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(In)Efficiencies of Current Financial Market Infrastructures – A Call for DLT?

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Abstract

We use unique individual bank-to-bank repo transaction data to empirically assess the efficiency of the existing Swiss financial market infrastructure (FMI) for executing delivery versus payment transactions. This approach enables us to identify its current benefits and drawbacks and discuss how these could be addressed and to what extent distributed ledger technology (DLT) could provide a remedy. We find that the fastest settlement time for repo transactions is 12 seconds, but that settlements are often delayed by more than 10 minutes due to the lack of collateral availability. We conclude that the cross-border availability of securities needs to be addressed by either improving interoperability of existing infrastructures or using new technologies.

JEL Classification: G15, G21, G23.

Keywords: financial market infrastructure, secured money market, distributed ledger technology, DLT

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1 Introduction

Financial market infrastructures (FMIs) play a key role in the clearing and settlement of financial transactions. By allowing for the timely settlement of transactions, such as securities or funding transactions, FMI assures that a bank can cover its refinancing needs and meet its payment obligations at all times. Especially at the height of the global financial crisis, i.e., after the collapse of Lehman Brothers in mid-September 2008, a timely settlement was important in order to prevent the emergence of rumours that a bank is in arrears with its payment obligations and potentially illiquid.

In this paper, we assess the efficiency of the existing FMI in Switzerland and try to identify the factors that slow the settlement of financial transactions. To identify these so-called settlement impediments, we use individual bank-to-bank transaction data from the secured money market, so-called repo transactions. Our data set spans from 2008 to 2020 and hence covers phases with both scarce and excess liquidity, heightened market stress, and positive and negative money market interest rates. The settlement of repo transactions is complex as it involves, in addition to the transfer of cash, the selection of securities and the simultaneous exchange of these securities against cash (i.e., delivery versus payment, or DvP). An essential element for the efficient functioning of secured money markets is thus the interoperability between the various FMI elements, i.e., the interlinkages between the trading venue and the payment and collateral settlement systems.

The Swiss case is interesting for the following reasons. First, the so-called Money Market Value Chain (MMVC) is a fully integrated and highly automated infrastructure which covers both trading as well as the settlement of the securities on the books of the Swiss central securities depository (CSD) and the transfer of cash in the central bank's real-time gross settlement (RTGS) system. Second, the secured Swiss franc money market is an international market, with one-third of its active financial institutions domiciled outside of Switzerland and hence, directly participating from abroad (see Auer and Kraenzlin (2011) and Kraenzlin/Nellen (2015)). Third, more than 70% of the securities delivered are so-called cross-border collateral, i.e., securities issued outside Switzerland and denominated in currencies other than the Swiss franc. This cross-border dimension increases the complexity of the settlement process, as non-domestic financial institutions have to transfer the securities from their domestic CSD to SIX SIS Ltd. (SIS), the Swiss CSD, to settle Swiss franc repo transactions.

We find that 20% of all transactions settle within 12 seconds, and we take this as evidence that 12 seconds is the fastest settlement time that the existing MMVC can attain. However, we also find that there are various non-technical factors, such as the counterparty's domicile or the size of the transaction, which can delay the settlement. Our regression results show that the settlement of repo transactions, where the cash taker is domiciled outside Switzerland, takes twice as long compared to when the cash taker is in Switzerland. The delay remains statistically and economically significant and has even increased over time. A more in-depth analysis reveals that the settlement delays are primarily due to insufficient collateral with SIS. Swiss financial institutions typically hold their securities at SIS and hence dispose of sufficient eligible collateral. In contrast,

financial institutions from abroad pool securities at their domestic CSDs, e.g., at Euroclear or Clearstream. Consequently, these participants need to transfer the securities to SIS for the repo transactions to settle. We take this as evidence that the cross-border collateral transfer is currently inefficient and could be further improved. An additional explanation for the increase in settlement delays over time is the availability of high-quality liquid collateral (HQLA), which is used as collateral in the Swiss repo market. The HQLA universe was reduced due to issuer downgrades during the global financial crisis and the higher demand for it due to the introduction of the liquidity coverage ratio (LCR) in 2015. Overall, we conclude that the market-wide scarcity of HQLA, the pooling of collateral within domestic CSDs and the inefficient initiation of collateral transfers to SIS are the primary drivers behind repo transaction settlement delays. Cross-border availability of securities thus needs to be addressed. In the final section of the paper, we discuss to what extent this could be done by improving the interoperability of existing infrastructures or by using new technologies.

The paper contributes to the existing literature by providing in-depth empirical evidence on the efficiency of an FMI for the settlement of repo transactions. The efficiency of financial market segments, such as the secured money market, has not been empirically analysed until now. By providing evidence on the current efficiency standard, and also current inefficiencies, we and others provide a benchmark for future experiments using DLT in financial markets. This is timely, as in the last year a growing number of initiatives have experimented with DLT to evaluate if the resiliency and efficiency of the FMI can be improved (see for example Bech et al. (2020)). These initiatives have been launched by central banks jointly with the private sector to assess the usage of DLT in testing an integrated end-to-end service for the trading and settlement of tokenised assets against central bank money (see for example BIS Innovation Hub et al. (2020), Deutsche Bundesbank et al. (2020), BoT (2019), BoC et al. (2018), BoJ/ECB (2018) and MAS et al. (2018)).

The remainder of this paper is organized as follows. Section 2 embeds our research into the broader literature. Section 3 describes the data set and the institutional setup of the Money Market Value Chain. We describe the methodology in Section 4. Subsequently, we discuss the regression results and conclude in Sections 5 and 6, respectively.

2 Literature

Established, centrally organized FMIs have seldom been focal points for public discussion or the economic literature. Nevertheless, FMIs play a critical role in the financial system and for the broader economy as they facilitate the settlement of financial transactions. In their role as settlement infrastructures, they reduce or eliminate certain settlement, credit and liquidity risks. In 2012, the Committee on Payment and Market Infrastructures (CPMI) in collaboration with the International Organization of Securities Commissions (IOSCO) defined a framework with minimum market standards. This led to so-called principles for financial market infrastructures (PFMI) which FMIs need to meet and are regularly assessed against (see CPMI/IOSCO (2017)).

Considering the secured money market, we find one principle that stands out, namely, Principle 21, which defines that FMIs shall settle transactions in an efficient and effective way. Efficient FMIs allow for a timely settlement of transactions. This assures that a bank can cover its refinancing needs and meet its payment obligations at all times. Especially, after the collapse of Lehman Brothers in mid-September 2008 a timely settlement was important, in order to prevent the emergence of rumours that a bank was in arrears with its payment obligations and potentially illiquid. An efficient FMI allows banks to manage their liquidity with tightly calculated prudential funds, which in turn reduces their opportunity costs.

We find that five PFMI are particularly relevant to ensure the goal of an efficient and secure money market. First, Principle 12, which outlines the concept and requirements of delivery versus payment (DvP). FMI can ensure the simultaneous settlement of two linked obligations, i.e., the delivery of securities against payments of cash, and thus significantly reduce counterparty and transaction risks. Closely related to this principle is Principle 9 (settlement in central bank money), which is combined with Principles 20 (establish FMI-links) and 5 (cross-border collateral arrangements). Settlement in central bank money – compared to commercial bank money – is essential for large-value financial transactions to eliminate credit and liquidity risks. For CSDs, it is thus important to establish a link to the central bank’s payment system. Beyond that, it is also important to have cross-border collateral arrangements in place to provide efficient liquidity bridges across markets. Establishing links to CSDs in other countries is a prerequisite for the acceptance of foreign-denominated securities and may eventually help relax collateral constraints for market participants. The acceptance of foreign-denominated collateral is an important feature in the secured money market in Switzerland. Due to the small capital market relative to the size of the financial industry, the secured money market would not function due to lack of ample collateral to cover the funding. Settlement finality (Principle 8), i.e., ensuring that all assets have been transferred in a final and irrevocable way, is the basis for a trustworthy and well-functioning financial system.

The importance and relevance of these PFMI have also been identified and addressed by the ECB. In 2001, Giovannini et al. (2001) identified the so-called “Giovannini Barriers” in cross-border clearing and settlement. Among others, they found that (a) there was no guaranteed intra-day settlement finality for cross-border transactions within the EU, (b) national clearing and settlement systems operated on a variety of non-standardized platforms, which eventually led to high operating costs as well as (c) differences in settlement conventions and operating hours. In response to this, the ECB launched the Target 2 Securities (T2S) initiative to address these barriers, pave the way for a harmonised securities settlement infrastructure in Europe and reduce the costs of cross-border settlements (see Weller (2012) and Bullmann/Pinna (2020)). T2S was successfully introduced in 2015 and has since improved the interoperability of securities settlement systems and reduced settlement risk by enabling simultaneous settlement of collateral in central bank money (ECB (2020)).

There have also been a growing number of initiatives in recent years experimenting with DLT to evaluate if the efficiency and resiliency of the FMI could be improved by using new technology instead of enhancing existing infrastructures (see Shabsigh et al. (2020)

and Bech et al. (2020)). These initiatives have been launched jointly by central banks and the private sector to assess the use of DLT for testing an integrated end-to-end service for the trading and settlement of tokenised assets against central bank money (see Deutsche Bundesbank et al. (2020), BoT (2019), BoC et al. (2018), BoJ/ECB (2018), and MAS et al. (2018)). The experiments settled transactions on a DvP basis either on a single ledger or between two separate ledgers (i.e., cross-ledger). The findings can be summarized as follows: First, all experiments successfully demonstrated that the DLT-based system could execute a simultaneous and irrevocable settlement of securities against central bank money. Second, they revealed that having all tokenised assets (cash and equity tokens) on a single ledger resulted in more efficient and faster DvP settlements relative to a setup where two systems – be it two existing infrastructures or cross-ledgers – interoperated. Third, operational costs and post-trading efforts (such as back-office reconciliations) could be reduced thanks to compressed settlement cycles and simplified post-trade settlement processes. Fourth, smart contracts allowed for consistent and coherent implementation of rights and obligations. The findings, however, stress that the operational value for market participants needs to be assessed in greater depth and that DLT infrastructures do not yet fulfil the same efficiency and performance levels as existing FMIs.

3 Data set, institutional setup and descriptive statistics

The analysis is based on unique data from the Swiss franc repo trading platform, which constitutes the prevailing secured money market in Switzerland and which is also used by the Swiss National Bank (SNB) to conduct its monetary policy operations. Each data point provides information on the two institutions involved, the interest rate charged, the cash amount provided, the time of transaction conclusion on the trading platform, the time when the transaction settles, and the number of securities delivered. In the analysis we focus on the initial settlement of repo transactions, i.e., on the purchase leg and not on the repayment leg, i.e., when the transaction matures.

Repo transactions in Switzerland are concluded and settled through the Money Market Value Chain (see Figure 1). The Money Market Value Chain is an integrated and automated infrastructure, which covers both trading as well as the settlement of securities on the books of SIS and cash in the SNB’s RTGS system (SIC). This integrated infrastructure allows for a fully automated settlement of repo transactions on a simultaneous, final and irrevocable DvP basis, i.e., the delivery of securities against cash payments. A settlement is conditional upon the cash taker having sufficient securities in its securities account with SIS and the cash provider having a large enough cash balance in its RTGS account with the SNB. As soon as these conditions are met, the transaction is settled, i.e., the securities are transferred to the cash provider’s securities account at SIS, and the cash is simultaneously credited to the cash taker’s RTGS account. SIS is not only the custodian of securities but, as an organization, is also mandated by market participants for the collateral selection and risk management process. SIS automatically selects the securities from a list of securities that financial institutions earmark for delivery in repo

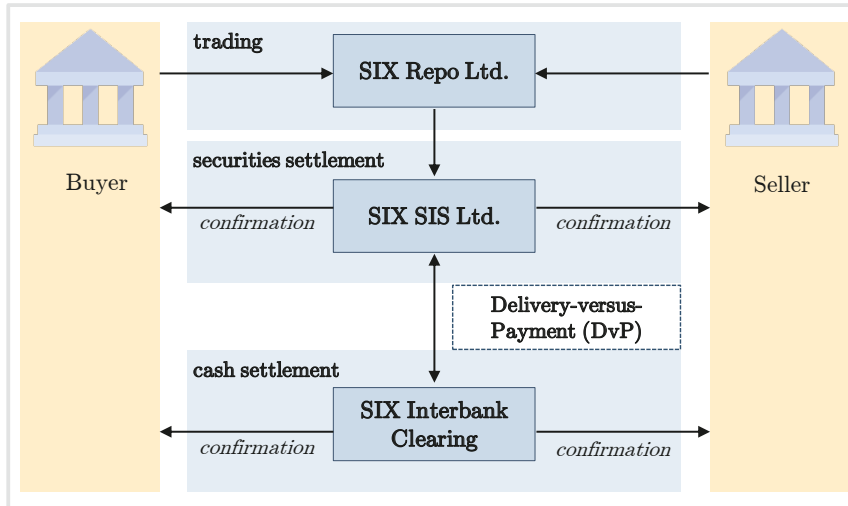


Figure 1: The Money Market Value Chain

transactions and ensures that neither the securities mature nor the coupon payments are due during the term of the transaction. Even though up to 33 different securities (i.e., ISINs) can be delivered in a single repo transaction, SIS will try to minimize the number of securities transferred.

The range of collateral that the SNB accepts is also the market standard for the interbank repo market. The SNB accepts collateral denominated in seven different currencies.¹ Approximately 95% of the eligible securities are denominated in non-Swiss franc currencies. The very high level of securities denominated in foreign currencies, as well as the importance of the market for financial institutions domiciled abroad, implies that a large part of the repo transactions in Swiss francs is secured by securities denominated in foreign currencies, i.e., so-called cross-currency repos. On average, 70% of the Swiss franc repo transactions were cross-currency repos, with euro and Danish krone as the most common currency denominations used for delivered collateral (see Kraenzlin/Moser (2019)). Securities in Swiss francs are issued within SIS, whereas securities denominated in foreign currencies are issued by the respective CSDs, e.g., euro-denominated securities are issued within Clearstream and Euroclear. In other words, the delivery of non-Swiss franc securities requires a transfer from the respective foreign CSD – where the securities were originally issued – to SIS, as the securities need to be settled within SIS. Transferring securities to SIS may take time and hence may delay the settlement of a transaction.

Overall, the data includes 125,000 individual bank-to-bank transactions between October 2008 and January 2020.² Approximately 25% of all transactions involve the SNB, primarily as a cash provider and with a term of one week. During the period of observation, 180 financial institutions were active in the market as cash providers or cash takers.

¹In addition to the Swiss franc, it accepts collateral denominated in euros, US dollars, British pounds, Danish krone, Norwegian krone and Swedish krona. See SNB (2020).

²SIX recently renewed its post-trading infrastructure. Data on the settlement performance is not available to the authors and hence it cannot be evaluated to what extent this impacted the settlement performance.

Seventy of these 180 financial institutions were domiciled outside Switzerland, such as in Germany, Austria or the United Kingdom. The fact that financial institutions outside Switzerland actively participate in the market makes the analysis particularly interesting as they hold their securities at their domestic CSD and hence need to transfer them to SIS for the repo transaction to settle. In addition to the settlement time, i.e., the time of the DvP, we also have information regarding the time the securities were “blocked for settlement” by SIS. This allows us to distinguish between the time it takes to select and block the collateral for settlement, and the time it takes to block the cash on financial institutions’ RTGS accounts (see Figure 1). This distinction in the settlement process allows us to obtain more insights on where efficiency might further be improved.

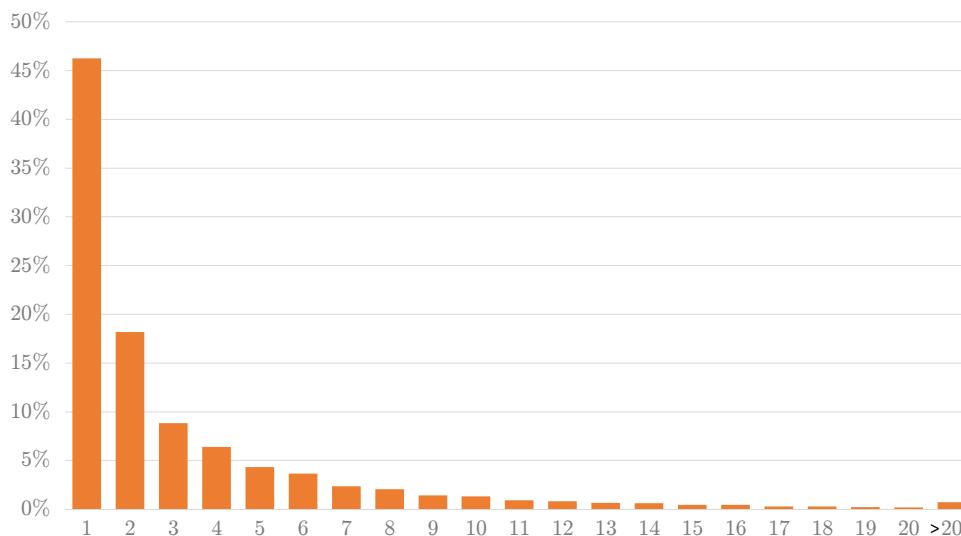


Figure 2: Number of securities delivered in a repo transaction in % of total

All transactions (incl. SNB) belong to the standardized secured money market segment and are hence fully comparable with each other (see Kraenzlin (2009) and Kraenzlin (2007) for a more detailed description on the secured money market in Switzerland). As in many other countries (see Gorton/Metrick (2004) and Guggenheim et al. (2011)) the market is used for short-term funding, and as a result, 85% of the transactions have a term of one week or less. On average, lending was secured by three different securities; only in 7% (1%) of all transactions were more than 10 (20) different securities employed (see Figure 2). The low number of different securities can be ascribed to the fact that SIS tries to minimize the number of securities transferred.

Taking simple averages, we find that it takes approximately 50 minutes for a repo transaction to settle (see Table 1 and Figure 3). Differentiating between the cash and the collateral side suggests that the securities leg of the repo transaction primarily accounts for the transaction delays. Table 1) shows that the securities leg takes twice as much time on average than it does to block the cash on the financial institutions’ RTGS account. Distinguishing between the domicile of the cash provider and taker further reveals that

Cash Provider	Cash Taker	Total	"lock-in" securities	"lock-in" cash	# obs.
All	All	00:51	00:33	00:18	124,819
Domestic	Domestic	00:18	00:11	00:07	67,394
Domestic	Foreign	01:13	01:04	00:08	36,578
Foreign	Domestic	01:19	00:24	00:54	16,096
Foreign	Foreign	02:05	01:06	00:59	4,753

Table 1: Average time to settlement for interbank transactions in hours and minutes

the settlement of interbank transactions was, on average, fastest when only financial institutions domiciled in Switzerland were involved – this can be ascribed to a faster “lock-in” of both securities and cash. Whenever a financial institution domiciled abroad was involved, the settlement time tripled from 18 minutes to at least 70 minutes. This can be attributed to both a long time period until the securities are blocked (60 versus 11 minutes) and the cash is “locked-in” (up to 60 versus 7 minutes). We also computed the fastest settlement, which was 12 seconds. In other words, after concluding the transaction on the repo trading platform, it took 12 seconds to block and simultaneously transfer the cash and the securities, respectively. We find that 20% of all transactions settled within 12 seconds and take this as evidence that 12 seconds is the fastest settlement time that the existing MMVC can attain. We also find that the majority of these transactions involve both a domestic cash taker and domestic cash provider.

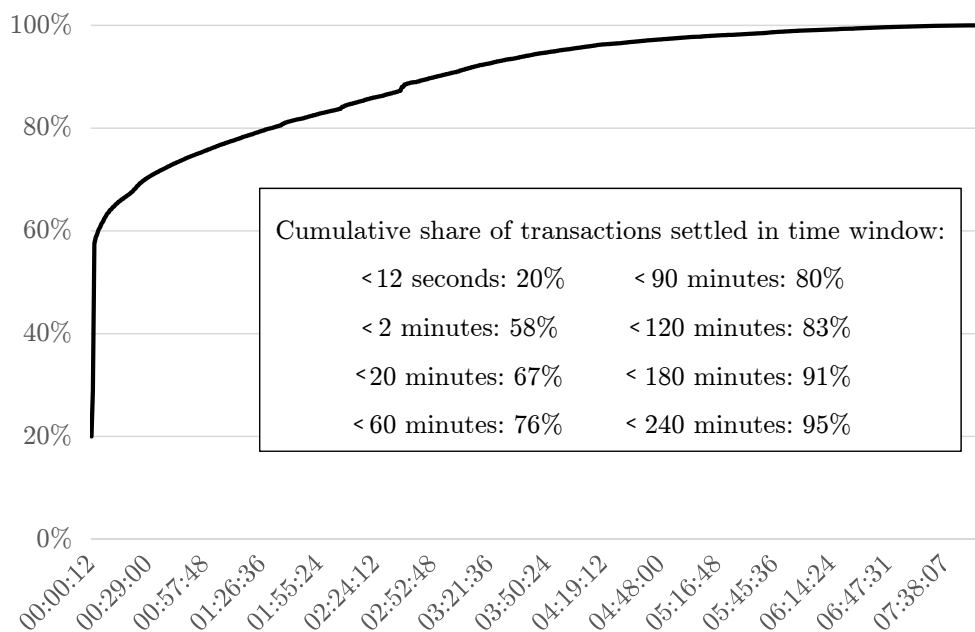


Figure 3: Cumulative distribution function of the time to settlement

Overall, we find that the fully integrated FMI is highly efficient and can settle complex transactions, such as repo transactions, in a very timely manner. However, we also find

that there are various non-technical factors which delay the settlement. Based on these findings from simple averages, we formulate hypotheses that we will then jointly test in our regressions.

- Hypothesis 1: Settlement of CHF repo transactions is faster if the cash provider or cash taker is domiciled in Switzerland. This is based on the fact that Swiss financial institutions are cash-rich as they have to hold cash balances due to minimum reserve requirements. Moreover, it is assumed that they hold their securities primarily with SIS, the Swiss CSD. Hence, the availability of cash or collateral is less of an issue.
- Hypothesis 2: The higher the cash providers' cash balances at the SNB, the faster the settlement will be, as a "lack of cash" is less likely to occur if the cash provider has more cash.
- Hypothesis 3: The cash taker's ability to deliver more than one security per repo transaction reduces the time for a transaction to settle, as otherwise, a cash taker would need to hold the exact amount in one security corresponding to the transaction volume.
- Hypothesis 4: The settlement of larger transactions or transactions with a long term takes more time. The larger or longer the repo transaction, the more complex the collateral selection process becomes (as no coupon payments may occur during the term).
- Hypothesis 5: The higher the market stress and level of volatility, financial institutions want to settle faster to avoid rumours that they are in arrears in terms of mobilizing securities or necessary cash.
- Hypothesis 6: Settlement discipline is higher, and hence settlement time is lower if the transaction involves the central bank.

4 Methodology

We use data ranging from October 2008 to January 2020 and run various regressions. As a left-hand-side variable, we use the settlement time, i.e., the time span between the conclusion of the transaction on the trading platform and the DvP. As explanatory variables we use the size ($size_{i,t}$) and the term of the repo transaction ($term_{i,t}$). For both variables, we expect a positive coefficient as (a) the larger the size of the repo transaction the more collateral is needed and (b) the longer the repo transaction, the more complex the collateral selection process becomes, as no coupon payments may occur during the term (testing of hypothesis 4). We also add the level of the cash providers' cash balances ($cash_{i,t}$) and the number of securities delivered ($collateral_{i,t}$). We thereby test hypothesis 2 and 3, and for both variables, we expect a negative coefficient. A repo transaction will settle faster as a "lack of cash" ("lack of securities") is less likely to occur if the cash provider (cash taker) has more cash (available securities). Furthermore, we also add dummy variables if the cash provider ($CP_{domestic_{i,t}}$) or the cash taker ($CT_{domestic_{i,t}}$) is

domiciled in Switzerland to account for the fact that Swiss financial institutions hold cash positions due to minimum reserve requirements and hold their securities primarily at SIS (testing of hypothesis 1). We also add a dummy variable for “pure” interbank transactions ($\text{interbank}_{i,t}$) to test hypothesis 6, namely, that settlement discipline and hence settlement time is lower if the transaction involves the SNB as counterparty. Finally, we also add the Merrill Lynch Option Volatility Estimate Index (MOVE index, MOVE_t). This index represents the level of (option-implied) expected volatility and hence stress in the US government bond market. We expect a positive coefficient showing that the higher the market stress, the faster financial institutions want to settle to avoid rumours that they are in arrears in terms of mobilizing securities or necessary cash (testing of hypothesis 5). As various variables are skewed to the right, we do a log-transformation on them. This is the case for the left-hand-side variable (i.e., settlement time) and the explanatory variables ($\text{size}_{i,t}$, $\text{term}_{i,t}$ and $\text{cash}_{i,t}$).

$$\begin{aligned} \text{time}_{i,t} = & \text{constant}_t + \beta_1 \cdot \text{size}_{i,t} + \beta_2 \cdot \text{collateral}_{i,t} + \beta_3 \cdot \text{term}_{i,t} + \beta_4 \cdot \text{interbank}_{i,t} \\ & + \beta_5 \cdot \text{CP domestic}_{i,t} + \beta_6 \cdot \text{CT domestic}_{i,t} + \beta_7 \cdot \text{cash}_{i,t} + \beta_8 \cdot \text{MOVE}_t \\ & + \beta_9 \cdot \text{creation time}_{i,t} + \beta_{10} \cdot \text{d}_{fxi} \cdot \text{size}_{i,t} + \text{d}_{fxi} \cdot \dots + \beta_{19} \cdot \text{d}_{liq} \cdot \text{size}_{i,t} \\ & + \text{d}_{liq} \cdot \dots + \beta_{27} \cdot \text{d}_{nz} \cdot \text{size}_{i,t} + \text{d}_{nz} \cdot \dots + \epsilon_t \quad (1) \end{aligned}$$

Crisis events and the SNB’s measures suggest distinguishing four phases. The first part represents the period before the start of the SNB’s intervention in the foreign exchange market in March 2009. The second period contains all the transactions that were undertaken during the SNB’s interventions, but before excess liquidity reached CHF 200 billion in August 2010. The third part represents the period where excess liquidity was above CHF 200 billion, while the fourth part marks the period after the SNB’s negative interest rate of 75 basis points had become effective in January 2015. See Kraenzlin/Moser (2019) and Kraenzlin/Nellen (2015) for a more detailed description of the SNB’s measures. We expect settlement time to decrease with the intensification of the global financial crisis and the ample liquidity that the SNB provided. To account for this effect we generate dummy variables for the specific periods (d_{fxi} , d_{liq} and d_{nz}) and multiply them with the individual variables.

We then run three regressions. The first regression is based on the whole sample, which also includes the SNB’s transactions and provides an overall picture. The second and third regression focus only on interbank transactions with a term of one week and above, and overnight maturity, respectively. The regression aims to evaluate if the settlement efficiency is different for longer-term transactions (those that settle two days after the conclusion of the transaction) and overnight transactions (which settle immediately and hence are more time-critical). For the regression with overnight transactions, we also add the time of the day at which the repo transaction concluded ($\text{creation time}_{i,t}$). We expect a negative coefficient, as settlement of overnight transactions is triggered immediately after the conclusion of the transaction on the trading platform and cut-off time is 6 pm. In other words, the later in the day a transaction is concluded, the faster it needs to settle.

A fixed effect (FE) regression was run in addition to a simple ordinary least squares (OLS) regression to test for robustness. In the FE regression, we added interaction variables for the subperiods to account for a change in behaviour by a specific bank. The FE regression shows the same results for the explanatory variables except for the dummy variable, which covers the effect when the cash provider or the cash taker is domiciled in Switzerland. This can be explained by the fact that the “domestic effect” is absorbed with the individual specific dummy on each cash taker and provider, respectively. Furthermore, the left-hand-side variable is skewed and not normally distributed. Looking at the distribution of the settlement times, we can bundle the observations into three categories: transactions which settle (a) within 12 seconds, (b) within 90 seconds and (c) those that take longer, i.e., between 5 minutes and 8 hours. We thus also ran separate regressions for the three bundles. The sub-sample regression provides very similar results and significance levels.

5 Regression results

The regression results, which are displayed in Table 2, confirm nearly all our hypotheses. The constants in the regressions reflect the average settlement time, which is between 2 and 10 minutes when accounting for the different characteristics of the transaction (e.g. domicile, term). We find that repo transactions settle faster if both the cash taker as well as a provider are domiciled in Switzerland, and the higher the cash providers’ cash balances at the SNB are. This confirms our assumption that transactions, which involve Swiss financial institutions, settle faster as they typically hold their securities at SIS and hence dispose of sufficient eligible collateral. We also find that the possibility to deliver more than one security per repo transaction reduced settlement time; the impact is greatest for longer-term transactions indicating that the collateral selection process is more complex for term transactions. Overall, we conclude that the option to deliver more than one security is an important feature for repo markets, especially for the conclusion of longer-term transactions. We also find that the settlement process is longer for larger transactions or transactions with long terms. This confirms that the larger or longer the repo transaction, the more complex the collateral selection process becomes (as no coupon payments may occur during the term) and hence the settlement time. Regression results also confirm that financial institutions want to settle repo transactions faster during times of higher market stress and levels of volatility. We find that the effect was most pronounced after the collapse of Lehman Brothers and then disappears. Finally, we find that settlement discipline is higher, and hence settlement time is lower if the transaction involves the SNB. We ascribe this primarily to the fact that a “lack of cash” never occurs with the SNB (as cash provider) and hence settlement times are reduced by half.

The regression results are displayed in Table 2 and divided along with the six hypotheses. In the first column, the regression coefficients are displayed, first for the variable and the whole period and thereafter for the specific periods, which account for the subperiods where the global financial crisis and the level of liquidity changed. The coefficients for the subperiods need to be added to the coefficients for the whole period to obtain the effect for the subperiods; this cumulative effect is displayed on the second column. To test their

significance, an F-test was conducted with the null hypothesis such that the subperiods effects are not significantly different from the overall effect. The significance level (based on the F-test) is displayed in parentheses. Finally, the goodness of fit of the regressions is good, since the different values of the adjusted R-squared are approximately 0.3, which is typical for regressions with daily frequency.

Regarding hypothesis 1, we find that the time to settle repo transactions is reduced if at least one financial institution is domiciled in Switzerland. The effect is highest if the cash provider is in Switzerland, reducing settlement time by 71%. If the cash taker is also domiciled in Switzerland repo transactions settle fastest. This confirms our assumption that transactions which involve Swiss cash takers settle faster, as they typically hold their securities at SIS and hence dispose of sufficient eligible collateral. In contrast, financial institutions domiciled outside Switzerland hold their securities at their domestic CSD and first need to transfer the securities to SIS for the repo transactions to settle. As overnight transactions settle on the same day (T+0), the cash taker's back office has (as compared to transactions which settle one or two business days after conclusion) no lead time and hence needs to initiate an immediate transfer of collateral to SIS if sufficient collateral is not available.

The effects for the subperiods remain highly significant, especially when the cash taker is domiciled in Switzerland. This signals that the bottleneck in the settlement lies primarily with the availability of collateral. We attribute this to the availability of high-quality liquid collateral (HQLA) which is used in the Swiss repo market, combined with banks' preferences for pooling their collateral with their domestic CSD. Two mutually reinforcing factors can be identified regarding the availability of HQLA: the HQLA universe was reduced due to issuer downgrades during the global financial crisis coupled with a higher demand for HQLA due to the introduction of the liquidity coverage ratio (LCR) in 2015 (Fuhrer et al. (2017)). This market-wide scarcity of HQLA along with the pooling of collateral in domestic CSDs delays the settlement of repo transactions involving foreign-domiciled financial institutions by one hour. We also find that the effect on settlement time becomes less significant or even becomes insignificant when the cash provider is domiciled in Switzerland. We ascribe this to the SNB's measures, which led to a situation where all financial institutions – irrespective if domiciled in Switzerland or abroad – possessed sufficient liquidity and hence the cash side was no more a bottleneck.

Our regression results also confirm hypothesis 2. Overall, we find that the level of the cash providers' cash balances at the SNB had a significant impact on settlement time, reducing it by 12 seconds (i.e., 0.20%) per additional million of Swiss franc cash. The effect even increased for the subperiods. As the global financial crisis intensified, the SNB provided the financial market with ample liquidity. This liquidity primarily ended up in Swiss financial institutions and provided (so to speak) the grease for the settlement of repo transactions.

Hypothesis 3 is also confirmed. The possibility to deliver more than one security per repo transaction reduced settlement time by approximately 6 seconds (1%) per additional security. The impact is highest for longer-term transactions (see second regression in Table 2), indicating that the collateral selection process is more complex for term transactions (as no coupon payments may occur on the securities during the term) and hence the option to deliver multiple, smaller securities provides a remedy. The positive impact on settlement time decreases in the subperiods and eventually becomes insignificant for longer-term repos. Overall, we can conclude that the option to deliver more than one security is an important feature for repo markets in general, and especially for markets where longer-term transactions are concluded.

Furthermore, our regression results demonstrate that the settlement of higher volume and longer-term repo transactions increases settlement time by up to 6 seconds (1.1%), confirming hypothesis 4. The increasing effect of a higher transaction volume on settlement time is highest for the period up to when the SNB started to intervene in the foreign exchange market. This also applies for the term effect, with settlement times increasing by approximately 3 seconds per additional day (0.6%). In other words, settlement of a one-month repo transaction takes 2 minutes longer on average (i.e., 10%) than for a one-week transaction. This leads us to conclude that the settlement process is longer for term repos and that this is primarily linked to the complex collateral selection process.

The coefficient on the MOVE index partially confirms hypothesis 5. i.e., that the level of stress in government bond markets influences settlement discipline. We find that the effect was most pronounced after the collapse of Lehman Brothers. During the first period of observation, settlement time shortened by up to six seconds (1%) per MOVE unit, i.e., the higher the market stress. This indicates that financial institutions wanted to settle faster to avoid rumours that they were in arrears in terms of mobilizing securities or necessary cash. In the subsequent periods, we find no clear-cut effect. The effect is either neutralized or even reversed, while it remains highly significant and negative for overnight transactions. We conclude that the level of market stress reduced settlement time in periods of elevated market stress and volatility to a certain extent, but it was not the primary driver.

Finally, we tested to see if settlement discipline is higher, and hence settlement time is lower, for a transaction involving the central bank (hypothesis 6). The regression results confirm that this is the case. In the period during the interventions in the foreign exchange market, as well as when cash balances were very high, the settlement time was reduced by half for transactions involving the SNB. We ascribe this primarily to the fact that a “lack of cash” never occurred when the SNB acted as a cash provider.

For overnight transactions, we also included the time that the transaction concluded on the trading platform. The regression results are in the third column of Table 2). As expected, we find a negative effect. In other words, the later in the day a transaction is concluded, the faster it needs to settle. The effect remains negative and highly significant, which underpins that settlement discipline and time for overnight transactions is crucial.

Variables	All (Interbank and SNB)		Interbank, term		Interbank, Overnight	
	Coeff.	cum. effect	Coeff.	cum. effect	Coeff.	cum. effect
<i>Average settlement time</i>						
constant	-4.917***	00:10	-5.492***	00:05	-6.292***	00:02
<i>Hypothesis 1: Domestic cash provider and taker</i>						
CP dom.	-1.247***	-71.3%	-2.515***	-91.9%	-1.219***	-70.4%
CP dom._FXI	0.507***	-52.3% (0.00)	1.487**	-64.25% (0.00)	0.892***	-27.9% (0.00)
CP dom._Liq	0.888***	-30.17% (0.00)	1.878**	-47.11% (0.00)	1.084***	-12.61% (0.17)
CP dom._NZ	1.565***	37.38% (0.00)	2.642***	13.45% (0.21)	1.024***	-17.67% (0.00)
CT dom.	-0.496***	-39.1%	0.278	32.0%	-0.210*	-18.9%
CT dom._FXI	-0.470***	-61.94% (0.00)	-0.473*	-17.71% (0.00)	-0.453***	-48.43% (0.00)
CT dom._Liq	-1.283***	-83.11% (0.00)	-1.279***	-63.26% (0.00)	-1.529***	-82.42% (0.00)
CT dom._NZ	-0.832***	-73.49% (0.00)	-2.218***	-85.63% (0.00)	0.227	1.8% (0.82)
<i>Hypothesis 2: cash balances at the SNB</i>						
reserves	-0.092***	-0.09%	-0.100***	-0.10%	-0.141***	-0.14%
reserves_FXI	-0.056***	-0.15% (0.00)	-0.029	-0.13% (0.00)	-0.038*	-0.18% (0.00)
reserves_Liq	-0.098***	-0.19% (0.00)	-0.011	-0.11% (0.00)	-0.028	-0.17% (0.00)
reserves_NZ	-0.147***	-0.24% (0.00)	-0.117***	-0.22% (0.00)	-0.024	-0.17% (0.00)
<i>Hypothesis 3: number of securities</i>						
coll.	-0.762***	-0.76%	-1.033***	-1.03%	-0.138*	-0.14%
coll._FXI	0.405***	-0.36% (0.00)	0.346***	-0.69% (0.00)	-0.024	-0.16% (0.00)
coll._Liq	0.470***	-0.29% (0.00)	0.659***	-0.37% (0.00)	0.051	-0.09% (0.00)
coll._NZ	0.693***	-0.07% (0.00)	1.008***	-0.03% (0.36)	-0.136*	-0.27% (0.00)
<i>Hypothesis 4: size and term of transaction</i>						
size	0.731***	0.73%	1.109***	1.11%	0.183***	0.18%
size_FXI	-0.483***	0.25% (0.00)	-0.685***	0.42% (0.00)	0.143*	0.33% (0.00)
size_Liq	-0.242***	0.49% (0.00)	-0.625***	0.48% (0.00)	0.493***	0.68% (0.00)
size_NZ	-0.467***	0.26% (0.00)	-0.743***	0.37% (0.00)	0.281***	0.46% (0.00)
term	0.352***	0.35%	0.571***	0.57%		
term_FXI	-0.328***	0.02% (0.00)	-0.223**	0.35% (0.00)		
term_Liq	-0.376***	-0.02% (0.05)	-0.661***	-0.09% (0.00)		
term_NZ	-0.396***	-0.04% (0.00)	-0.452***	0.12% (0.00)		
<i>Hypothesis 5: market stress and level of volatility</i>						
MOVE	-0.009***	-0.91%	-0.008**	-0.75%	0.000	-0.02%
MOVE_FXI	0.009***	-0.05% (0.15)	0.008**	0.03% (0.74)	-0.006**	-0.61% (0.00)
MOVE_Liq	0.010***	0.14% (0.08)	0.013***	0.51% (0.00)	-0.007***	-0.76% (0.00)
MOVE_NZ	0.013***	0.36% (0.00)	0.008**	0.03% (0.86)	-0.010***	-0.97% (0.00)
<i>Hypothesis 6: settlement discipline for SNB transactions</i>						
IB	0.801***	122.7%				
IB_FXI	0.182*	167.1% (0.00)				
IB_Liq	-0.588***	23.66% (0.00)				
IB_NZ	-1.011***	-19.02% (0.09)				
<i>For ON transactions: time in day</i>						
cr. time					-3.251***	-3.3%
cr. time_FXI					0.655***	-2.6% (0.00)
cr. time_Liq					1.406***	-1.84% (0.00)
cr. time_NZ					1.620***	-1.63% (0.00)
No. obs	123,456		23,783		28,904	
Adj. R2	0.274		0.32		0.334	

***: significance on the 1% level; **: 5% level; *: 10% level; F-Test in parentheses

Table 2: Regression results

6 Discussion and Conclusion

Based on a unique data set, we empirically assess the efficiency of the Swiss Money Market Value Chain (MMVC). The MMVC allows for integrated trading and settlement of repo transactions. Our analysis shows that the Swiss infrastructure has the technical capacity of settling repo transactions – which are considered complex– within 12 seconds. We find that 20% of all transactions settle within 12 seconds and take this as evidence that 12 seconds is the fastest settlement time that the existing MMVC can attain. However, we also find that there are various non-technical factors, such as counterparty domiciles or the size of the transaction, which delay the settlement. In this paper, we identify the various factors and their impacts on the settlement time. This contributes to the empirical literature and to the current dialogue that FMI providers are conducting with central banks and private sector representatives. One key topic is the redesign of FMIs and the potential usage of new technologies, such as DLT.

One decisive factor for a fast settlement is to have the securities available at the right time and place. The Swiss franc repo market is an international money market, and roughly one-third of the participating financial institutions are domiciled outside Switzerland (e.g., Germany, Austria or the United Kingdom). Financial institutions outside Switzerland actively participate, especially as cash takers, in the repo market. The regression results show that the settlement of repo transactions where the cash taker is domiciled outside Switzerland takes twice as long as for transactions where the cash taker is domiciled in Switzerland. We find that the delay remains statistically and economically significant and has even increased over time. A more in-depth analysis reveals that delays in settlement are primarily due to insufficient collateral at SIS. Swiss financial institutions typically hold their securities at SIS and hence dispose of sufficient eligible collateral. In contrast, financial institutions from abroad pool the securities at their domestic CSD, e.g., at Euroclear or Clearstream. Consequently, these participants need to transfer the securities to SIS for the repo transactions to settle. We take this as evidence that the initiation of a cross-border collateral transfer is currently inefficient and could be further improved. An additional explanation for the increase in settlement delays over time is the availability of high-quality liquid collateral (HQLA), which is used as collateral in the Swiss repo market. The universe of available HQLA has been reduced since the global financial crisis – on the one hand due to lower supply as a result of the downgrading of issuers and on the other hand due to higher demand following the introduction of the liquidity coverage ratio (LCR) in 2015. We thus conclude that the market-wide scarcity of HQLA, along with the pooling of collateral with domestic CSDs and the inefficient initiation of collateral transfers to SIS are the primary drivers behind repo transactions settlement delays.

When redesigning or improving FMIs, it is thus important to find ways to improve the transfer of collateral across borders. This is particularly important as financial institutions want to pool collateral with one CSD and the scarce and declining HQLA universe requires an even more efficient usage across borders. The European Central Bank (ECB), for example, launched Target 2 Securities (T2S) in 2015 and took the first step in improving the collateral transfer between CSDs (see ECB (2020)). With T2S, the ECB integrated

and harmonised the fragmented securities settlement infrastructure in Europe and thereby reduced the costs of cross-border settlements. In June 2020, the Swiss FMI operator SIX successfully launched its new collateral management system (triparty agent, see SIX (2020)). SIX has set the basis for future improvements in the area of collateral availability – within SIX but also across borders – by improving the existing infrastructure and introducing a new “collateral cockpit”. This may bring considerable benefits to financial institutions, as the current bottlenecks are not with the transfers themselves, but rather with the initiation of the collateral transfer. With the “collateral cockpit”, the internal processes of financial institutions can be streamlined. In addition, a lack of securities can be identified and addressed more quickly, eventually reducing settlement delays caused by the unavailability of securities.

An alternative to the T2S platform (and hence built on existing infrastructures) could be the use of DLT to address the identified inefficiencies simultaneously. A growing number of initiatives have experimented with DLT in recent years to evaluate if the resiliency and efficiency of FMI could be improved. One of the promises of DLT is that it could improve the efficiency of the trading, settlement and management of such assets by utilising the tokenisation of securities. Several central banks have been testing the use of DLT in the area of collateral management. As an example, Deutsche Bundesbank et al. (2020) have found that using DLT for collateral management has advantages for financial institutions, as securities are on a single ledger and hence no longer need to be moved across custodians (which will eventually enable the 24/7 availability of collateral). They also found that having a single ledger synchronised among all parties reduces the necessity for reconciling records held by the CSDs and financial institutions’ back offices. The use of DLT would hence allow for substantial cost reductions.

Best of all would be to create a single (global) ledger where financial institutions could hold and transfer all their securities.³ Due to different jurisdictions and laws, however, this is unlikely to occur, which is why many private sector initiatives have focused on a first step of building national ledgers and interlinking them. This would eventually lead to the same interoperability issues as with existing market infrastructures. In addition, a secure settlement mechanism would be needed to allow for a simultaneous transfer of securities against cash. Financial market participants have thus been working on the tokenisation of securities and also on the design of a cash token in a DLT system. Such privately issued cash tokens – which take the form of a stable coin – would, however, be equivalent to commercial bank money and thus not constitute central bank money. To reduce this issuer risk and reach the same risk level as existing FMI, the question on how to integrate central bank money into DLT frameworks would also need to be addressed. The SNB, together with the BIS Innovation Hub and SIX Group Ltd., investigated two approaches of doing so and successfully ran two proof of concepts (PoCs) (see BIS Innovation Hub et al. (2020)). In the first PoC, a technical interface between the “new” and “existing” world is created, i.e., it works towards a hybrid FMI where existing, centrally run infrastructures and DLT co-exist and interoperate. In this scenario, payment instructions would be exchanged between the DLT ecosystem and the existing Swiss RTGS system. This would be similar to the current Money Market Value Chain. In the second PoC, the issuance of central bank

³See also Bech et al. (2020), pp. 74.

money in the form of digital tokens into a DLT ecosystem is tested. The SNB uses the DLT ecosystem run by SIX Digital Exchange (SDX). Overall, they conclude that the two approaches have different benefits and challenges (see BIS Innovation Hub et al. (2020) for a more detailed discussion). The tokenisation of central bank money and integration into the DLT platform unlocks more of the functionalities possible with tokenisation (e.g., instant and simultaneous settlement). In contrast, linking the DLT platform to the RTGS system raises fewer policy questions, such as access policy or remuneration, as central bank money remains in the current environment.

DLT is still in its infancy and is not ready for large-scale usage at present. Central banks, together with the private sector, have been experimenting with DLT and have concluded that they do not fulfil the same efficiency and performance level as existing FMIs. While DLT has shown the ability to replicate specific FMI functionalities, more work is needed to answer the question of whether DLT can meet the benchmarks of the existing FMIs, which in the case of Switzerland have been presented in this paper.

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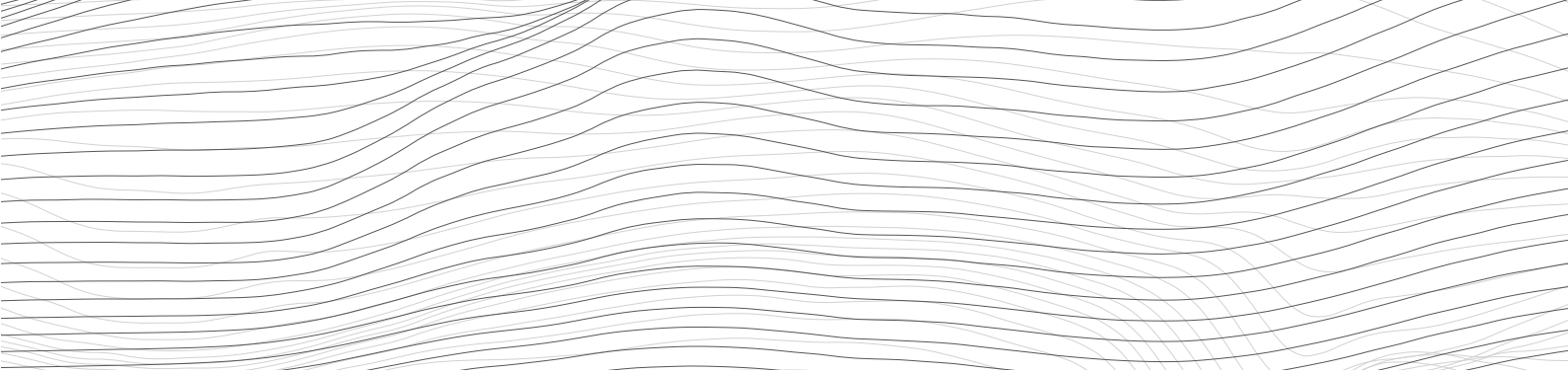
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