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(In)efficiencies of current financial market infrastructures: an empirical assessment

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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 as well as where new technologies, such as distributed ledger technology, could provide a remedy. We find that the fastest settlement time for repo transactions is 12 s, but that settlements are often delayed by more than 10 min 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.

Keywords: Financial market infrastructure, Secured money market, Distributed ledger technology

Mathematics Subject Classification: G15, G21, G23

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, FMIs assure that a bank can cover its refinancing needs and meet its payment obligations at all times. Particularly 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 and Nellen (2015)]. Third, more than 70% of the securities delivered are so-called cross-border collateral, i.e.

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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 local CSD to SIX SIS Ltd. (SIS), the Swiss CSD, to settle Swiss franc repo transactions.

We find that no transaction settles faster that 12 s and take this as evidence that 12 s is the fastest settlement time that the existing MMVC can attain. We also find that 20% of all transactions settle at this minimum. 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 analysis indicates that the bottleneck in settlement is not the cash side but is rather related to the management and availability of eligible collateral, i.e. high-quality liquid assets (HQLA). HQLA is the collateral standard in the Swiss repo market. During the global financial crisis, the HQLA universe was reduced due to issuer downgrades. Furthermore, the demand for HQLA increased due to the introduction of the LCR in 2015. As a consequence, the stock of freely available HQLA became scarce and hence led to settlement times which were higher than the 12 s that would technologically be possible. For a well-functioning and efficient repo market, it will thus be important that participants hold sufficient HQLA and that the assets are available at the right time and place. Banks domiciled outside Switzerland are very active cash takers and typically pool their securities at their local CSD, e.g. at Euroclear or Clearstream. Consequently, these participants need to transfer the securities to SIS for the repo transactions to settle. Cross-border availability of securities thus needs to be addressed and improved. 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 FMI, which can rely either on a centralized or decentralized architecture.

The remainder of this paper is organized as follows. "Literature" section embeds our research into the broader literature. "Data set, institutional set-up, and descriptive statistics" section describes the data set and the institutional set-up of the Money Market Value Chain. We describe the methodology in "Methodology" section. Subsequently, we discuss the regression results and conclude in "Regression results" section and "Discussion and conclusion" section, 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 Committee (2012)].

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. Particularly, 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 PFMIs are particularly relevant to ensure the goal of an efficient and secure money market. First, Principle 12 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

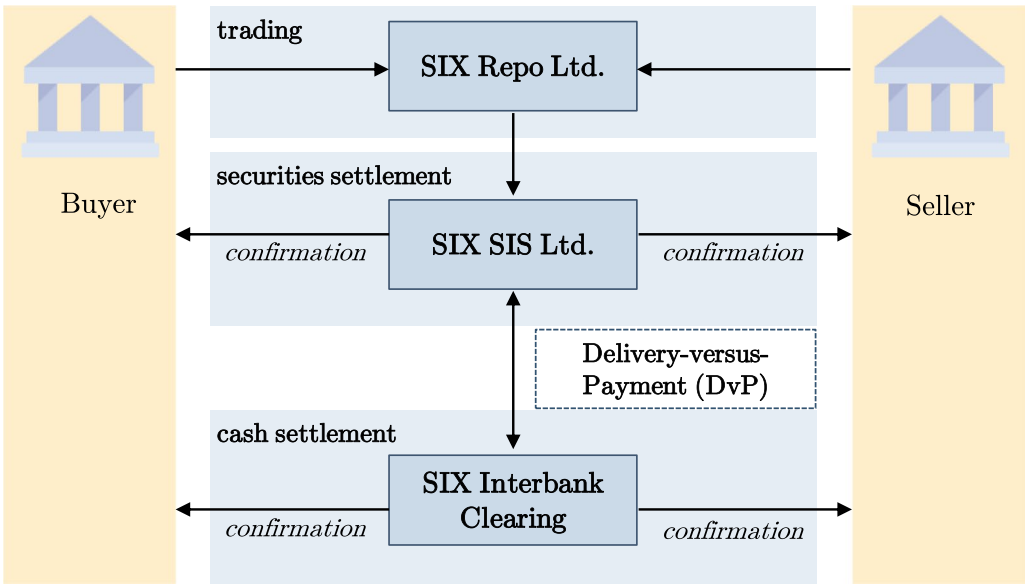

Fig. 1 The Money Market Value Chain

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 PFMIs have also been identified and addressed by the ECB. In 2001, Giovannini (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 harmonized securities settlement infrastructure in Europe, and reduce the costs of cross-border settlements [see Weller (2012) and Bullmann and 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 (European 2020).

This paper presents the first empirical findings on the settlement performance of the Swiss franc money market. Other empirical work on the Swiss franc money market done so far focused on intraday liquidity patterns [see Fuhrer (2017)], bargaining power [see Kraenzlin and Scarpatetti (2011)], interest rate setting behaviour [see Kraenzlin (2009) and Kraenzlin and Nellen (2010)], or the re-use of collateral (Fuhrer et al. 2015). Overall, empirical work on settlement delays is very limited. For money markets in general, Bartolini et al. (2010) analysed settlement delays and found a tendency by lenders to delay delivery of loaned funds until the afternoon hours. However, settlement performance has not yet been empirically studied for secured money markets, including those in other currencies.

3 Data set, institutional set-up, 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 Fig. 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 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 and Moser (2018)]. 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. Seventy of these 180 financial institutions were domiciled outside Switzerland, such as in Germany, Austria, or the UK. The fact that financial institutions outside Switzerland actively participate in the market makes the analysis particularly interesting as they hold their securities at their local 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 Fig. 1). This distinction in the settlement process allows us to obtain more insights on where efficiency might further be improved.

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 and Metrick (2012) 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 Fig. 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 min for a repo transaction to settle (see Table 1; Fig. 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 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

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

[2] SIX 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.

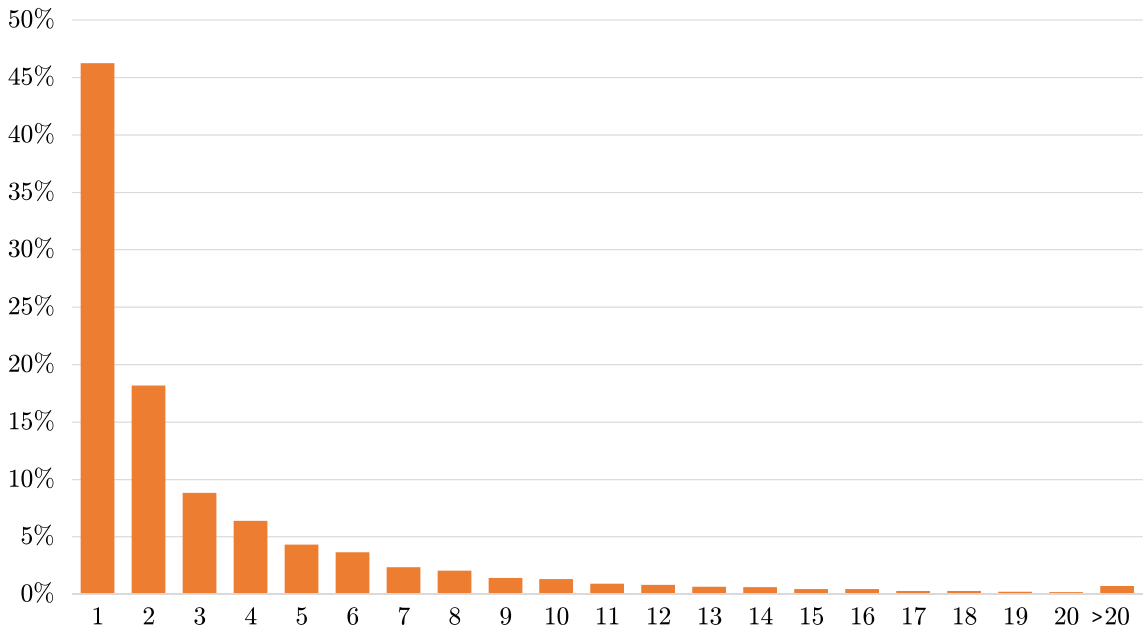

Fig. 2 Number of securities delivered in a repo transaction in % of total

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

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	4753

cash. Whenever a financial institution domiciled abroad was involved, the settlement time tripled from 18 min to at least 70 min. This can be attributed to both a long time period until the securities are blocked (60 vs. 11 min) and the cash is "locked-in" (up to 60 vs. 7 min). We also computed the fastest settlement, which was 12 s. In other words, after concluding the transaction on the repo trading platform, it took 12 s to block and simultaneously transfer the cash and the securities, respectively. We find that no transaction settles faster that 12 s and take this as evidence that 12 s is the fastest settlement time that the existing MMVC can attain. 20% of all transactions settle at this minimum. We also find that the majority of these transactions involve both a domestic cash taker and domestic cash provider.

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 and/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).

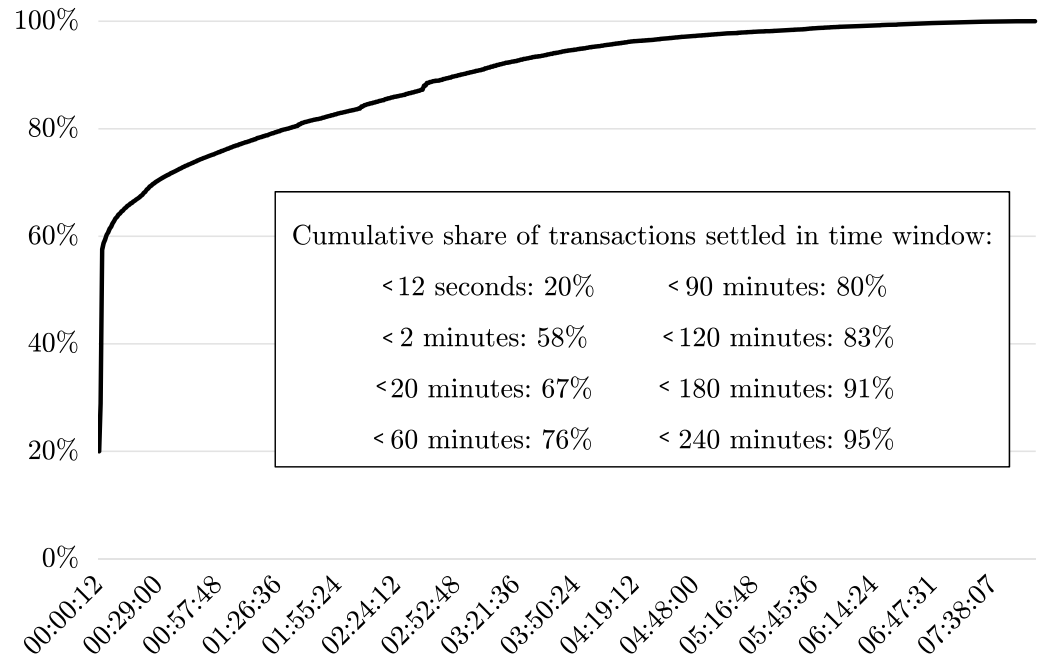

Fig. 3 Cumulative distribution function of the time to settlement

- 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 the same, irrespective if the transaction involves the central bank or not.

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 ($\text{size}_{i,t}$) and the term of the repo transaction ($\text{term}_{i,t}$). 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 (testing of hypothesis 4). We also add the level of the cash providers' cash balances ($\text{cash}_{i,t}$) and the number of securities delivered ($\text{collateral}_{i,t}$). We thereby test hypotheses 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 $\text{domestic}_{i,t}$) or the cash taker (CT $\text{domestic}_{i,t}$) 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 $\text{cash}_{i,t}$). Finally, we clustered the errors at the level of the cash taker to account for the fact that a cash taker could experience a shock that will cause a correlation in disturbances over the whole period of observation.

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

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 and Moser (2018) and Kraenzlin and 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 focuses 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 (creation $\text{time}_{i,t}$). 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 that the distribution of the settlement times, we can bundle the observations into three categories: transactions which settle (a) within 12 s, (b) within 90 s and (c) those that take longer, i.e. between 5 min and 8 h. 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 min when accounting for the different characteristics of the transaction (e.g. domicile, term). We find that repo transactions settle faster if the cash provider is domiciled in Switzerland, and the higher the cash providers' cash balances at the SNB are. However, transactions do not settle significantly faster if the cash taker is domiciled in Switzerland. In other words, even though Swiss financial institutions typically hold their securities at SIS and hence dispose of sufficient eligible collateral, the settlement time is not significantly reduced. 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 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 the same irrespective if the transaction involves the SNB. We ascribe this to the fact that the automated settlement process applies equally to interbank transactions and transactions involving the SNB.

The regression results are displayed in Table 2 and divided along with the six hypotheses. In the first

Table 2 Regression results

All (Interbank and SNB) Interbank,			**term Interbank,**		**Overnight**	
Variables	**Coeff.**	**Cum. effect**	**Coeff.**	**Cum. effect**	**Coeff.**	**Cum. effect**
Average settlement time						
Constant	− 4.917***	00:10	− 5.492***	00:05	− 6.292***	00:02
Hypothesis 1: Domestic cash provider and taker						
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)
Hypothesis 2: cash balances at the SNB						
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)
Hypothesis 3: number of securities						
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)
Hypothesis 4: size and term of transaction						
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)		
Hypothesis 5: market stress and level of volatility						
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)
Hypothesis 6: settlement discipline for SNB transactions						
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)				
For ON transactions: time in day						
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

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 the cash provider is domiciled in Switzerland. Settlement time is reduced by 71%. The coefficient on the cash taker dummy is negative, but not significant. In other words, our hypothesis that transactions settle faster if the cash taker is domiciled in Switzerland is not confirmed. The effects for the subperiods remain highly significant, when the cash taker is domiciled in Switzerland.

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 s (i.e. 0.20%) per additional millions 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 s (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 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.

The regression results and the confirmation of hypotheses 1 to 3 implicitly reveal that the bottleneck in settlement is not on the cash side but rather related to the management and availability of eligible collateral, i.e. HQLA, which are used in the Swiss repo market. During the global financial crisis, the HQLA universe was reduced due to issuer downgrades, while the introduction of the liquidity coverage ratio (LCR) in 2015 led to a higher demand for HLQA (Fuhrer 2017). Differently said, the stock of freely available HQLA became scarce and hence led to settlement times, which are higher than the 12 s that would technologically be possible.

Furthermore, our regression results demonstrate that the settlement of higher volume and longer-term repo transactions increases settlement time by up to 6 s (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 s per additional day (0.6%). In other words, settlement of a one-month repo transaction takes 2 min 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. 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 not case. We ascribe this to the fact that the automated settlement process applies equally to interbank transactions and transactions involving the SNB.

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.

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—in just 12 s. We take this as evidence that 12 s is the fastest settlement time that the existing MMVC can attain. 20% of all transactions settle at this minimum. 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.

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 UK). Financial institutions outside Switzerland actively participate, especially as cash takers, in the repo market. The regression results show that the settlement of repo transactions is fastest when the cash provider is domiciled in Switzerland, whereas we find no significant difference in settlement time based on the cash taker domicile. Combined with the results on explanatory variables, such as the ability to deliver more than one security per transaction and the complexity of settling long term transactions, our analysis indicates that the bottleneck in settlement is not the cash side but is rather related to the management and availability of eligible collateral, i.e. HQLA. HQLA is the collateral standard in the Swiss repo market. During the global financial crisis, the HQLA universe was reduced due to issuer downgrades. Furthermore, the demand for HQLA increased due to the introduction of the LCR in 2015. As a consequence, the stock of freely available HQLA became scarce and hence led to settlement times which were higher than the 12 s that would technologically be possible. For a well-functioning and efficient repo market, it will thus be important that participants hold sufficient HQLA and that the assets are available at the right time and place. Banks domiciled outside Switzerland are very active cash takers and typically pool their securities at their local CSD, e.g. at Euroclear or Clearstream. Consequently, these participants need to transfer the securities to SIS for the repo transactions to settle. It will thus be important to further improve the initiation of a cross-border collateral transfer.

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 HLQA 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 European (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 new technologies, such as DLT to address the identified inefficiencies simultaneously. There have 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 Morten and Hancock (2020)]. Central banks, together with the private sector, have been experimenting with DLT and have concluded that they do not yet 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.

Abbreviations

BIS: Bank for International Settlements; CPMI: Committee on Payment and Market Infrastructures; CSD: Central Securities Depository; ECB: European Central Bank; ECB: European Central Bank; DLT: Distributed Ledger Technology; DvP: Delivery versus payment; FMI: Financial Market Infrastructure; FE: Fixed effect; HQLA: High-quality liquid assets; IOSCO: International Organization of Securities Commissions; ISIN: International Securities Identification Number; LCR: Liquidity coverage ratio; MMVC: Money Market Value Chain; MOVE: Merrill

Lynch Option Volatility Estimate Index; OLS: Ordinary least squares; PFMI: Principles for Financial Market Infrastructures; RTGS: Real-time gross settlement; SDX: SIX digital exchange; SIC: Swiss Interbank Clearing; SIS: SIX SIS Ltd.; SNB: Swiss National Bank; T2S: Target 2 securities.

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All authors contributed equally to the concept of the manuscript. Data handling was primarily done by BG and CM. BG and SK did the empirical work. SK and BG wrote the first draft. All the authors read and approved the final manuscript.

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References

Auer, R., & Kraenzlin, S. (2011). International liquidity provision during the financial crisis: A view from Switzerland. *Federal Reserve Bank of St. Louis Review, 93*(6), 409–418.
Bartolini, L., Hilton, S., & McAndrews, J. J. (2010). Settlement delays in the money market. *Journal of Banking and Finance, 34,* 934–945.
Bech., M., & Jenny, H. (2020). Tara Rice and Amber Wadsworth (2020): On the future of securities settlement. *BIS Quarterly Review*.
Bullmann, D., & Pinna, A. (2020). The future of European financial market infrastructure: A business case for distributed ledger technology. *Journal of Securities Operations and Custody, 9*(1), 2020.
Committee on Payments and Market Infrastructures and International Organization of Securities Commissions. (2012). Principles for financial market infrastructures (April 2012).
European Central Bank. (January 2020). 10th T2S Harmonisation Progress Report—Harmonisation of European securities settlement and collateral management arrangement.
Fuhrer, L. M. (2017). Liquidity in the Repo Market, Swiss National Bank working paper, no. 6.
Fuhrer, L. M., Guggenheim, B., & Schumache, S. (2015). Re-use of collateral in the repo market, Swiss National Bank working paper, no. 2.
Fuhrer, L. M., Benjamin, M., & Steiner, L. (2017). The liquidity coverage ratio and security prices. *Journal of Banking and Finance, 75,* 292–311.
Gorton, G., & Metrick, A. (2012). Securities banking and the run on repo. *Journal of Financial Economics, 104,* 425–451.
Guggenheim, B., Kraenzlin, S., & Schumacher, S. (2011). Exploring an uncharted market: Evidence on the unsecured Swiss franc money market. *Aussenwirtschaft, 66*(1), 2011.
Kraenzlin, S., & Moser, D. (2018). *Wechselwirkung zwischen der SNB-Geldpolitik und der Liquiditätsregulierung, book chapter in Krisenfeste Schweizer Banken? Die Regulierung von Eigenmitteln, Liquidität und Too big to fail, by Armin Jans* (p. 2018). NZZ Libro: Christoph Lengwiler and Marco Passardi.
Kraenzlin, S., & von Scarpatetti, B. (2011). Bargaining power in the Repo Market, Swiss National Bank working paper, no. 14, 2011.
Kraenzlin, S. (2007). The characteristics and development of the Swiss Franc repurchase agreement market. *Financial Markets and Portfolio Management, 21*(2), 2007.
Kraenzlin, S. (2009). Interest rate setting on the Swiss Franc repo market. *Swiss Journal of Economics and Statistics, 145*(3), 2009.
Kraenzlin, S., & Nellen, T. (2010). Daytime is money. *Journal of Money, Credit and Banking, 42*(8), 1689–1702.
Kraenzlin, S., & Nellen, T. (2015). Access policy and money market segmentation. *Journal of Monetary Economics, 71,* 1–12.
Shabsigh, G., Khiaonarong, T., & Leinonen, H. (2020). Distributed ledger technology experiments in payments and settlements, IMF Fintech Note, June 2020.
SIX (2020). SIX Launches a New Triparty Agent to Enhance Collateral and Liquidity Management, press release, June 24, 2020.
Swiss National Bank. (2020). Instruction sheet on collateral eligible for SNB repos, February 2020.
The Giovannini Group. (2001). Cross-Border clearing and settlement arrangements in the European Union, Brussels, November 2001.
Weller, B. (2012). T2S benefits: Much more than fee reductions. In *ECB T2S special series* (p. 1).

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