0.38)
MoU active quoting	-2.79***	-3.09***	-0.01	-0.05
	(-3.53)	(-3.73)	(-0.23)	(-0.40)
BOS (lag 1 time period)	0.55***			
	(7.15)			
EFF (lag 1 time period)		0.59***		
		(8.55)		
PIM (lag 1 time period)			0.37***	
			(4.51)	
VOL (lag 1 time period)				0.58***
				(10.96)
Constant	-6.14***	-7.25***	-0.31*	-1.86***
	(-4.21)	(-4.79)	(-1.80)	(-2.60)
Observations	1948	1948	1948	1948
Adjusted R^2	0.57	0.61	0.42	0.60
Controls	Yes	Yes	Yes	Yes
Error specification	Newey West	Newey West	Newey West	Newey West

Table 12 shows the OLS regression results with daily data using a lagged dependent variable as an explanatory variable. Coefficients are in bps. The following dependent variables (see definition in Section 4.2) are used: bid-offer spread (BOS), effective spread (EFS), price impact (PIM), and volatility of repo trade rates (VOL). Independent variables are described in Table 2. The sample period ranges from 3 April 2006 to 2 May 2014. Control variables are not reported. Heteroskedasticity and autocorrelation robust t-statistics are presented in parentheses, using the Newey and West (1987) correction. ***, **, and * denote statistical significance (two-tailed) at the 1%, 5%, and 10% significance level, respectively.

Table 13: OLS regression – liquidity neutral period

	(1) BOS	(2) EFS	(3) PIM	(4) VOL
Positioning in corridor (lag 1 day)	0.34	1.03	0.42	-2.27
	(0.05)	(0.31)	(0.41)	(-0.36)
MiRe 1d - liquidity neutral period	1.56	3.55**	0.70**	5.95**
	(1.05)	(2.34)	(2.08)	(2.27)
MiRe 2d - liquidity neutral period	4.25***	2.55***	0.47**	4.43***
	(3.28)	(3.76)	(2.29)	(4.23)
MiRe 3d - liquidity neutral period	1.99*	1.86**	0.20	2.64***
	(1.89)	(2.07)	(1.27)	(2.80)
MiRe 4d - liquidity neutral period	1.11	1.73***	0.44*	6.07*
	(1.27)	(2.65)	(1.83)	(1.87)
VIX (lag 1 day)	0.13***	0.18***	0.05***	0.17**
	(2.95)	(4.43)	(5.10)	(2.57)
Ultimo: month-end	0.62	1.25	-0.04	0.54
	(0.67)	(1.59)	(-0.21)	(0.47)
Ultimo: quarter-end (add-on)	1.26	1.25	0.79*	2.17
	(0.73)	(0.65)	(1.66)	(0.92)
Ultimo: year-end (add-on)	6.16***	4.65**	0.21	2.65
	(2.83)	(2.28)	(0.34)	(1.01)
Constant	-0.55	-0.26	-0.48	0.42
	(-0.17)	(-0.09)	(-0.71)	(0.11)
Observations	614	614	614	614
Adjusted R^2	0.08	0.13	0.12	0.10
Controls	Yes	Yes	Yes	Yes
Error specification	Newey West	Newey West	Newey West	Newey West

Table 13 shows the OLS regression results with daily data for the liquidity neutral period. Coefficients are in bps. The liquidity-neutral period lasts from 3 April 2006 to 14 September 2008. The following dependent variables (see definition in Section 4.2) are used: bid-offer spread (BOS), effective spread (EFS), price impact (PIM), and volatility of repo trade rates (VOL). Independent variables are described in Table 2. Control variables are not reported. Heteroskedasticity and autocorrelation robust t-statistics are presented in parentheses, using the Newey and West (1987) correction. ***, **, and * denote statistical significance (two-tailed) at the 1%, 5%, and 10% significance level, respectively.

Table 14: OLS regression – excess liquidity period

	(1) BOS	(2) EFS	(3) PIM	(4) VOL
Positioning in corridor (lag 1 day)	53.91***	56.38***	8.20***	43.87***
	(9.31)	(9.58)	(8.92)	(8.25)
MiRe 1d - excess liquidity period	0.03	-0.05	0.34	-0.03
	(0.04)	(-0.05)	(1.32)	(-0.08)
MiRe 2d - excess liquidity period	1.11	0.83	0.44	-0.33
	(0.86)	(0.87)	(1.11)	(-0.95)
MiRe 3d - excess liquidity period	-0.35	-0.45	0.07	-0.36
	(-0.33)	(-0.48)	(0.34)	(-0.92)
MiRe 4d - excess liquidity period	-0.92	-0.85	-0.24**	-0.59*
	(-1.13)	(-0.98)	(-2.11)	(-1.82)
VIX (lag 1 day)	0.22***	0.25***	0.02***	0.12***
	(4.59)	(4.76)	(4.08)	(3.91)
Fixed-rate full allotment policy	-5.04***	-5.45***	-0.32***	-2.28***
	(-5.46)	(-5.58)	(-3.84)	(-4.08)
Ultimo: month-end	1.00	0.88	0.28	0.35
	(1.04)	(0.80)	(1.59)	(1.01)
Ultimo: quarter-end (add-on)	-0.26	-1.50	0.03	-1.01
	(-0.16)	(-0.88)	(0.12)	(-1.56)
Ultimo: year-end (add-on)	45.08*	45.97*	-0.34	1.24
	(1.65)	(1.66)	(-0.84)	(1.61)
MoU active quoting	-6.01***	-7.36***	0.11	0.77**
	(-5.55)	(-6.45)	(1.15)	(2.40)
Constant	-20.26***	-25.18***	-0.84***	-3.96***
	(-9.30)	(-11.36)	(-3.12)	(-4.35)
Observations	1334	1334	1334	1334
Adjusted R^2	0.42	0.43	0.36	0.50
Controls	Yes	Yes	Yes	Yes
Error specification	Newey West	Newey West	Newey West	Newey West

Table 14 shows the OLS regression results with daily data for the excess liquidity period. Coefficients are in bps. The excess liquidity period lasts from 15 September 2008 to 2 May 2014. The following dependent variables (see definition in Section 4.2) are used: bid-offer spread (BOS), effective spread (EFS), price impact (PIM), and volatility of repo trade rates (VOL). Independent variables are described in Table 2. Control variables are not reported. Heteroskedasticity and autocorrelation robust t-statistics are presented in parentheses, using the Newey and West (1987) correction. ***, **, and * denote statistical significance (two-tailed) at the 1%, 5%, and 10% significance level, respectively.

Table 15: Probit regression – availability of intraday market liquidity indicators (1=available)

	(1) BOS	(2) EFS	(3) PIM	(4) VOL
main				
Cash provider quote volume (lag 1 time period)	0.02***	0.02***	0.02***	0.03***
	(3.21)	(5.44)	(5.38)	(6.19)
Cash taker quote volume (lag 1 time period)	0.13***	0.10***	0.11***	0.02***
	(48.19)	(35.07)	(40.16)	(8.71)
Trade volume (lag 1 time period)	-0.01**	0.02***	0.01***	0.02***
	(-2.18)	(6.60)	(5.25)	(6.71)
Positioning in corridor (lag 1 day)	0.65***	-1.97***	-1.44***	-2.61***
	(3.67)	(-12.62)	(-9.63)	(-16.30)
MiRe 1d - liquidity neutral period	-0.53***	-0.41***	-0.44***	-0.23*
	(-4.48)	(-3.52)	(-3.84)	(-1.76)
MiRe 2d - liquidity neutral period	-0.31**	-0.29**	-0.46***	-0.14
	(-2.46)	(-2.33)	(-4.03)	(-1.06)
MiRe 3d - liquidity neutral period	0.16	-0.06	-0.05	-0.03
	(0.85)	(-0.36)	(-0.32)	(-0.19)
MiRe 4d - liquidity neutral period	-0.19	-0.28**	-0.33***	-0.09
	(-1.36)	(-2.10)	(-2.60)	(-0.58)
MiRe 1d - excess liquidity period	0.04	0.08	0.00	0.03
	(0.45)	(1.10)	(0.01)	(0.39)
MiRe 2d - excess liquidity period	-0.00	-0.06	-0.11	0.02
	(-0.02)	(-0.82)	(-1.59)	(0.21)
MiRe 3d - excess liquidity period	0.05	-0.03	-0.08	-0.02
	(0.64)	(-0.44)	(-1.11)	(-0.24)
MiRe 4d - excess liquidity period	0.02	0.11	0.13*	0.08
	(0.28)	(1.48)	(1.83)	(1.11)
VIX (lag 1 day)	-0.00	0.02***	0.01***	0.01***
	(-0.49)	(10.33)	(8.11)	(8.35)
Fixed-rate full allotment policy	-0.54***	0.11***	-0.06*	0.29***
	(-12.67)	(2.74)	(-1.66)	(6.64)
Ultimo: month-end	0.00	-0.14**	-0.12*	-0.11
	(0.01)	(-2.13)	(-1.78)	(-1.54)
Ultimo: quarter-end (add-on)	0.01	0.16	0.22*	0.13
	(0.07)	(1.29)	(1.74)	(0.99)
Ultimo: year-end (add-on)	-0.73***	-0.20	-0.10	-0.25
	(-3.08)	(-0.91)	(-0.47)	(-1.16)
MoU active quoting	0.48***	-0.14***	-0.15***	-0.21***
	(6.27)	(-2.98)	(-3.13)	(-4.34)
Constant	-7.22	2.45***	1.88***	3.41***
	(-0.06)	(20.98)	(16.73)	(27.96)
Observations	20340	20340	20340	20340
Time FE	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
Pseudo R-squared	.58	.45	.43	.45

Table 15 shows the probit regression results, explaining the availability of intraday market liquidity indicators. The dependent variables are binary indicators, which take the value one if a market liquidity indicator is available at time t and zero otherwise. The following dependent variables (see definition in Section 4.2) are used: bid-offer spread (BOS), effective spread (EFS), price impact (PIM), and volatility of repo trade rates (VOL). Independent variables are described in Table 2. The sample period ranges from 3 April 2006 to 2 May 2014. Time-of-day fixed effects and control variables are not reported. ***, **, and * denote statistical significance (two-tailed) at the 1%, 5%, and 10% significance level, respectively. t-statistics are in parentheses below the coefficients.

Table 16: Heckman regression

	(1) BOS	(2) EFS	(3) PIM	(4) VOL
main				
Positioning in corridor (lag 1 day)	21.94***	18.24***	2.53***	3.79***
MiRe 1d - liquidity neutral period	2.95***	3.20***	0.73***	1.66***
MiRe 2d - liquidity neutral period	4.26***	1.56**	0.28	0.52**
MiRe 3d - liquidity neutral period	2.26***	2.08***	0.14	0.46*
MiRe 4d - liquidity neutral period	1.61**	1.42**	0.39**	0.40
MiRe 1d - excess liquidity period	0.14	0.25	0.54***	-0.05
MiRe 2d - excess liquidity period	0.78*	1.08**	0.75***	-0.00
MiRe 3d - excess liquidity period	0.12	0.16	0.24	0.22
MiRe 4d - excess liquidity period	-0.89**	-0.53	-0.16	-0.02
VIX (lag 1 day)	0.24***	0.29***	0.04***	0.11***
Fixed-rate full allotment policy	-6.32***	-6.13***	-0.64***	-1.25***
Ultimo: month-end	1.65***	1.36***	0.25**	0.32**
Ultimo: quarter-end (add-on)	-0.03	0.34	0.41*	0.58**
Ultimo: year-end (add-on)	21.92***	7.20***	0.26	0.95*
MoU active quoting	-5.83***	-5.02***	0.09	0.65***
Constant	-13.10***	-7.37***	0.63***	2.46***
select				
Cash provider quote volume (lag 1 time period)	0.02***	0.03***	0.02***	0.03***
Cash taker quote volume (lag 1 time period)	0.13***	0.10***	0.11***	0.02***
Trade volume (lag 1 time period)	-0.01***	0.01***	0.01***	0.01***
Positioning in corridor (lag 1 day)	0.25	-1.97***	-1.45***	-2.61***
MiRe 1d - liquidity neutral period	-0.37***	-0.42***	-0.44***	-0.23*
MiRe 2d - liquidity neutral period	-0.18	-0.29**	-0.46***	-0.14
MiRe 3d - liquidity neutral period	0.10	-0.06	-0.04	-0.03
MiRe 4d - liquidity neutral period	-0.11	-0.27**	-0.33***	-0.08
MiRe 1d - excess liquidity period	0.04	0.08	0.00	0.03
MiRe 2d - excess liquidity period	-0.01	-0.06	-0.11	0.01
MiRe 3d - excess liquidity period	0.05	-0.03	-0.08	-0.02
MiRe 4d - excess liquidity period	0.01	0.11	0.13*	0.08
VIX (lag 1 day)	-0.00	0.02***	0.01***	0.01***
Fixed-rate full allotment policy	-0.43***	0.12***	-0.05	0.29***
Ultimo: month-end	-0.01	-0.14**	-0.12*	-0.11
Ultimo: quarter-end (add-on)	0.01	0.17	0.22*	0.13
Ultimo: year-end (add-on)	-0.66***	-0.20	-0.10	-0.25
MoU active quoting	0.24***	-0.14***	-0.15***	-0.21***
Constant	-0.75***	2.74***	2.21***	3.61***
mills				
lambda	0.78**	5.08***	0.23**	1.26***
Observations	20340	20340	20340	20340
Time FE	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes

Table 16 reports the regression results for the Heckman regression using intraday market liquidity indicators. The upper panel shows the regression coefficients for the main regression model while the lower panel reports the regression coefficients for the selection equation. The selection equation controls for not observing a market liquidity indicator. Coefficients in the main equation are in bps. The following dependent variables (see definition in Section 4.2) are used: bid-offer spread (BOS), effective spread (EFS), price impact (PIM), and volatility of repo trade rates (VOL). Independent variables are described in Table 2. The sample period ranges from 3 April 2006 to 2 May 2014. Time-of-day fixed effects and control variables are not reported. The Heckman regression is estimated using the two-step procedure and standard errors are calculated based on the two-step variance estimator derived by Heckman. ***, **, and * denote statistical significance (two-tailed) at the 1%, 5%, and 10% significance level, respectively.

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