Settlement liquidity in SIC

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Abstract

Settlement liquidity of RTGS payment systems with central queuing arrangements is more holistically captured analyzing queuing and release time. Abundant settlement balances foster earlier settlement reducing queuing time. However, abundant settlement balances do not foster earlier release and shorter queuing time induces participants to release payments later, offsetting the positive effects of abundant reserves. Earlier release time and more retail payments shorten queuing time even in the absence of hybrid netting functionalities. Also, release management takes place despite abundant settlement balances and release time remains unaffected in times of elevated default risk and a negative interest rate regime.

JEL classification: G23, E42, E58

Keywords: settlement liquidity, large-value payment systems, real-time gross settlement, central queing arrangement, liquidity-saving mechanism, negative interest rate policy, normalization

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1 Introduction

This paper analyzes settlement liquidity, defined as the ease with which market participants can discharge their payment obligations in a real-time gross settlement (RTGS) payment system with a central queuing arrangement. Swiss Interbank Clearing (SIC) represents one of the oldest such large-value payment systems. Its basic settlement algorithm ("first-in-first-out", FIFO) has essentially remained unchanged since SIC went live in 1987. While payment priorities were added to accomodate the delivery-versus-payment (DVP) link with the central security depository (CSD) in 1994, SIC has never been enriched with a liquidity-saving mechanism (LSM) that runs bilateral or multilateral netting cycles.

Similar to other liquidity concepts, settlement liquidity is hard to gauge. Common proxies used to capture settlement liquidity are queing (e.g. Galbiati and Soramäki, 2011) and settlement time (e.g. Bech et al., 2012). For RTGS systems without central queuing arrangements, release and settlement time coincide, i.e. after a payment is released immediate settlement is triggered either by means of available funds or automated overdrafts. For RTGS payment systems with central queuing arrangements, settlement time is the sum of release time and queuing time, i.e. payments are not necessarily settled immediately after release. Rather, payments are released to central queuing arrangements and remain pending until settlement balances become available. While settlement time serves as a valid proxy for settlement liquidity in case of RTGS systems without central queuing arrangements (Armentier et al., 2008, Bech et al., 2012, and McAndrews and Kroeger, 2016), queuing time is not necessarily a sufficient proxy for settlement liquidity in case of RTGS systems with central queuing arrangements. We document that the analysis of both release and queuing time reveals additional facets of settlement liquidity for RTGS system with central queuing arrangements that remain hidden if only one of these indicators is analyzed.

We base our study on proprietary individual payment data from January

2005 to April 2017. This sample allows us to cover pre-crisis times, the global financial crisis 2007 to 2009 (GFC), the European sovereign debt crisis and the period of the negative interest rate (NIR) policy in Switzerland starting 15 January 2015. The sample covers a period of greatly changing levels of settlement reserves, as the Swiss National Bank (SNB) intervened in the FX market to fight deflationary pressure caused by the overvaluation of the Swiss franc from 2009 on. While we analyze aggregate data, we do so for different payment categories: five payment size bandwiths, two different payment purposes (customer related or bank-to-bank payments) and different payment priorities. We can further differentiate payments that are institutionalized – i.e. ancillary systems determine the release time of such payments – and payments that are non-institutionalized – i.e. the payor determines the release time. Trying to shed light on settlement liquidity, we base our study on value-weighted indicators of release and queuing time.

We let our empirical investigation be guided by six hypotheses derived from theoretical, empirical and simulation-based literature on payment behavior:

Hypothesis 1: Increasing settlement balances induce earlier release and settlement.

Particularly theoretical literature unanimously predicts that ample settlement balances improve settlement liquidity as a reduced liquidity cost increases incentives to settle early (Angelini, 1998, Bech and Garratt, 2003, McAndrews and Martin, 2008, Mills and Nesmith, 2008, and Martin and Jurgilas, 2013). This prediction is empirically well documented for RTGS systems with no central queuing arrangement (Bech et al., 2012, and McAndrews and Kroeger, 2016). SIC data, however, does not support this prediction in relation to an RTGS system with a central queuing arrangement. While abundant settlement balances almost eliminate queuing time, they do not induce earlier release time. Rather, a greater intraday credit demand is associated with slightly later release. Even more astonishingly, we find that a shorter average queuing time is associated with later release. Overall, shorter queuing time is more than offset by later release time.

Hypothesis 2: A central queuing arrangement and ample settlement balances eliminate strategic payment management.

Based on a model of liquidity-saving mechanisms (LSM) in RTGS systems, Martin and Jurgilas (2013) predict that earlier release of payments is an equilibrium outcome for payment systems with collateralized and free intraday liquidity. In this type of systems, earlier release to the LSM, respectively the central queuing arrangement helps to economize on expensive liquidity and to avoid delay costs. Hence, the potential for earlier release might be largely exhausted in normal times and may be further eliminated in times of abundant settlement balances. In constrast to this prediction, the data suggests that the release time of non-institutionalized payments remains subject to strategic release management even in times of abundant settlement balances. However, as also outlined in Vital (1990), substantial sequencing of payments takes place in SIC, a pattern that has rather strenghtened with increasing settlement balances. In contrast to the overall pattern, participants have substituted large with extra large payments and have released extra large payments much earlier since 2013. Furthermore, coordination of payment timing has not stopped to play a relevant role in relation to changes in the level and concentration of settlement value and the concentration of the number of payments. Moreover, the release time of insitutionalized payments seems to work as a focal point for the release of non-institutionalized payments (a result also found for Fedwire; Armentier et al., 2008 and Bech et al., 2012). These examples are indicative of non-negligible release time management, suggesting that – even in times of abundant reserves – internal queuing matters for RTGS systems with central queuing arrangements.

Hypothesis 3: Earlier release to a simple central queuing arrangement improves settlement liquidity through a more efficient reuse of settlement balances.

The conventional wisdom about central queuing arrangements suggests that these are beneficial, as they allow to install LSM, i.e. the netting of queued payments. Martin and McAndrews (2008) and Jurgilas and Martin (2013) show that a simple central queuing arrangement represents an LSM without hybrid capabilities, as it can trigger earlier release and reduces the trade-off between available settlement balances and settlement delay. While we cannot address the first prediction[1], we provide affirmative evidence for the second prediction. Despite the absence of LSMs allowing for bilateral or multilateral offsetting, we find earlier release to be associated with a lower queuing time. In other words, the availability of payments in the central queuing arrangement allows for a more efficient reuse of available settlement balances.

Hypothesis 4: The integration of retail payments into RTGS large-value payment systems improves settlement liquidity.

In a similar vein as above, we believe that the integration of retail payments into RTGS payment systems with a simple central queuing arrangement allows to reuse available liquidity more efficiently. For instance, Armentier et al. (2008) find that Fedwire payments tend to settle earlier on days with more customer payments. Indeed, we find queuing time to be negatively related to the number of payments settled.

Hypothesis 5: Elevated levels of default risk among the participants of RTGS systems induces participants to release later.

Based on individual participants' payment data in CHAPS, Benos et al. (2014) document that – relative to the time before the GFC – settlement was slightly delayed during the two months after the failure of Lehman Brothers.[2] In case of SIC, such responses seem to be absent despite the presence of two

[1]See Nellen (2015) for a comparison of settlement times in Fedwire and SIC. Indeed, settlement takes place much earlier in SIC than in Fedwire (the latter being an RTGS without a central queuing arrangement in place).

[2]Many related studies focus on operational disruptions and provide similar evidence on settlement delay. See for instance McAndrews and Potter (2001), Klee (2010). Bech and Garratt (2012) add a theoretical perspective.

Swiss G-SIBs that were both heavily affected by the GFC and subsequent events. However, neither do we observe a changes in release behavior after Lehman nor during the euro area sovereign debt crisis or the more recent phase of doubts about the sustainability of the investement banking arms of some european G-SIBs in 2016.

Hypothesis 6: Negative interest rate policy does not affect settlement liquidity in RTGS systems with a central queuing arrangement.

While we cannot back this hypothesis with any literature, we believe that there is a money market based rationale for why earlier release might be triggered by a NIR policy. For instance, the NIR policy revided the Swiss franc repo market, as capacity to absorb reserves began to be traded to avoid NIR. This could provide incentives for participants to gain a clear picture of their end-of-day position as early as possible to be first to find a counterparty willing to trade. Hence, participants have an incentive to reach release payments early to speed up settlement and reduce end-of-day position uncertainty. However, the data does not support earlier release time.

The next section provides a brief description of SIC. Section 3 explains the data. Section 4 analyzes release time and section 5 investigates queuing time. The final section concludes.

2 SIC and stylized facts

SIC is a plain vanilla RTGS payment system. Participants and anciliary systems release all payment orders to the system where they are pending in centrally located queues. Conditional on the availability of settlement balances, the system settles pending payments according to a first-in-first-out (FIFO) algorithm with priorities (see Heller et al., 2000 and Oleschak and Nellen, 2013). If enough funds are available to settle a predefined number of payments that were released within a predefined time frame in a participant's queue, this batch of payments is settled at the same time. While the system features a bilateral off-setting mechanism to resolve a gridlock situation, the settlement algorithm does not apply any hybrid elements such as regular bilateral and multilateral netting cycles.[3]

SIC is a large-value payment system that is also used for small-value payments. As a consequence, the huge bulk of the number of payments consists of small-value payments, while the huge bulk of the total value of transactions originates from large-value payments. Most small-value payments are settled overnight. The overnight settlement of most small-value payments is incentivized by the fee structure that punishes late release and settlement time (Vital 1990) and overnight settlement is made possible as the SIC operating day starts at 5pm the day before the value date. The operating day stops on value date at 4.15 pm.[4] However, from 3 pm onwards, only bank-to-bank payments are accepted as new payment orders. From 4 pm on, the only new payment orders accepted are payments from or to the SNB.[5]

SIC serves as a payment settlement system to other financial market infrastructures such as CLS, the Swiss CSD, central counterparties (CCP) and automated clearing houses (ACH) of retail payments. With the exception of CLS transactions that settle in dedicated subaccounts[6], all payments settle on the main accounts of SIC participants. Some anciliary systems are

[3]Neither batch settlement nor the bilateral off-setting mechanism represent hybrid features. Batches are settled gross and the bilateral off-setting mechanism applies to a single pair of off-setting payments, if and only if a gridlock occurs for some time. If the bilateral off-set kick-starts settlement, no further off-setting takes place until the next gridlock occurs. On average the bilateral off-setting mechanism has been applied once a day before the GFC. Due to growing settlement balances, it hasn't been used since 2009.

[4]Note, settelment days on Mondays and public holidays defer from other settlement days having longer opening hours over the weekend and during the public holiday. Hence, we exclude Mondays and settlement days after a public holiday from our regular sample. However, we use Mondays to run robustness check.

[5]Note, from May 2017 on, the settlement day starts at 7 pm the day before value date and stops at 6.15pm.

[6]Note, from May 2017 onwards CLS payments newly settle on the main accounts. Subaccounts were disestablished, as a new functionality allows to block reserves and to dedicate these reserves to specific payments.

authorized to submit direct debit orders to SIC with the third-highest or second-highest priority attached. This allows for a fast settlement of institutionalized payments such as repurchase agreement (repo) and other DVP transactions. We refer to (the payment leg of) these transactions as institutionalized payments because participants do not control the release time. While regular participants can release credit orders only, they can choose to submit payment orders with the second, forth and lowest priority attached (the highest priority is reserved for the SNB). We refer to these transactions as non-institutionalized payments. These payments are subject to strategic delay.

Figure 1 displays the total settlement value considered in our study (i.e the sum of institutionalized and non-institutionalized payment values) and the value of payments excluded from this study. The latter consists of payments on CLS subaccounts, SNB payments and payments below a value of CHF 10'000.[7]

[[about here: Figure 1: Total settlement value, settlement value of institutionalized, non-institutionalized and excluded payments]]

SIC settles on the basis of settlement balances that consist of settlement reserves[8] and collateralized intraday credits free of interest. In addition to the intraday credity facility, the SNB also offers a discount window facility, namely the "liquidity shortage financing facility" (LSFF). LSFF credit extensions are meant to address unexpected liquidity shortages by participants or the market more widely that could cause settlement gridlocks in SIC. How-

[7]As CLS transactions are settled in dedicated CLS subaccounts during predefined time slots, they are uninteresting from a settlement liquidity and a strategic point of view. The same holds true for SNB payments, as the SNB does not face any frictions. We further ignore payments below CHF 10'000, as banks automatically release and settle most of these payments during the night.

[8]Reserves are transferred from the SNB reserve account to the SIC settlement account at the beginning of the settlement day; depending on the net reserves provided by the SNB and on other autonomous factors, the level of settlement reserves may change in the course of the day. We define settlement reserves as the reserves transferred to the SIC settlement account.

ever, LSFF credit extenstions have usually been drawn at the end of the settlement day and have always remained negligble. Hence, we can safely ignore them. As depicted in Figure 2, settlement reserves account for the dominant share of settlement balances from the end of 2008 on. Appendix B2 provides a short summary of monetary policy developments during the period considered.

The main intention of the SNB's intraday credit facility is to facilitate the settlement of payments via SIC and foreign exchange transactions in the CLS subaccounts of SIC (Heller et al., 2000, Kraenzlin and Nellen, 2010 and Nellen, 2015). All participants that have established access to the Swiss franc repo platform can obtain intraday credits from the SNB. All SIC participants are eligible to access the repo platform and participants that do so account for the overhelming part of the value and number of payments in SIC (Kraenzlin and Nellen, 2015). Intraday credit is interest rate free and granted in the form of a repo that is covered with 110% of collateral eligible for repo operations with the SNB. Banks can draw and repay the intraday liquidity at any time during the day between 8.00 am and 2.45 pm. Furthermore, they can draw intraday credit at 4 pm for the next settlement day starting at 5pm the same day. If repayment has not been accomplished by 2.45 pm, it is automatically initiated as a direct debit payment with the highest priority attached. The intraday credit facility was introduced in 1999 and has been used intensively since then. As shown in Figure 2, starting with the introduction of CLS in 2002, aggregate intraday credit extensions increased from CHF 3 billion to approximately CHF 7 billion. Additional intraday liquidity was meant to settle FX transactions on CLS subaccounts. During the GFC, SIC participants increased their intraday credit demand substantially. At the onset of the crisis, demand increased by CHF 1 billion and subsequently raised to over CHF 10 billion during the peak of the crisis. With increasing reserve levels, intraday credit demand almost vanished. As we exclude CLS payments in our analysis, we do not consider CLS related intraday credit extensions too.

[[about here: Figure 2: Reserves, settlement balances, settlement reserves and aggregate intraday credit extensions]]

In line with Hypothesis 1, we would assume that the increase in settlement balances has caused release and settlement to take place earlier. Figures 3a and b depict release and settlement time of non-institutionalized payments for different value percentiles (see Figure 9 on queuing time). Indeed, increasing settlement balances go along with a slightly earlier release and earlier settlement timing until mid 2009. However, the effects are rather modest. If looking at higher release time percentiles, for both release and settlement time the effect reverts after mid 2009 and later release and settlement result for greater percentiles. Only for the first 30 percentiles a pronounced earlier release and for the first 50 percentiles earlier settlement time remains until the end of the sample. For greater percentiles from 2009 on later release and from 2013 on later settlement times have resulted. Hence, lower coordination is a result of earlier release (and consequently settelment) and of later release (and conseuqently settlement). This is in stark contrast to the findings reported by Bech et al. (2012) and McAndrews and Kroeger (2016) who report a pronounced earlier settlement (and consequently release) time in Fedwire as a result of increasing settlement balances. Against the background of a fee structure that punishes late release and settlement in SIC, a feature absent in Fedwire, these findings are noteworthy and are not in line with Hypothesis 1.

[[about here: Figure 3: a) Release time for different value percentiles of non-institutionalized payments, b) Settlement time for different value percentiles of non-institutionalized payments]]

3 Data

Payment data is retrieved from a proprietary SNB data base that contains all payments released to and settled in SIC. We consider a sample ranging from January 2005 to April 2017.[9] Considered payments fall within two types, namely institutionalized (i) and non-institutionalized payments (ni). Institutionalized payments are not released by the payor itself but by some ancillary system. Hence, the release time is not controlled by the payor. In constrast, non-institutionalized payments are released by the participant itself and are subject to strategic delay.

Payments can be further categorized according to their size, purpose and priority. We differentiate five size bandwiths: tiny ($10'000 \leq t < 100'000$), small ($100'000 \leq s < 1'000'000$), medium ($1'000'000 \leq m < 10'000'000$), large ($10'000'000 \leq l < 100'000'000$) and extra large payments ($xl \geq 100'000'000$). The payment purpose can either be bank-to-bank ($b2b$) or customer related payments (c). Payments can have five different priorities attached. The highest priority is reserved for SNB payments. Institutionalized payments are either of the second-higest priority or the third-highest priority. Participants can either attach the second-highest (labelled as1), the forth-highest (2) or the lowest priority (3) to their credit payments.

We can differentiate the release (r) and the settlement time (s) of payments. The difference denotes the time spent in central queues (q). We analyze release time on the system level and consider the time span (in minutes) between beginning of the settlement day and the time by which a specific percentile (p) of payments is released r_p. At a certain date t, we are interested in the release time of non-institutionalized payments ($r_{p,t}^{ni}$) or any subcategories of non-institutionalized payments such as $b2b$ payments ($r_{p,t}^{ni,b2b}$) for instance. When considering queuing, we analyze the queuing time of all payments $\bar{q}^{all}$. As we focus on settlement liquidity, we consider value-weighted indicators.

[9] In May 2017, a new time and a new fee schedule were introduced simultaneously. Thus, we end our sample in April 2017.

We use a number of explanatory variables in the regression analyses. When analyzing the release time of non-institutionalized payments $r_{p,t}^{ni}$, we are particularly interested in the interdependence between non-institutionalized payments and institutionalized payments. Furthermore, we are interested – once payments are released – whether the speed of settlement influences release behavior. Hence, we use the value-weighted average release time of insitutionalized $\bar{r}^i$and the value-weighted average queuing time of all payments $\bar{q}^{all}$ as explanatory variables. When analyzing average queuing time of all payments $\bar{q}^{all}$, rather than$\bar{r}^i$ we use $\bar{r}^{all}$ as explanatory variable.

For both dependent variables, we consider aggregate settlement balances (sb) as the sum of aggregate settlement reserves (sr) made available for settlement and the aggregate amount of intraday credits (ic) drawn on a gvien day to supplement settlement balances on main accounts. We control for the concentration of settlement balances using its Herfindahl-Hirschman Index ($HHIsb$). We further consider the aggregate settlement value (sv) and control for its concentration ($HHIsv$). Next to the settlement value, the aggregate number of transactions and its concentration might similarly affect settlement liquidity (n ,$HHIn$).

Money markets may be important determinants of settlement liquidity too. Hence, for release and queuing time as dependent variables, we consider the effect of money market activities. We differentiate between the unsecured (umm) and the secured money market (rmm). This is important, as the unsecured money market is subject to strategic delay, while the secured money market – the repo market – is settled via a tri-party agent and, hence, belongs to the tpye of institutionalized payments (Guggenheim et al., 2011).

The introduction of negative interest rates might alter release incentives. Any changes of release behavior might either be related to the negative interest rate policy itself or to the aggregate extent participants are exposed to negative interest rates.[10] Hence, we suggest the two following indica-

[10]The SNB implements negative interest rates using a tiered system, i.e. negative in-

tors. First, we define a dummy variable as additional explanatory variable that exhibits a value of one for the time period with a negative interest rate policy (NIR).[11] Second, the level of reserves above the sum of individual exemption thresholds might change the effects of negative interest rates on release behavior. To control for this, instead of NIR, we simply consider the aggregate amount of reserves subject to the negative interest rate ($RS2N$), where $RS2N$ takes the value of zero before and the sum of reserves above the individual exemption thresholds after the introduction of the negative interest rate policy.

Similarly, the GFC and other periods associated with elevated default risk of major SIC participants might effect changes in release behavior. While the maximum 5Y CDS premia of all G-SIBs participating in SIC (CDS) might serve as a valid indicator of the extent of default risk present[12], we believe that payment risk management does not react on daily changes of CDS spreads. Rather, changes in release behavior represent one-time decisions by risk managers that remain effective for some time. Such decisions may be triggered by the exceedance of some threshold CDS premia perceived to be critical. Thus, we create a dummy variable ($CDSX$) that takes the value of 1 if CDS exceeds some threshold level X and 0 otherwise. We choose a threshold that reflects the GFC around the failure of Bear Stearns.[13] We associate this event with a CDS premia that exceeds 150bp. We take $CDSX$ as our baseline regression indicator. Based on the same reasoning, the de-

terest rates are applied on reserves above an exemption threshold. See Appendix B1 for more details on monetary policy implementation from 2005 to April 2017.

[11] In so doing, we ingore the fact that on 18 December, the SNB announced a -0.25 interest rate on reserves above exemption thresholds effective from 22 January onwards. This decision was overrun on 15 January, when a negative interest rate of -0.75 was effectively implemented.

[12] The choice is driven by the fact that the GFC and events thereafter have left the domestically oriented Swiss banks unaffected whereas Swiss and foreign G-SIBs – that are represented in SIC – were affected strongly. See Appendix B2 for a more detailed discussion.

[13] JP Morgan Chase bought Bear Stearns on 16 March 2008; however, the liquidity situation of Bear Stearns became rapidly unsustainable after 10 March 2008.

fault of Lehman Brother might be the key trigger event, as it made evident that a large bank failure is possible. Similarly, it is likely that risk managers reversed precautionary release changes after it became clear that further insolvencies of a comparable size would be prevented by government interventions. In relation to SIC, government backing became evident latest with the recapitalization of UBS on 16 October 2008. However, similar government interventions took place worldwide around the same time. Hence, we define the dummy variable $LB2UBS$ to equal 1 from the default of Lehman Brothers to the recapitalization of UBS and 0 otherwise. Further below we use default risk dr_t to denote all three variables indicating default risk.

When analyzing queuing, we control for the share of extra large sxl and large sl payments in aggregate settlement value. Additionally, we control for the effect of payment priorities. Hence, we include the share of second highest priority payments $s1$ in total aggregate settlement value. Such payments may either block settlement balances to freely float and other payments from being settled.

Tables B4.1 and B4.2 in Appendix B shows descriptive statistics of all variables used in the following regression analyses.

4 Release time

This section analyzes release time of non-insitutionalized payments that are released by participants themselves and as such are subject to potential strategic delay. We shortly discuss descriptive evidence and then move to the econometric analysis.

4.1 Descriptive evidence

For each subcategory of size, Figure 4 depicts the average release time of non-institutionalized payments. Insepction reveals a strong pattern of payment sequencing as discussed in Vital (1990) and Rochet and Tirole (1996), i.e. the size of the payment is a decisive factor for its release time and, in case of SIC, smaller payments are released before larger payments. With the exception of xl payments, this sequencing has become stronger over time as the gap between subcategories of sizes has widened. From 2013 on, xl payments were released much earlier whereas other categories show a slight or more pronounced later release time. This change in the release time of xl payments resulted in earlier release of all payments. This effect is reinforced by the increasing share of xl payments in total payments as depicted in Figure 5. Interestingly, Figure 5 further reveals that the share of xl payments has increased simultaneously with a decreasing share of l payments. Also, the increasing share of xl payments seems to be aligned with increasing settlement balances (see Figure 2).

[[about here: Figure 4: RT(ni, all) and RT(ni, size)]]

Sequencing is likely done to smooth settlement and to save on costly liquidity (Vital, 1990, Rochet and Tirole, 1996). Sequencing of payment is further triggered by the fee structure that incentivizes early release and settlement of tiny payments (Vital, 1990, Heller et al., 2000). While the first motive fades with increasing settlement balances, the second motives remains intact. This reasoning might help to understand why the sequencing structure in principle remained intact throughout the sample and became even more pronounced for all but xl payments (Figure 3a). The two motivations also help to understand the drastic changes in release time of xl payments. On the one hand, abundant settlement balances allow banks to settle xl payments without creating settlement delay. On the other hand, the substitution of many l payments with xl payments and the earlier release and settlement of xl payments allows banks to save release and settlement fees. However, it remains unclear why the thrust of payment value remains released late and is even released later over time.

Based on Figures 3 and 4, it is difficult to assess whether default risk concerns were at play. However, it seems unlikely that the negative interest rate policy has caused a particular change in the release pattern. The comparatively high volatility of the average release time of xl payments is related to the lower number of payments in this category.

[[about here: Figure 5: Percentage of different size subcategories in the total value of non-institutionalized payments]]

Many xl payments fall into the category of $b2b$ payments and the change in 2013 affected the release time of $b2b$ payments accordingly (see Figure B3.1 in Appendix B). In line with the later release time of m and l payments, $b2b$ payments are released later until 2013, when earlier release time resulted as a consequence of earlier release of xl payments. Somehow in line with increasing reserve levels, customer payments show a declining trend until mid 2013. Since then, a reverse trend of later release can be noticed. Again, neither default risk nor the negative interest rate policy seem to affect release time.

The release times of different categories of priorities are relatively volatile and it is difficult to assess their interplay with explanatory variables (see Figure B3.2 in Appendix B). The effect of earlier released xl payments primarily affects the lowest priority as xl payments mostly fall into this category.

Overall, descriptive evidence well suggests that Hypothesis 1 and 2 may likely not be supported by the data. To further validate these assertions, while controlling for other influences, and to address remaining hypotheses, we rely on the following econometric approach.

4.2 Econometric evidence

We apply the econometric approach by Armentier et al. (2008). The same approach is applied by Bech et al. (2012) and McAndrews and Kroeger (2016). To explicitly associate timing shifts with various potential factors, regression analysis is used on the daily times series of the SIC release time distribution. We conduct 100 linear regressions, one for each percentile of value released to SIC throughout the day. Variables are differenced from one business day to the next to adress the issue of nonstationarity. To take into account serial correlation and heteroskedacticity of the error terms, we use Newey-West corrected standard errors. A maximum lag length of 10 is used for the Newey-West procedure.

As institutionalized payments are not released by participants themselves, for the analysis of release timing we only consider non-institutionalized payments as dependent variable. To control for interdependencies, we consider the average release time of institutionalized payments $\bar{r}^i$ and the average queuing time of all payments $\bar{q}^{all}$ as explanatory variables. We further consider money market activity, default risk and negative interest rate policy indicators. Self-evidently, with settlement balances, settlement value, the number of payments and their respective HHI, we consider the usual suspects as explanatory variables.

We perfom seperate regressions for all payments (all) and for each subcategory of payments, i.e. for the different size bandwith $\{t, s, m, l, xl\}$, for each payment purpose $\{c, b2b\}$ and for all three priorities $\{1, 2, 3\}$. Considering for instance the release time of non-institutionalized payments $r^{ni,all}_{p,t}$ as the dependent variable, we estimate the following specification:

$$\triangle r^{ni,all}_{p,t} = \begin{cases} \alpha_p + \beta^1_p \Delta sr_t + \beta^2_p \Delta ic_t + \beta^3_p \Delta HHIsb_t + \beta^4_p \Delta sv_t + \\ \beta^5_p \Delta HHIsv_t + \beta^6_p \Delta n_t + \beta^7_p \Delta HHIn_t + \beta^8_p \Delta umm_t + \\ \beta^9_p \Delta smm_t + \beta^{10}_p \Delta \bar{r}^i_t + \beta^{11}_p \Delta \bar{q}^{all}_t + \beta^{12}_p dr_t + \\ \beta^{13}_p NIR_t + \beta^{14}_p \Delta RS2N_t + \varepsilon_{p,t} \end{cases}$$

The regression equation remains the same for all categories of payments. Figure 6 below and Figures B5.1 to B5.10 in Appendix B show the results of the above mentioned regressions for all payments (Figure 6) and payment categories (Figures B5.1 to B5.10). Note that the coefficients reported are standardized; i.e. the figures show the impact of a one standard deviation change of the explanatory variable on release time. In the following, we mainly summarize results for all payments and focus on categories of payments where we identify a notable deviation from the result found for all payments.

[[about here: Figure 6: Regression results with release time of all non-institutionalized transactions as dependent variable]]

We find that changes in settlement reserves are not associated with changes in release time. Small and tiny payments show a somewhat later release time but do not affect value-weighted release time of all payments. Interestingly, more intraday credit extensions are generally associated with later release. This is most pronounced for large, b2b and normal priority payments, whereas tiny and customer payments show a slightly earlier release time. While significant for a number of percentiles, economically the impact is small. Even if accounting for the maximum impact, we talk about approximately three minutes in case of a few percentiles.[14] Both pieces of evidence clearly reject Hypothesis 1, as their is generally no indication of earlier release. The evidence in relation to intraday credit demand may be associated with the GFC, as demand rose considerably at the onset and during the hight of the GFC. One may associate this as evidence that healthy participants delayed payments to affected participants. However, this narrative is in conflict with the results obtained for various default risk meassures that all indicate no change of release time (see further below). Also, the impact is negligible. A larger concentration of settlement balances (intraday credit plus settlement reserves) is not associated with changes in release time. However, small, tiny, customer and second-highest priority payments are released slightly earlier.

Increasing settlement value is associated with later release. This holds

[14]Remember, we estimate standardized coefficients. You find descriptive statistics of all variables used in Appendix B.4. In both cases, the maximum impact on certain percentiles amounts to around one minute. The differences between minimum and maximum settlement reserves and intraday credit extensions amounts to approximately 3 times the standard deviation. Hence a maximum impact of 3 minutes may result.

true for all categories but medium sized and second-highest priority payments that show earlier release. Later releaselikely mirrors coordination endeavors. When settlement value increases, participants coordinate on later release to save costly liquidity. However, this rationale has been lost with increasing settlement balances. We take this as a further indication to reject Hypothesis 2. Also, the impact accounts for up to 18 minutes for low percentiles to around 4 minutes up to the 60 percentile. Accounting for the fact that the difference between the minimum and the maximum settlement value is about 11 times its standard deviation, we talk about economically relevant release time changes. A higher concentration of settlement value generally indicates earlier release but for customer payments. While the impact is smaller than before, it is persitent and of an economically significant magnitude.[15]

Changes in the number of payments are not associated with changes in release time. However, noticable later release can be seen for extra large, small, tiny and second-highest piority payments. Customer payments exhibit earlier release. While tiny payments are released later up to the 60 percentile, the remaining 40 percentiles are released earlier. By and large, it looks like operational questions determine the release behavior in relation to the number of payments. Naturally, categories with a higher number of payments are more affected. Interestingly, a higher concentration of the number of payments is associated with earlier release but for extra large and second-highest priority payments. Tiny payments are released later for lower percentiles and earlier for higher percentiles. The effects are persistent and significant.[16].

[15]This is interesting, as – ex ante – it is not evident what the effect of a higher concentration in settlement value would be. While participants with more settlement value may be tempted to release earlier, those with less settlement value are tempted to release later to await incoming payments. Furthermore, the effect of changes in concentration indicates that there may be differences in release behavior among differently sized participants of SIC. This may reflect different behaviors of differently sized participants, but may also indicate that larger participants find it easier to coordinate payment flows among each other. While this is noteworthy, a closer investigation of this observation is beyond the scope this paper.

[16]As discussed in the previous footnote, it would be interesting to understand the un-

Changes in the turnover of the unsecured money market is not associated with release time changes. However, more turnover in the secured money market is associated with earlier release. In particular, large and b2b payments are released earlier, whereas tiny and customer payments exhibit later release. The effects are economically significant at a relevant number of percentiles. The latter findings are consistent with the observation that the release time of institutionalized payments seems to work as a coordination device and further add to the rejection of Hypothesis 2.

A longer queuing time is associated with earlier release. This is the case for the first 60 percentiles. Between the 70th and 90th percentiles, we observe the opposite effect. However, overall earlier release dominantes. Similar patterns are observed for all payment categories. Looking at standardized coefficient and descriptive statistics, again, we talk about an economically significant effect. In turn, this implies that the shorter payments are queued, the later payments are released. This clearly contradicts Hypothesis 1. The more settlement balances are available, the shorter becomes queuing time and, as a consequence, the later are payments released.

The release time of insitutionalized payments is positively correlated with the release time of non-institutionalized payments. The effect is persistently observed and shows economic significant values. These observations hold true for all categories of payments. This sort of payment coordination is not in line with Hypothesis 2.

Changes in default risk are not associated with changes in release time. Hence, rather than later release due to risk management considerations, we observe no change in behavior. Results are consistent for all categories. Thus, Hypothesis 5 is supported by the data.

Finally, the negative interest rate regime is not associated with changes in release behavior. Both the fact of being in a negative interest rate regime nor the aggregate amount of reserves above exemption thresholds affect release

derlying reasons of the effects of concentration on release behavior.

behavior. Thus, Hypothesis 6 is not supported by the data.

4.3 Robustness

We run the regression for all payments for Mondays only. Qualitatively the results remain the same.[17]

Our focus is on the value-weighted release time. However, the main results remain qualitatively unchanged, if the unweighted release time is considered as dependent variable. In particular, changes in settlement balances (settlement reserve and intraday credits) are not associated with changes in release time. While longer queuing time is still associated with later release, the effect is less significant. The release time of institutionalized payments remains strongly positively correlated with the release time of non-institutionalized payments. A greater settlement value and a greater number of payments lead to more coordination through a higher concentration of payments. Default risk and the negative interest rate regime do not affect release timing.

In the regression results discussed above, $CDSX$ is taken as proxy for default risk. Results remain qualitatively unchanged, if the default risk indicators CDS or $LB2UBS$ are considered instead. Our study deviates from Benos et al. (2014) in three respects. Most relevant, we analyze aggregate data and findings are subject to the caveat that scenarios realized that do not allow to identify a changed release behavior with aggregate data. One likely scenario could be that participants may have released payments to affected participants later but in turn released payments to unaffected participants earlier. To rule out such a scenario we analyze the release time of the two Swiss G-SIBs and the category of all other banks among each other. Given our scenario, UBS and CS likely release payments later to each other but release payments earlier to all other banks. Furthermore, all other banks speed up release among each other and UBS and CS speed up payments to all others. We do not find any corresponding evidence of a changes in release

[17]Results of all robustness checks are available on request.

timing.[18] Last but not least, we consider release time rather than settlement time as in Benos et al. (2014). However, participants in SIC drew substantially more intraday credits during the GFC and the SNB injected substantial amounts of liquidity into the financial system during and in the aftermath of the GCF. Against the background of an unchanged release time, increased settlement balances naturally result in earlier settlement as a consequence of a shorter queuing time. Hence, a comparison of settlement times before and during the GFC would actually lead to the conclusion that settlement liquidity in SIC increased during times of market turmoil.

In relation to the negative interest rate regime, results remain qualitativey unchanged, if only one of the two explanatory variables is used.

5 Queuing time

In this section, we investigate queuing time. When analyzing queuing time, we deal with a rather mechanical relationship imposed by the settlement algorithm of the RTGS system considered, the available settlement balances and the payment flow to be worked off. Consequently, in choosing explanatory variables, we focus on those that could affect settlement liquidity through their consumption of settlement balances and the creation of settlement frictions for other payments. Also, when analyzing settlement, we consider all payments rather than only non-institutionalized payments, i.e. we include institutionalized payments. These payments affect queuing time in the same way as payments subject to strategic delay in their consumption of settlement balances and in their creation of settlement frictions.[19]

[18]Unfortunately, these robustness checks cannot be shared.

[19]Payments below CHF 10'000, CLS and SNB payment remain excluded from the analysis. Also, Mondays and days after a public holiday are not considered.

5.1 Descriptive evidence

We consider queuing time of each single payment as the difference between release and settlement time $q_t = s_t - r_t$. Queuing time as dependent variable is defined as the average value-weighted queuing time over all payments considered. As displays in Figure 9 – despite the unprecedented amount of settlement balances available – queuing is hard to eliminate completely. Even more strikingly, at very similar levels of settlement balances, the variability of queuing time is substantial. However, the variability reduces with increasing settlement balances as zero queuing time sets a lower bound.

[[about here: Figure 9: Scatterplot of QT(all) and SB]]

5.2 Econometric evidence

The evident convex relationship between queuing time and available settlement balances lends itself to a simple specification as laid out in the following regression equation:

$$\Delta ln\bar{q}_t = \begin{cases} \alpha + \beta_1 \Delta ln(sb_t) + \beta_2 \Delta ln(HHIsb_t) + \beta_3 \Delta ln(sv_t) + \\ \beta_4 \Delta ln(HHIsv_t) + \beta_5 \Delta ln(n_t) + \beta_6 \Delta ln(HHIn_t) + \\ \beta_7 \Delta ln(\bar{r}_t^{all}) + \beta_8 \Delta ln(summ_t) + \beta_9 \Delta ln(ssmm_t) + \\ \beta_{10} \Delta ln(sxl_t) + \beta_{11} \Delta ln(sl_t) + \beta_{12} \Delta ln(s1_t) + \varepsilon_t \end{cases}$$

Variables are differenced from one business day to the next to address the issue of nonstationarity. To take into account serial correlation and heteroskedacticity of the error terms, we use Newey-West corrected standard errors. A maximum lag length of 10 is used for the Newey-West procedure. Table 1 shows the results of the regression specified above. Note that all coefficients are log transformed; i.e. the coefficients measure the impact of a percentage change in the independent variable in percentage points of average queuing time.

Three variables are associated with a significant negative affect on the average value-weighted queuing time: the settlement balances, the number of payments settled in the system as well as the average release time. In other words, the more small payments are released, the more settlement balances are available and the earlier payments are released, the lower is the average value-weighted queuing time. The negative effect of more settlement balances is self-evident. More settlement balances reduce frictions associated with extra large, large or urgent payments that block other payments from being settled (Koponen and Soramäki, 1998).

At first sight, it might be more of a surprise that earlier release reduces queuing time. However, the earlier payments are released, the more effectively can available settlement balances be turned over. In other words, the more payments are available, the faster a liquidity-seeking account can be fueled and the less settlement balances lie idle on such an account. This accelerates settlement speed by reducing queuing time. Thus, the data support Hypothesis 3.

An increasing number of payments is associated with a lower average value-weighted queuing time. This may come as a surprise too at first sight. However, the number of payments is driven by the settlement of tiny and small payments. Tiny and small payments in turn do settle faster than large payments. Hence, the queuing time is reduced on days on which the number of payments increases. This effect is even stronger, if we consider the average unweighted queuing time. As we consider the average value-weighted queuing time, the negative coefficient indicates that the integration of retail payment settlement into an RTGS payment system with a central queuing arrangement fosters settelment liquidity. The settlement of of retail payments allows to improve the efficient usage of settlement balances similarly as described above. Hence, the data support Hypothesis 4.

In contrast, the settlement value, the share of large and very large payments, the share of urgent payments as well as the share of secured and unsecured money market transactions are associated with a significant positive affect on queuing time. Greater settlement value lengthens queuing time as available settlement balances need to be turned over more often. The positive coefficient of the share of large transactions is related to these payments' liquidity needs. Before settlement can take place, enough settlement balances need to be accumulated on the participant's accounts. This hinders other payments on the respective account from being settled and blocks liquidity for some time that could be used on other accounts too. Similarly, the share of urgent transactions imposes a longer queuing time on other payments. Money market transactions combine both latter effects as they are often of a relatively large value and of a high priority.

Concentration measures influence release timing to a greater or lesser extent. It is surprising that this is not the case for queuing time. Depending on the variabes considered, one would expect concentration to reduce (settlement value) or increase (settlement balances) frictions. However, concentration coefficients are mostly statistical insignificant but for settlement balances that is significant at the 5% level.

[[about here: Table 1: Queuing time regression]]

5.3 Robustness

Qualitatively the same results are obtained, if the same regression is performed for Mondays only. Also, results of unweighted queuing time qualitatively mirror results of value-weighted queuing time.

6 Conclusion

This paper contributes to the literature on settlement liquidity providing the first empirical analysis of settlement liquidity for an RTGS payment systems with a central queuing arrangement. Importantly, we document that the analysis of release time and queuing time allows to gather a more holistic picture of settlement liquidity for such systems than focusing on either queuing or settlement time. Namely, earlier settlement in SIC is exclusively owned to reduced queuing time. However, more settlement balances are not associated with earlier release and a shorter queuing time goes hand in hand with later release. The latter effect largely offsets earlier settlement through reduced queuing time for lower percentiles and results in later settlement for higher percentiles. Unfortunately, we lack the possibility to compare our results to similar studies for other RTGS systems with central queuing arrangements. As a bold policy conclusion, however, central banks that run RTGS systems with central queuing arrangements may want to put a stronger emphasis on the release time of institutional and non-institutionalized payments and their driving forces.

This paper's findings challenge the theoretical literature on settlement behavior. In contrast to model predictions, we observe no reaction of release time to abundant settlement balances and later release in response to a shorter queuing time. These observations are hard to reconcile with existing theories of settlement behavior as set out by Angelini (1998, 2000), Bech and Garratt (2003) and Mills and Nesmith (2008). Findings are also at odds with models of LSM by Martin and McAndrews (2009) and Jurgilas and Martin (2013). The former find an LSM to alter payment behavior and, consequently, they warn that payment simulation excercises might not be able to account for behavioral changes. While Galbiati and Soramäki's (2010) agent-based simulation approach addresses this caveat, our findings point to a potential shortcoming of the theory in accounting for payment behavior. This is relevant, as it concerns economic theories of settlement behavior on which policy advise rests.We further provide direct empirical evidence on two issues brought forward by the theoretical literature on LSM. The first piece of evidence again challenges the literature. Based on a model of LSM, Jurgilas and Martin (2013) predict that earlier release of payments is an equilibrium outcome in payment systems with collateralized and free intraday liquidity as represented by SIC.[20] In this type of systems, earlier release to the LSM, respectively the central queuing arrangement always helps to economize on expensive settlement balances. Pushing the argument to the limit, the potential for earlier release might be largely exhausted in normal times and one would not expect earlier release in times of abundant settlement balances. More generally speaking, we would expect that the scope for strategic payment management is rather low in such systems. In contrast to this prediction, our findings suggest that the release time of non-institutionalized payments remains subject to strategic behavior as non-negligible release time management takes place. This suggests that – even in times of abundant reserves – internal queuing matters for systems with central queuing arrangements and that other frictions not captured by the theoretical literature matter .

The second piece of evidence is affirmative. A simple central queuing arrangement with no hybrid features is predicted to improve the trade-off between delay and costly settlement balances. Earlier release of payments reduces settlement time through a reduction of queuing time. In other words, available settlement balances are turned over more efficiently. While the payment system simulation literature provides an account of the benefits of hybrid features (see for instance Galbiati and Soramäki, 2009, and Johnson et al., 2004), to the best of our knowledge, this is the first paper to provide direct empirical evidence of the benefit of a central queuing arrangements without netting features. This finding in combination with the insight that lower queuing time may result in later release is policy relevant. In particular, is it worth to invest in a further reduction of queuing time investing in hybrid features?

We further shed new light on policy issues related to the optimal scope

[20] See Nellen (2015) for a comparison of settlement time in Fedwire and SIC. Settlement of non-institutionalized payments in SIC takes place substantially earlier than in Fedwire. In contrast to SIC, Fedwire does not offer a central queuing arrangement.

of an RTGS system. First, we provide evidence that a higher number of payments is associated with a decreasing value-weighted average queuing time. At first sight, this seems to be counterintuitive. However, the number of payments in SIC is owned to the integration of retail payments that make up for the huge bulk of payments. The integration of retail payments fosters settlement liquidity through a more efficient turnover of available settlement balanaces. Additionally, the higher the number of payments to be settled, the earlier payments are released. These findings are policy relevant and remain topical despite a more than thirty year history of RTGS systems. As discussed in a recent report by the Committee on Payment and Market Infrastructures (CPMI, 2016)[21], current developments are suggestive of a disintegration of fast payments into dedicated fast payments systems rather than an integration into RTGS systems.

However, we also find that – despite extraordinary settlement balances – average value-weighted queuing time was still around two minutes at the end of our sample. Hence, even though retail payment integration can foster settlement liquidity, settlement liquidity in RTGS systems with central queuing arrangements might not be high enough to accomodate fast payments even in small countries as Switzerland.

Related to the finding that early release of institutionalized payments trigger early release of non-institutionalized payments, the integration of ancillary systems can positively affect settlement liquidity if institutionalized payments from ancillary system are released rather earlier than later.

Our paper adds further empirical evidence to the literature on participant behavior in times of elevated default risk.[22] Based on individual participants' payment data in CHAPS, Benos et al. (2014) document that – relative to the time before the GFC – settlement was slightly delayed during the two

[21]See also Bech et al. (2017) on the potential diffusion process of fast payments.

[22]Many related studies focus on operational disruptions and provide similar evidence on settlement delay. See for instance McAndrews and Potter (2001), Klee (2010) and Bech and Garratt (2012).

months after the failure of Lehman Brothers. In case of SIC, such responses seem to be absent.

To the best of our knowledge, this is the first paper to document the effects of a negative interest rate policy on settlement liquidity. The evidence provided suggests that the introduction of the negative interest rate policy does not affect release behavior. This holds true in relation to the bite of the policy, i.e. the level of reserves above the sum of individual exemption thresholds, and the fact that a negative policy rate is in place. While the policy rate remained constant during our sample period, the level of reserves subject to the negative interest rate policy increased substantially. Against the background of NIR in Denmark, the eurozone, Japan, Sweden and Switzerland, this is comforting policy news for the plumbing of the economy.

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References

[1] Angelini, Paolo (1998). An analysis of competitive externalities in gross settlement systems. Journal of Banking and Finance, 22, 1-18.

[2] Angelini, Paolo (2000). Are Banks Risk Averse? Intraday Timing of Operations in the Interbank Market. Journal of Money, Credit and Banking, vol. 32(1), 54-73.

[3] Armantier, Olivier, Jeffrey Arnold, and James McAndrews (2008) "Changes in the Timing Distribution of Fedwire Funds Transfers," FRBNY Economic Policy Review, Vol. 14(2), pp. 83–112.

[4] .

[5] Bech, Morten and Rodney Garratt (2003). The Intraday Liquidity Management Game. Journal of Economic Theory, Vol. 109, pp. 198–219.

[6] Bech, Morten and Rodney Garratt (2012). Illiquidity in the Interbank Payment System Following Wide-scale Disruptions. Journal of Money, Credit and Banking 44(5), 903-29.

[7] Bech, Morten, Antoine Martin and James McAndrews (2012). How the High Level of Reserves Benefits the Payment System. Liberty Street Economics Blog Post, 27 February 2012.

[8] Bech, Morten, Antoine Martin and James McAndrews (2012). Settlement Liquidity and Monetary Policy Implementation. FRBNY Economic Policy Review, Vol. 18(1), pp. 1–25.

[9] Bech, Morten, Yuuki Shimizu and Paul Wong (2017). The quest for speed in payments. BIS Quarterly Review, March 2017, 53-68.

[10] Benos, Evangelos, Rodney Garratt and Peter Zimmerman (2014). The Role of Counterparty Risk in CHAPS Following the Collapse of Lehman Brothers. International Journal of Central Banking, Vol. 10, No. 4, 143-171.

[11] Committee on Payment and Market Infrastructures (2016). Fast payments – Enhancing the speed and availability of retail payments. Bank for International Settlements, Basel, November 2016.

[12] Ercevik, Kemal A. and John Jackson (2010). Simulating the impact of a hybrid design on the efficiency of large-value payment systems. Mimeo, Bank of England.

[13] Galbiati, Marco and Soramäki, Kimmo (2009). Liquidity saving mechanisms and bank behaviour. In Leinonen, H. (Ed.): Simulation analyses and stress testing of payment networks, Bank of Finland Studies, E:42.

[14] Galbiati, Marco and Soramäki, Kimmo. (2011). An agent-based model of payment systems. Journal of Economic Dynamics and Control, Elsevier, vol. 35(6), 859-875.

[15] Garratt, Rodney, Antoine Martin and James McAndrews (2014). Turnover in Fedwire Funds Has Dropped Considerably since the Crisis, but It's Okay. Liberty Street Economics Blog Post, August 25, 2014.

[16] Glaser, Martina and Philipp Haene. (2009). Liquidity effects of a participant-level operational disruption in the Swiss Interbank Clearing System. In: Leinonen, H. (Ed.): Simulation analyses and stress testing of payment networks, Bank of Finland Studies, E:42, 59-81.

[17] Guggenheim, B., S. Kraenzlin and S. Schumacher (2011). Exploring an uncharted market: Evidence on the unsecured Swiss franc money market. Aussenwirtschaft, Vol. 66, 59-87.

[18] Heller, Daniel, Thomas Nellen and Andy Sturm (2000). The Swiss Interbank Clearing. Finanzmarkt und Portfolio Management, 14. Jahrgang 2000 - Nr. 4.

[19] Johnson, Kurt, James McAndrews and Kimmo Soramäki (2004). Economizing on liquidity with deferred settelment mechanisms. Economic Policy Review, Federal Reserve Bank of New York, December, 51-72.

[20] Keister, Todd, Antoine Martin, and James McAndrews (2008). Divorcing Money from Monetary Policy. FRBNY Economic Policy Review, Vol. 14(2), pp. 41–56.

[21] Klee, Elizabeth (2010). Operational outages and aggregate uncertainty in the federal funds market. Journal of Banking and Finance, 24, 2386-2404.

[22] Koponen, Risto, and Kommo Soramäki (1998). Intraday Liquidity Needs in a Modern Interbank Payment System - A Simulation Approach. Bank of Finland Studies E:14.

[23] Kraenzlin, Sébastien, and Thomas Nellen (2010). Daytime is money. Journal of Money, Credit and Banking, 42(8), 1689—1702.

[24] Kraenzlin, Sébastien, and Thomas Nellen (2015). Access policy and money market segmentation. Journal of Monetary Economics, 71, 1-12.

[25] Martin, Antoine and Marius Jurgilas (2013). Liquidity-saving mechanisms in collateral-based RTGS payment systems. Annals of Finance, 9, 29–60.

[26] Martin, Antoine and James McAndrews (2008). Liquidity-saving mechanisms. Journal of Monetary Economics, 55, 554—567.

[27] Martin, Antoine and James McAndrews (2009). A study of competing designs for a liquidity-saving mechanism. Journal of Banking and Finance, 34, 1818-1826.

[28] McAndrews, James and Alexander Kroeger (2016). The Payment System Benefits of High Reserve Balances. FRBNY Staff Reports, June 2016, Number 779.

[29] McAndrews, James and Simon Potter (2002). The Liquidity Effects of the Events of September 11, 2001. FRBNY Economic Policy Review, Vol. 8(2), pp. 59–79.

[30] Mills, David C. Jr. and Travis D. Nesmith (2008). Risk and concentration in payment and securities settlement systems. Journal of Monetary Economics, 55, 542-553.

[31] Mills, David and Samia Husain (2013). Interlinkages between payment and securities settlement systems. Annals of Finance, 9(1), 61-81.

[32] Nellen, Thomas (2010). What drives settlement performance? Published in: Nellen, Thomas (2010). Essays in Payment Economics. Dissertation at the University of Berne. http://www.zb.unibe.ch/download/eldiss/10nellen_t.pdf.

[33] Oleschak, Robert and Thomas Nellen (2013). Does SIC need a heartpace maker? SNB Working Paper 2013-10.

[34] Nellen, Thomas (2015). Collateralized liquidity, two-part tariff and settlement coordination. SNB Working Paper 2015-13.

[35] Rochet, Jean-Charles, and Jean Tirole (1996). Controlling risks in payment systems. Journal of Money, Credit and Banking, Vol. 28, No. 4, 832-862.

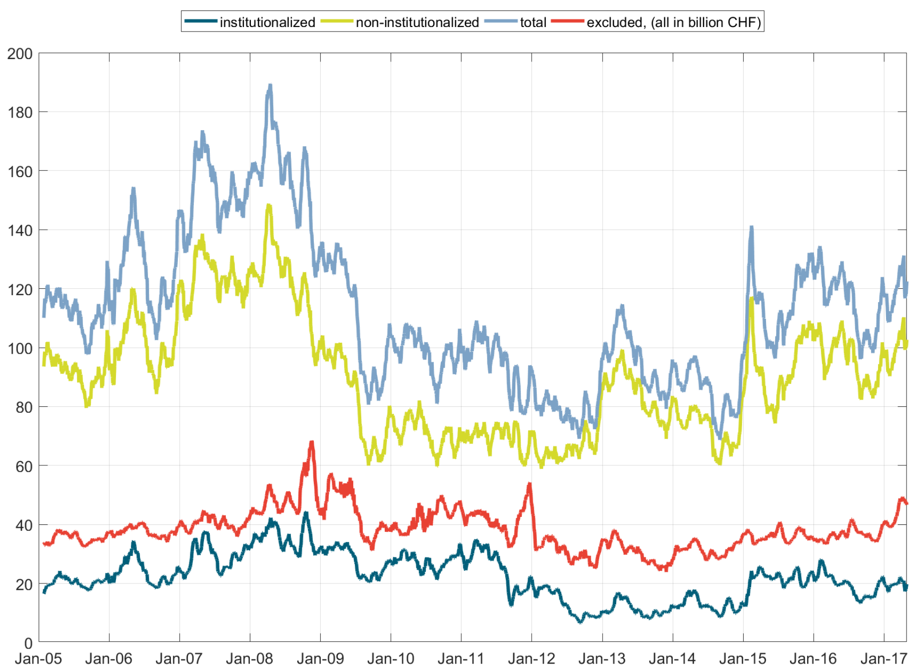
[36] Vital, Christian (1990). Swiss Interbank Clearing: further experience with a queuing mechanism to control payment system risk. Paper presented at a Conference on Electronic Banking, Munich, Germany. World Bank (2008). Payment Systems Worldwide. A snapshot. Outcomes of the

global payment system survey 2008. World Bank Financial Infrastructure and Research Series.

Appendix A - Figures and Tables to be included in the paper

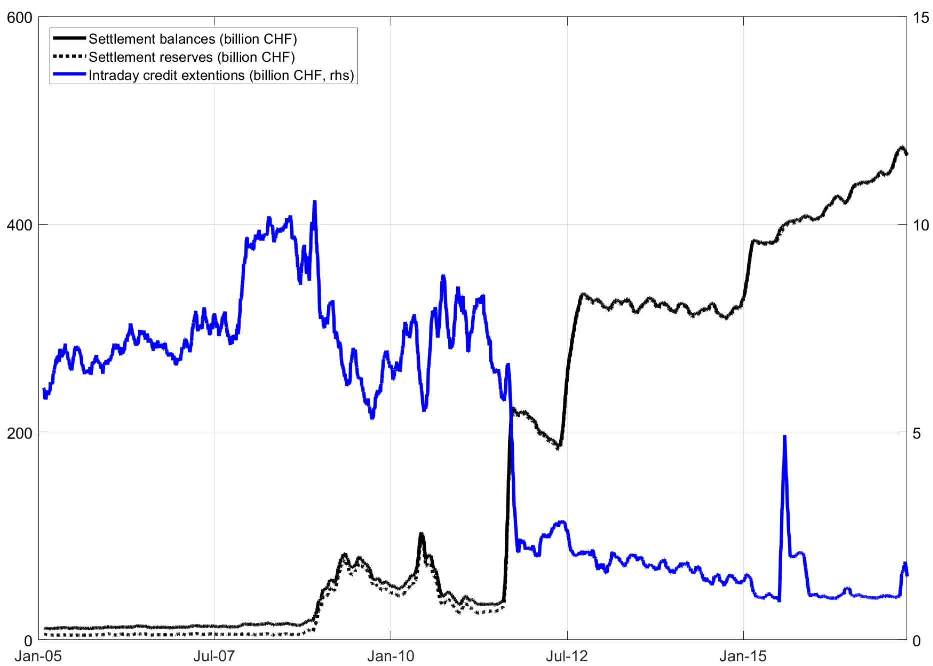
Appendix A 1 - Figures

Figure 1: Settlement value of all, institutionalized, non-institutionalized and excluded payments



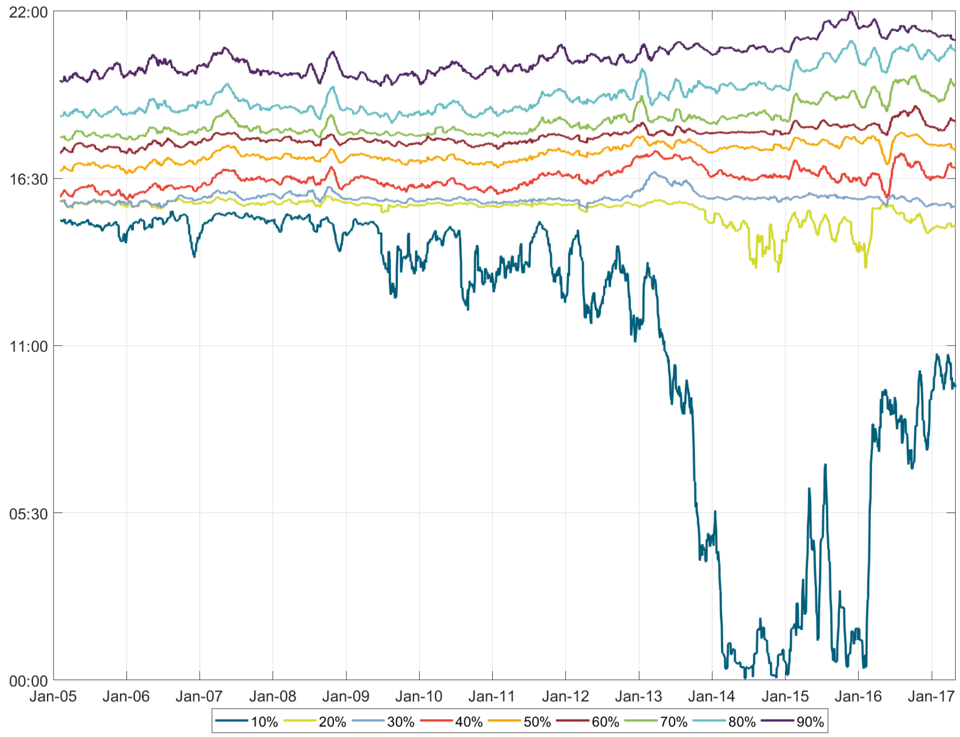
Notes: 20-day moving averages of the value of all payments (the sum of institutionalized and non-institutionalized payments considered in the study), the value of institutionalized and non-institutionalized payments considered in the study and the value of payments that were extracted (payments below CHF 10000, SNB and CLS payments).

Figure 2: Reserves, settlement balances, settlement reserves and aggregate intraday credit extensions



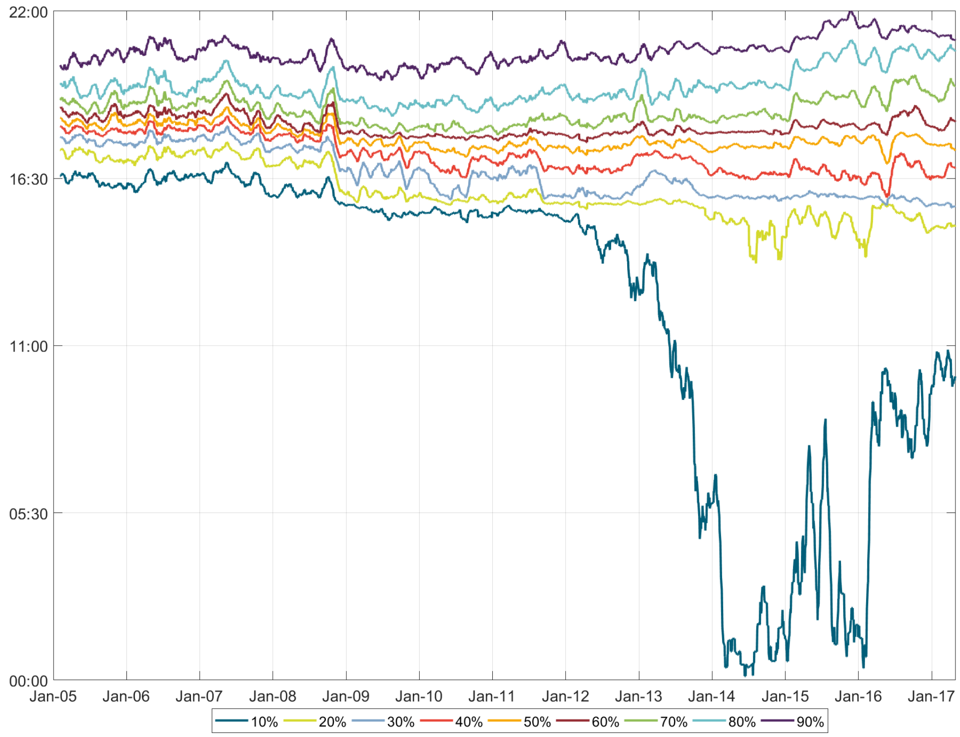
Notes: 20-day moving averages of settlement reserves (the sum of reserves tranferred to SIC accounts), intraday credit extensions (the sum of intraday credits drawn, right hand side) and settlement balances (the sum of settlement reserves and intraday credit extensions) .

Figure 3: a) Release time for certain value percentiles of non-institutionalized payments



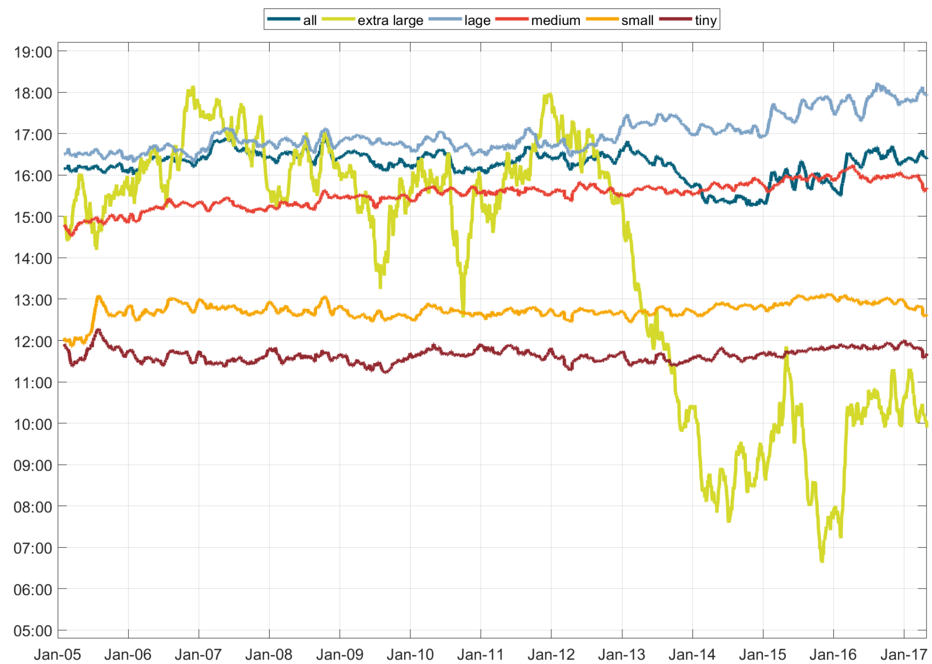
Notes: Data shown as 20-day moving averages.

Figure 3: b) Settlement time for value percentiles of non-institutionalized payments



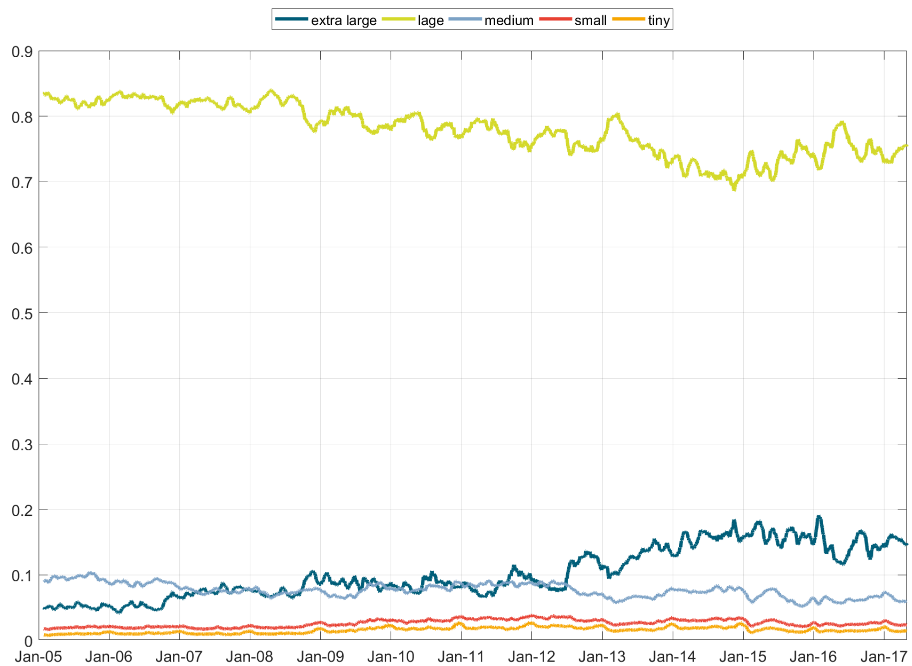
Notes: Data shown as 20-day moving averages.

Figure 4: Release time for of non-institutionalized payments for different sizes subcategories



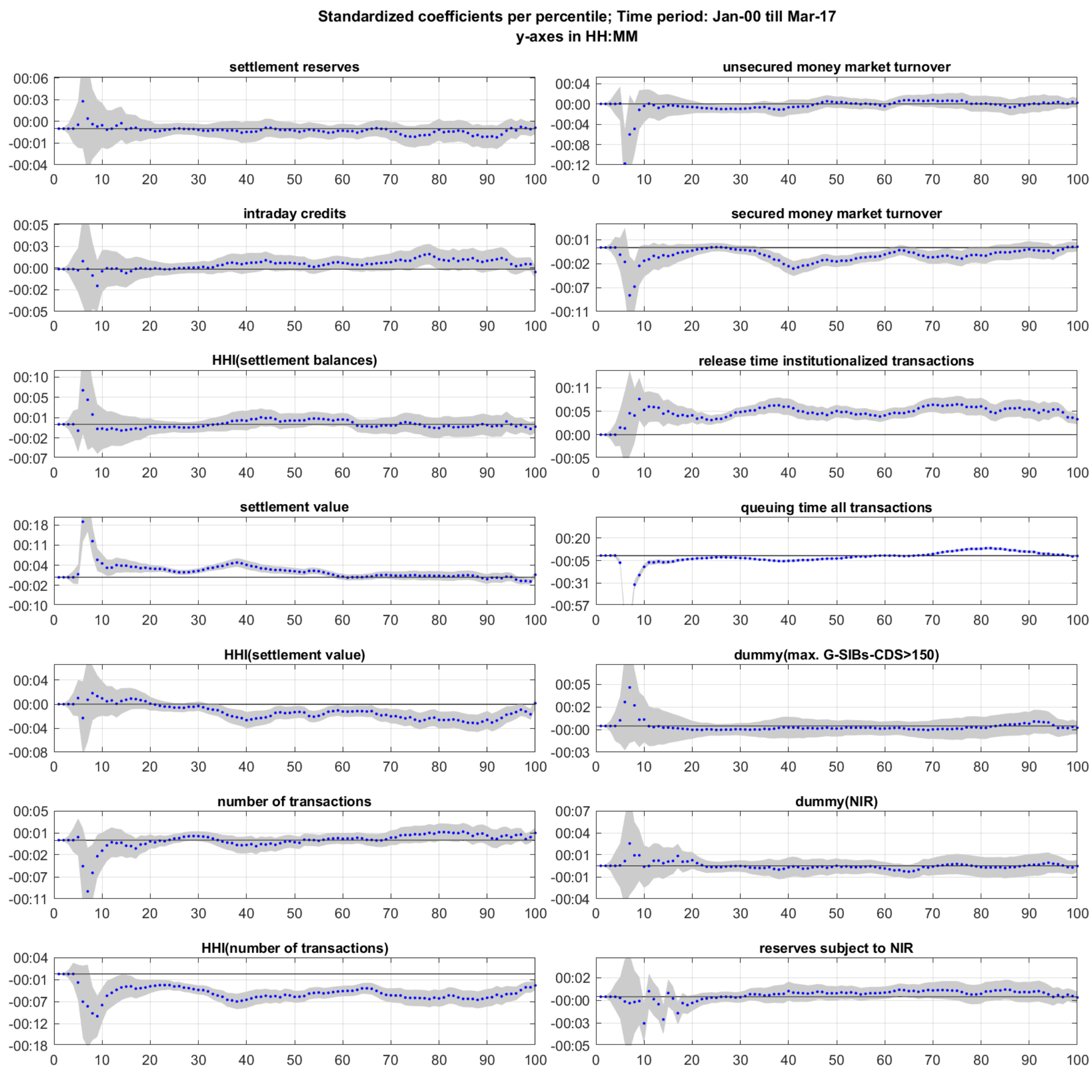
Notes: 20-day moving averages of the value-weighted average release times.

Figure 5: Percentage of different size subcategories in the total value of non-institutionalized payments



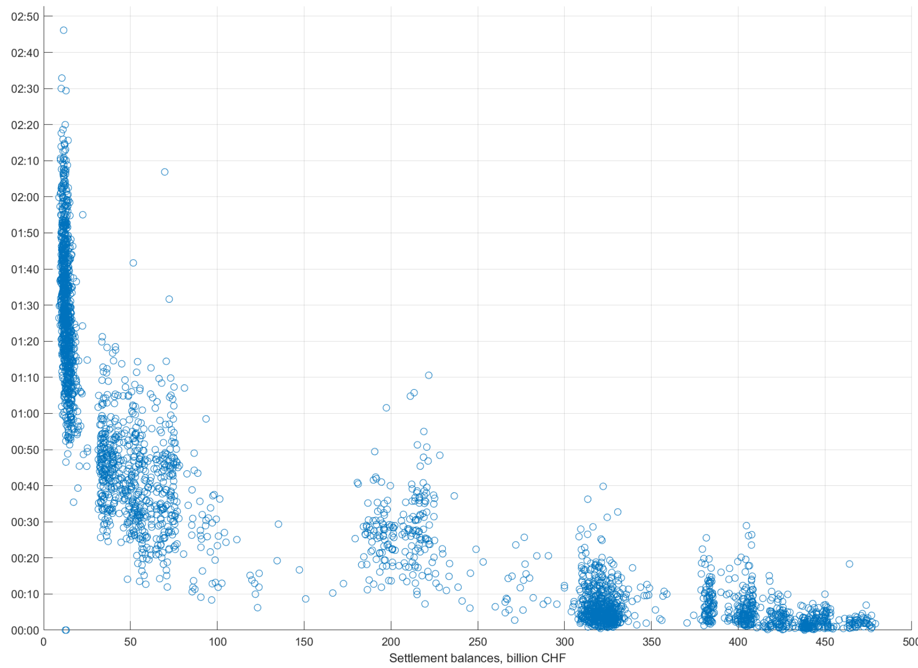
Notes: 20-day moving averages of percentage of different size subcategories in the total value of non-institutionalized payments

Figure 6: Regression results with release time of all non-institutionalized transactions as dependent variable



Notes: Blue dots show the point estimate; the grey area the 95% confidence interval; the y-axis shows the impact in hours and minutes. Reported are standardized coefficients and Newey-West corrected standard errors (maximum lag length of 10).

Figure 7: Scatterplot of QT(all) and SB



Notes: The y-axis displays the value-weighted average queuing time in hours and minutes. The scatterplot is daily from 2005 to April 2017. Considered are all payments (insitutionalized and non-institutionalized payments).

Appendix A - Tables

Table 1: Queuing regression for all payments

	Coeff.	Std. Err.	p-value
Δln(sb)	- 0.189	0.084	0.024
Δln(HHIsb)	- 0.069	0.035	0.047
Δln(sv)	0.327	0.048	0.000
Δln(HHIsv)	- 0.122	0.075	0.106
Δln(n)	- 0.100	0.044	0.022
Δln(HHIn)	- 0.026	0.124	0.835
Δln(r)	- 1.613	0.271	0.000
Δln(summ)	0.100	0.023	0.000
Δln(ssmm)	0.047	0.008	0.000
Δln(sxl)	0.142	0.052	0.006
Δln(sl)	0.856	0.289	0.003
Δln(s1st prio)	0.071	0.030	0.018
const.	- 0.000	0.007	0.992
No. of obs.	1646		
R^2	0.095		

Notes: Average value-weighted queuing time as dependent variable. Reported are Newey-West corrected standard errors.

Appendix B - Internet Appendix

Appendix B1 - Monetary Policy

The SNB conducts its monetary policy by steering the interest rate level in the Swiss franc money market. To this end, it uses the three-month Libor as its operational target and aims to keep the three-month Libor in a defined operational target range. Before the financial crisis in August 2007 and before the collapse of Lehman Borthers, the SNB provided reserves to the banking system via daily repo transactions, normally with a maturity of 1 week (Kraenzlin and Schlegel, 2012). With the collapse of Lehman Brothers in mid-September 2008, funding costs in the Swiss franc unsecured interbank money market increased sharply in line with other currencies. As a reaction to this, the SNB began providing its counterparties with a generous supply of reserves. From 28 October 2008 onwards, it started to fully allot all bids submitted in the daily repo auctions. As a result, the outstanding repo volume increased to CHF 65 billion in 2009.

In October 2008, the SNB jointly announced with the ECB and, subsequently, with the Narodowy Bank Polski (NBP) and the Magyar Nemzeti Bank (NMB) that it would indirectly distribute Swiss franc funds via EURCHF swaps with these central banks. The Swiss franc reserves provided via swaps with other central banks quickly reached a level of CHF 65billion. In mid-March 2009, the SNB announced unconventional measures to combat deflationary risks. The SNB started to conduct longer-term repo transactions, to purchase Swiss franc denominated bonds and to intervene in the foreign exchange market. With the foreign exchange interventions the SNB built up a foreign reserve position worth over CHF 200 billion by mid-2010, compared to a pre-2009 level of less than CHF 50 billion. In effect, the SNB provided the banking system with permanent reserves to an extent that the demand in the repo and EURCHF swap auctions ceased to exist altogether. As of 12 May 2010, the SNB discontinued its reserves-providing operations.

To control potential inflationary pressure of an increasing reserve level, from 2009 onwards, the SNB engaged in liquidity-absorbing operations. The SNB used a combination of reverse repos and SNB bills. Most liquidity was absorbed by means of SNB bills. Outstanding SNB bills reached a maximum level of CHF 117 billion in December 2010 and remained slightly below this level until August 2011.

In 2011, the European sovereign debt crisis intensified and – through the appreciation of the Swiss franc – exerted a strong deflationary pressure on the Swiss economy. To combat deflationary pressures, the SNB reversed liquidity-absorbing operations during August 2011. In addition to the ending of liquidity-absorbing operations, the SNB intervened in the FX market by means of outright purchases of foreign currency and foreign exchange swaps to further increase reserve levels (see Christensen and Krogstrup, 2015). As the pressure on the Swiss franc intensified further, the SNB installed a minimum exchange rate for the Swiss franc to the euro of 1.20 Swiss francs per euro on 6 Sepetember 2011. FX interventions necessary to support the minimum exchange rate regime led to subsequent increase in reserve levels to CHF 450 billions when the minimum exchange rate regime was discontinued on 15 January 2015 (see Mirkov et al., 2016).

Before the discontinuation, on 18 December 2014 and effective 22 January 2015, the SNB announced a rate cut of -0.25 into negative territory to additionally fight exchange rate pressure. Together with the discontinued minimum exchange rate on 15 January 2015, the SNB announced a further rate cut down to -0.75 with immediate effect (see Grisse et al., 2017). To implement negative interest rates, the SNB chose a tiered system. Reserve accounts are renumerated with zero interest below an exemption threshold. For account holders not subject to minimum reserve requirements, the exemption threshold was set to CHF 10 millon. For account holders subject to minimum reserve requirements the exemption threshold was set to twenty times the minimum reserve requirement. This resulted in an aggregate exemption threshold of approximately CHF 300 billions at the time. The aggegate exemption threshold has remained almost constant since then. Reserve holdings above the applicable exmption threshold are renumerated with -75bp. The negative interest rate policy remained effective as stated until the end of our sample in April 2017. Despite the negative interest rate policy on reserves, the pressure on the Swiss franc continued and the SNB was forced to engage in further FX interventions, leading to reserve levels of CHF 550 billions by the end of April 2017.

Appendix B2 - Financial crisis

The Swiss financial system was strongly affected by the financial crisis via two channels (see SNB, 2008 and 2009).

First, the two Swiss domiciled global systemically important banks (G-SIBs) UBS and Credit Suisse were both affected through huge write-downs caused by their structured financial product businesses linked to the U.S. residential real estate market. While UBS was more strongly affected during the financial crisis with total write downs of more than CHF 50 billion and three major capital increases necessary to remain in business, also Credit Suisse engaged in one major capital increase (see SNB, 2009). On 10 December 2007, UBS announced that it had taken measures to increase its capital base, including the issuance of a CHF 13 billion mandatory convertible bond to two investors. This and two other measures enabled UBS to increase its overall equity base by a total of CHF 19.4 billion. The amount of capital raised through these measures was higher than the write-downs that had been announced up to that time. Further write-downs in the first half of 2008 made another capital increase necessary. On 1 April 2008, UBS approached its shareholders and in June 2008 UBS was able to raise approximately CHF 15 billion in additional funds through a public capital increase. On 16 October 2008, the government announced a recapitalization of UBS by an amount of CHF 6 billion. On the same day, the SNB announced that it concluded an agreement with UBS and will establish a fund to acquire securities held by UBS in an amount of up to USD 60 billion to de-risk and reduce the balance sheet of UBS. A similar recapitalization offer was announced to be open to Credit Suisse. However, Credit Suisse announced a capital increase by private investors of CHF 10 billion on the same day. UBS' crisis was worsened when the U.S. Department of Justice and later the U.S. Securities and Exchange Commission informed that they had opened investigations into the bank's activities regarding alleged irregularities in its US cross-border business. However, UBS returned to profitability during the course of 2010 and 2011. On 15 September 2011, UBS announced that it had discovered unauthorized trading by a trader in its investment bank, resulting in a loss of USD 2.3 billion. Around the same time, the solvency of G-SIBs was generally questionned in the course of the European sovereign debt crisis. For instance, Credit Suisse went through a further capital increase in 2012. Together with other European G-SIBs, Credit Suisse had to make sizeable write downs in the course of 2015 and 2016. Similarly as with some other European G-SIBs, losses were related to its investment bank activities and the sustainability of the size of investment banking arms of some European G-SIBs was more generally questionned. As a consequence, Credit Suisse went through two further capital increases in the years 2015 and 2016[23].

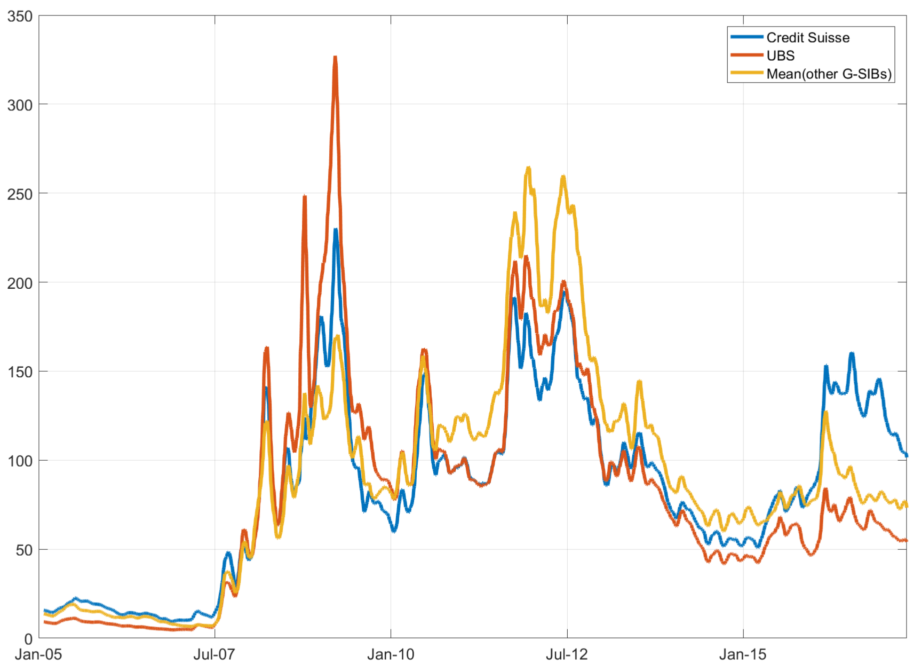
Second, Switzerland as a major financial center is home to branches of G-SIBs from around the world. Most of these G-SIBs were heavily affected by the financial crisis (see Figure 4a). Via their branches in Switzerland, most foreign G-SIBs participate in SIC. Other G-SIBs access SIC remotely from their branches in London and Frankfurt. In contrast to G-SIBs, the domestically oriented banking sector in Switzerland was left almost unaffected by the financial crisis (see Figure 4b). The same holds true for the subsequent European sovereign debt crisis that led to substantial increases in CDS premia of the two Swiss and of the foreign G-SIBs, but left the domestically oriented banking sector largely unaffected.

The average share in settlement value in SIC of domestic and foreign G-SIBs are considerable. While UBS and Credit Suisse are clearly the largest participants in SIC, foreign G-SIBs account for a relevant share of SIC's settlement value too.

[23]See the following media releases at https://www.credit-suisse.com/corporate/en/media/news.html: 18 August 2012; 21, 26 and 27 October 2015 and 19 and 23 November as well as 3 December 2015; 26, 27 and 28 April, 18 and 19 May 2017 and 7 June 2017.

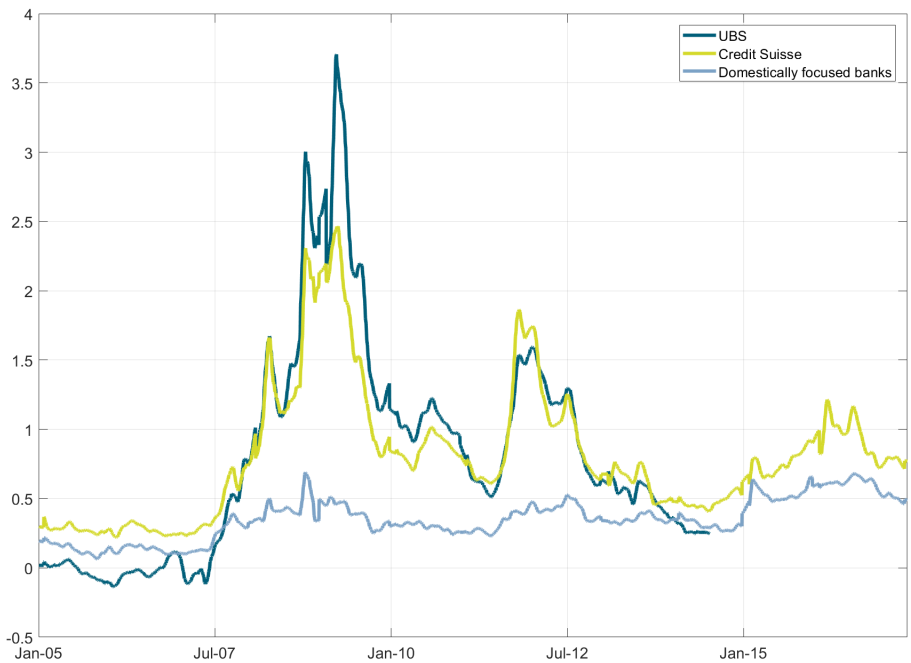
Figures B2.1: a) 5Y CDS premia of UBS, Credit Suisse and G-SIBs from 2006 to April 2017; b) bond spreads of UBS and Credit Suisse and domestically oriented Swiss banks from 2006 to April 2017

a) 5Y CDS premia of UBS, Credit Suisse and G-SIBS from 2006 to April 2017



Notes: Data Source Bloomberg. Author calculations. CDS spread of G-SIBs is calculated as a simple average. All CDS spreads are displayed as 20-day moving averages.

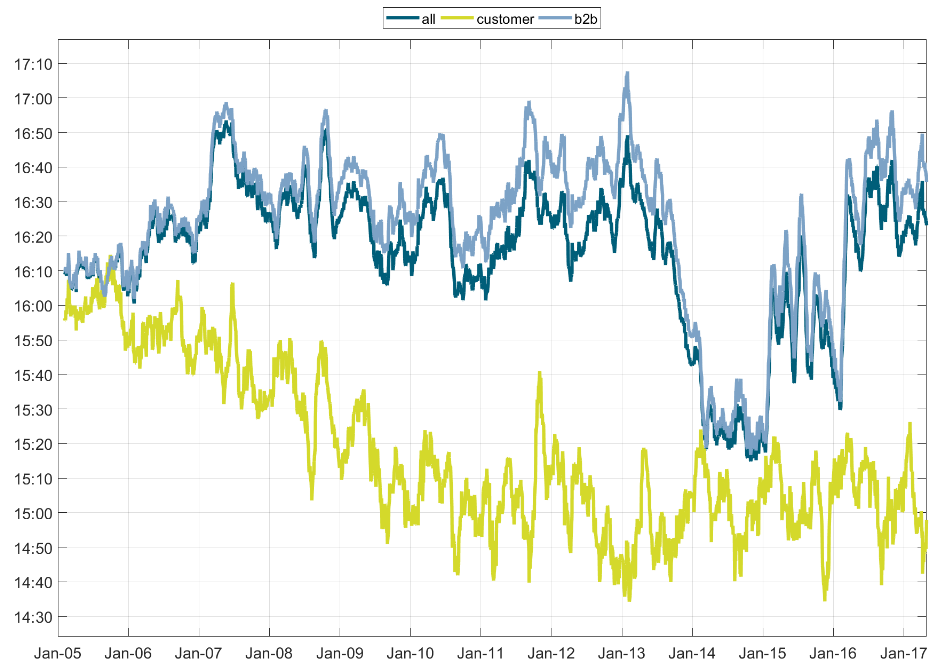
b) Bond spread of UBS, CS and domestically focused banks



Notes: Data source SNB. Authors' calculation. Bond spreads are calculated as simple averages of spreads of 2 to 8 year maturity bonds to the same maturity of government bonds. The spread of domestically focused banks is calculated as a simple average over all banks in this category. All bond spreads are displayed as 20-day moving averages.

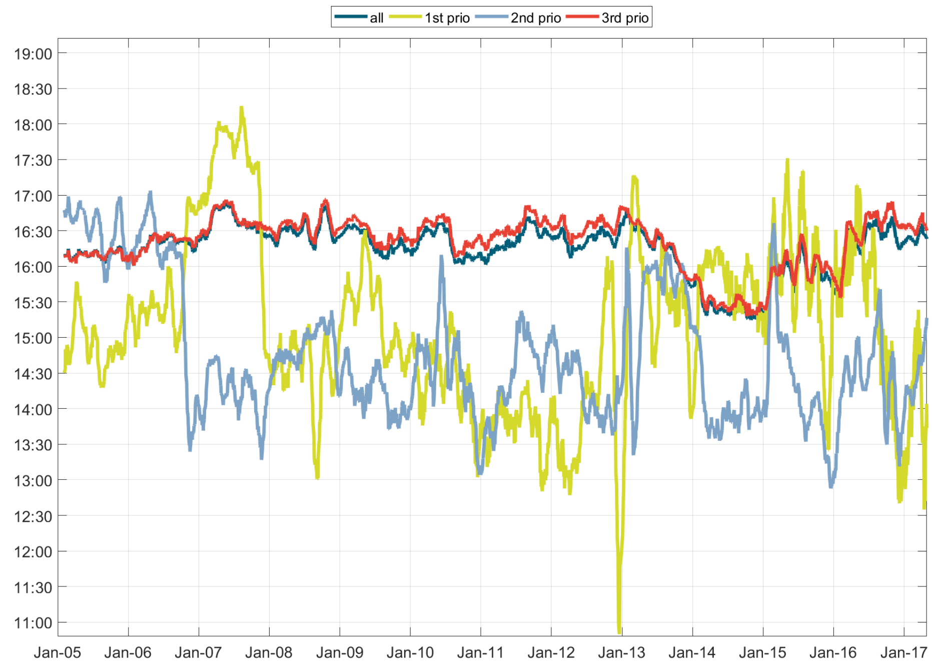
Appendix B3 - Figures

Figure B3.1: RT(ni, all) and RT(ni, purpose)



Notes: 20-day moving averages of the value-weighted average release time of all payments and the different purpose subcategories.

Figure B3.2: RT(ni, all) and RT(ni, priority)



Notes: 20-day moving averages of the value-weighted average release time of all payments and the different priority subcategories.

Appendix B4 - Descriptive statistics

Table B4.1: Descriptive statistics of explanatory variables for the release time regressions

	mean	min	P5	median	P90	max	std. dev.
sr	170.82	2.83	4.45	65.64	440.40	477.54	168.77
ic	4.77	0.10	1.00	5.68	9.48	14.43	3.07
HHI(sb)	0.07	0.03	0.04	0.05	0.13	1.00	0.06
sv	112.19	42.02	71.88	107.44	168.01	267.13	30.36
HHI(sv)	0.15	0.00	0.12	0.15	0.17	0.25	0.02
n	92.43	35.25	66.69	84.47	153.32	400.56	30.82
HHI(n)	0.08	0.00	0.07	0.08	0.09	0.12	0.01
umm	4.56	0.07	0.31	3.91	9.61	13.33	2.98
smm	1.43	0.00	0.11	1.15	3.62	10.64	1.22
r(i)	0.58	0.00	0.49	0.59	0.64	0.72	0.05
q(all)	0.03	0.00	0.00	0.02	0.07	0.70	0.03
CDSX	0.31	0.00	0.00	0.00	1.00	1.00	0.46
NIR	0.19	0.00	0.00	0.00	1.00	1.00	0.39
RS2N	23.55	0.00	0.00	0.00	146.96	185.67	50.63

Notes: Units in CHF are shown in CHF billion; number of payments in 1000; release time in hours after beginning of day; queuing time in hours.

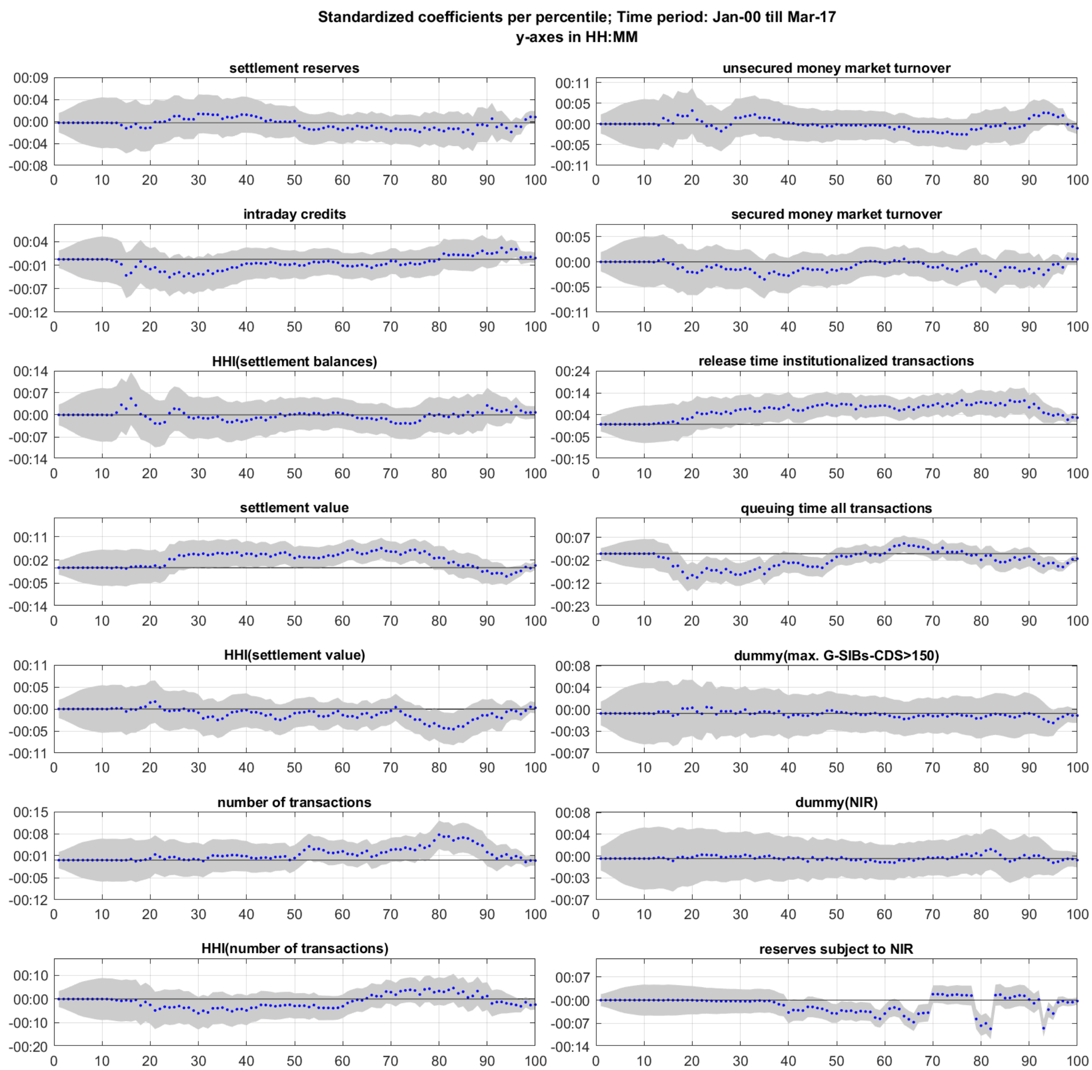
Table B4.2: Descriptive statistics of explanatory varaiables for the queing time regressions

	mean	min	P5	median	P90	max	std.dev.
sb	175.47	9.55	11.17	72.59	441.37	479.04	165.89
HHI(sb)	0.07	0.03	0.04	0.05	0.13	1.00	0.06
sv	112.19	42.02	71.88	107.44	168.01	267.13	30.36
HHI(sv)	0.15	0.00	0.12	0.15	0.17	0.25	0.02
n	92.43	35.25	66.69	84.47	153.32	400.56	30.82
HHI(n)	0.08	0.00	0.07	0.08	0.09	0.12	0.01
r(all)	0.66	0.00	0.62	0.66	0.69	0.71	0.02
summ	0.04	0.00	0.00	0.04	0.08	0.10	0.02
ssmm	0.01	0.00	0.00	0.01	0.03	0.09	0.01
sxl	0.13	0.04	0.07	0.12	0.18	0.32	0.03
sl	0.72	0.50	0.64	0.72	0.77	0.83	0.04
s1st prio	0.04	0.01	0.02	0.04	0.09	0.14	0.02

Notes: Units in CHF are shown in CHF billion; number of payments in 1000; release time in hours after beginning of day; queuing time in hours.

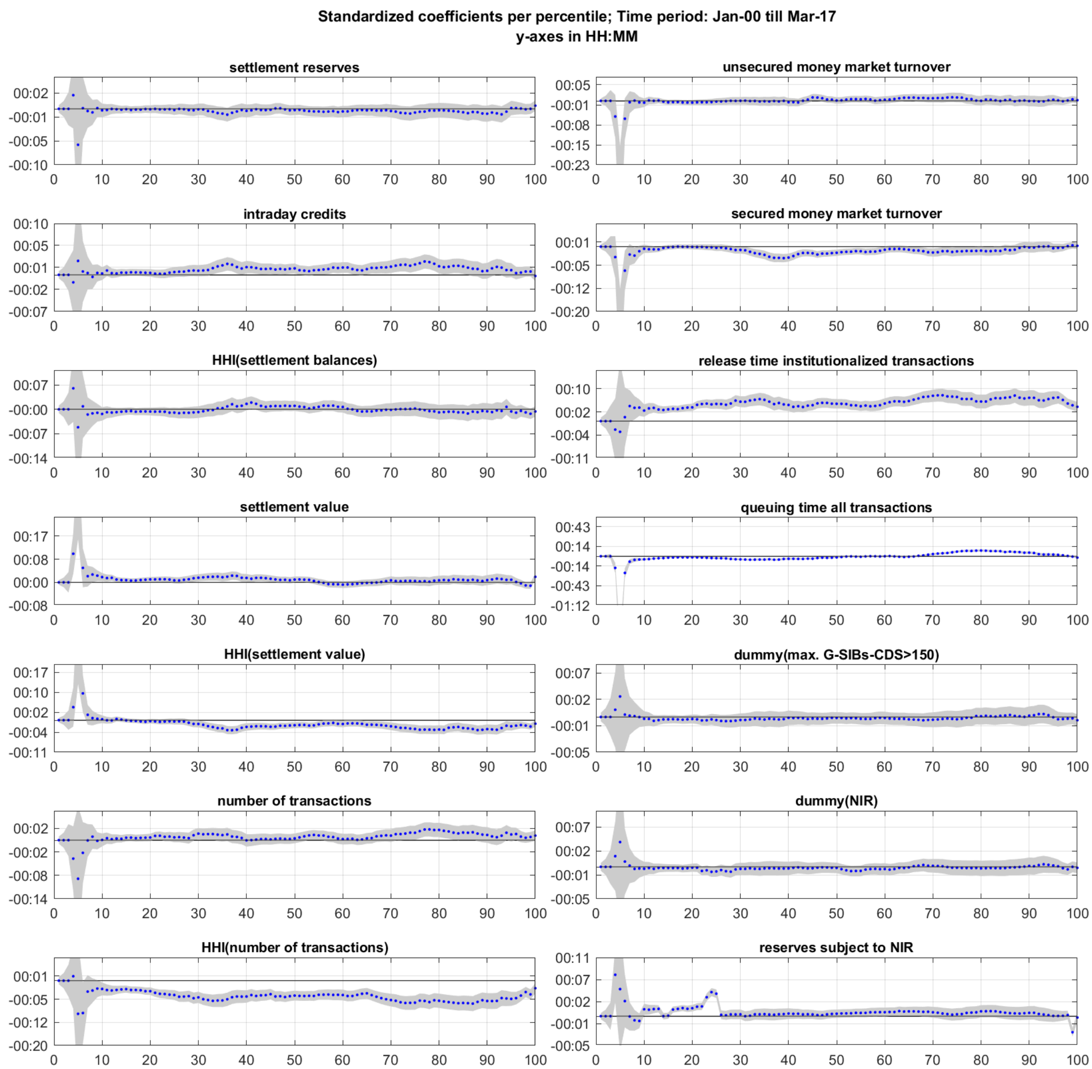
Appendix B5 - Release Regressions

Figure B5.1: Regression results with release time of very large non-institutionalized transactions as dependent variable



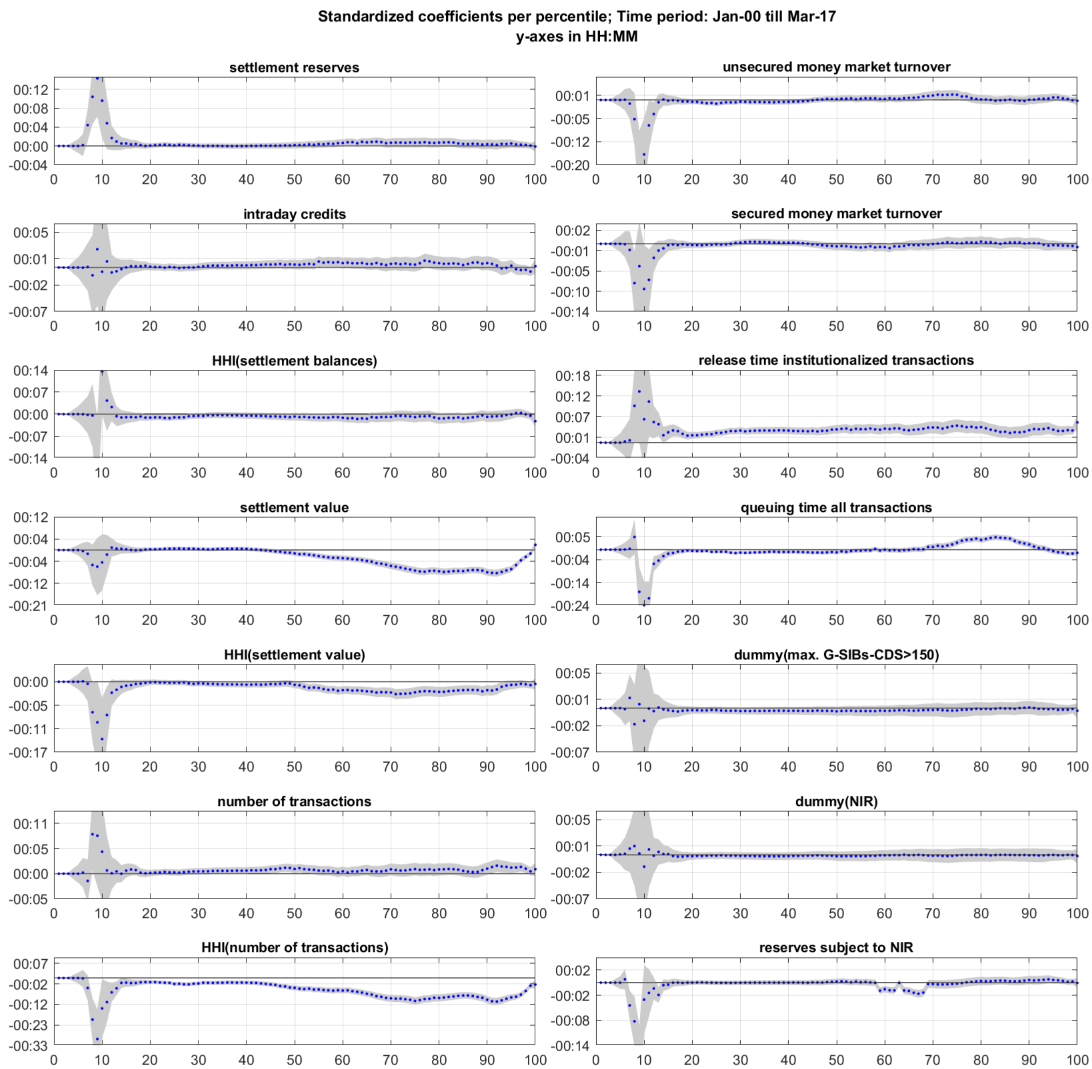
Notes: Blue dots show the point estimate; the grey area the 95% confidence interval; the y-axis shows the impact in hours and minutes. Reported are standardized coefficients and Newey-West corrected standard errors (maximum lag length of 10).

Figure B5.2: Regression results with release time of large non-institutionalized transactions as dependent variable



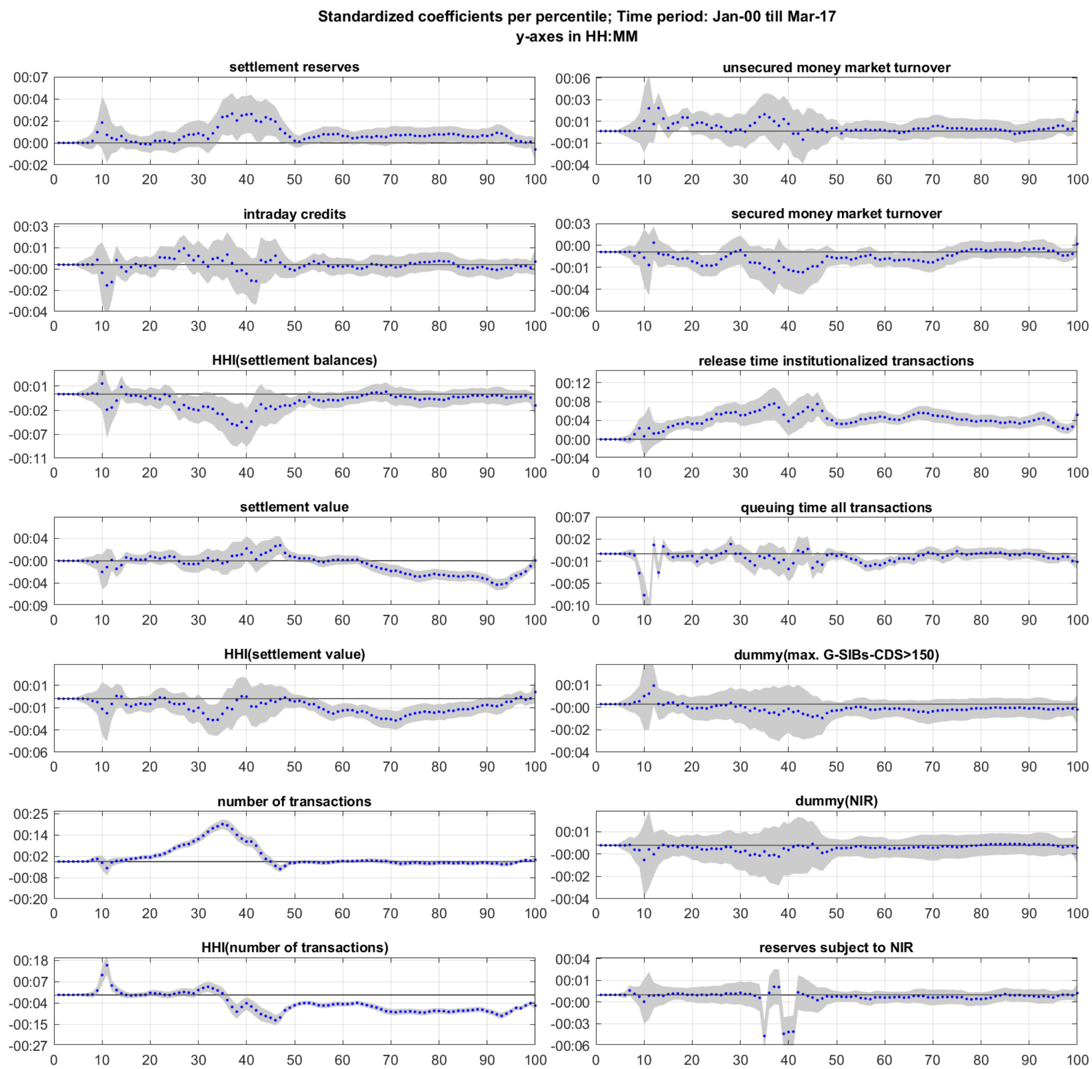
Notes: Blue dots show the point estimate; the grey area the 95% confidence interval; the y-axis shows the impact in hours and minutes. Reported are standardized coefficients and Newey-West corrected standard errors (maximum lag length of 10).

Figure B5.3: Regression results with release time of medium non-institutionalized transactions as dependent variable



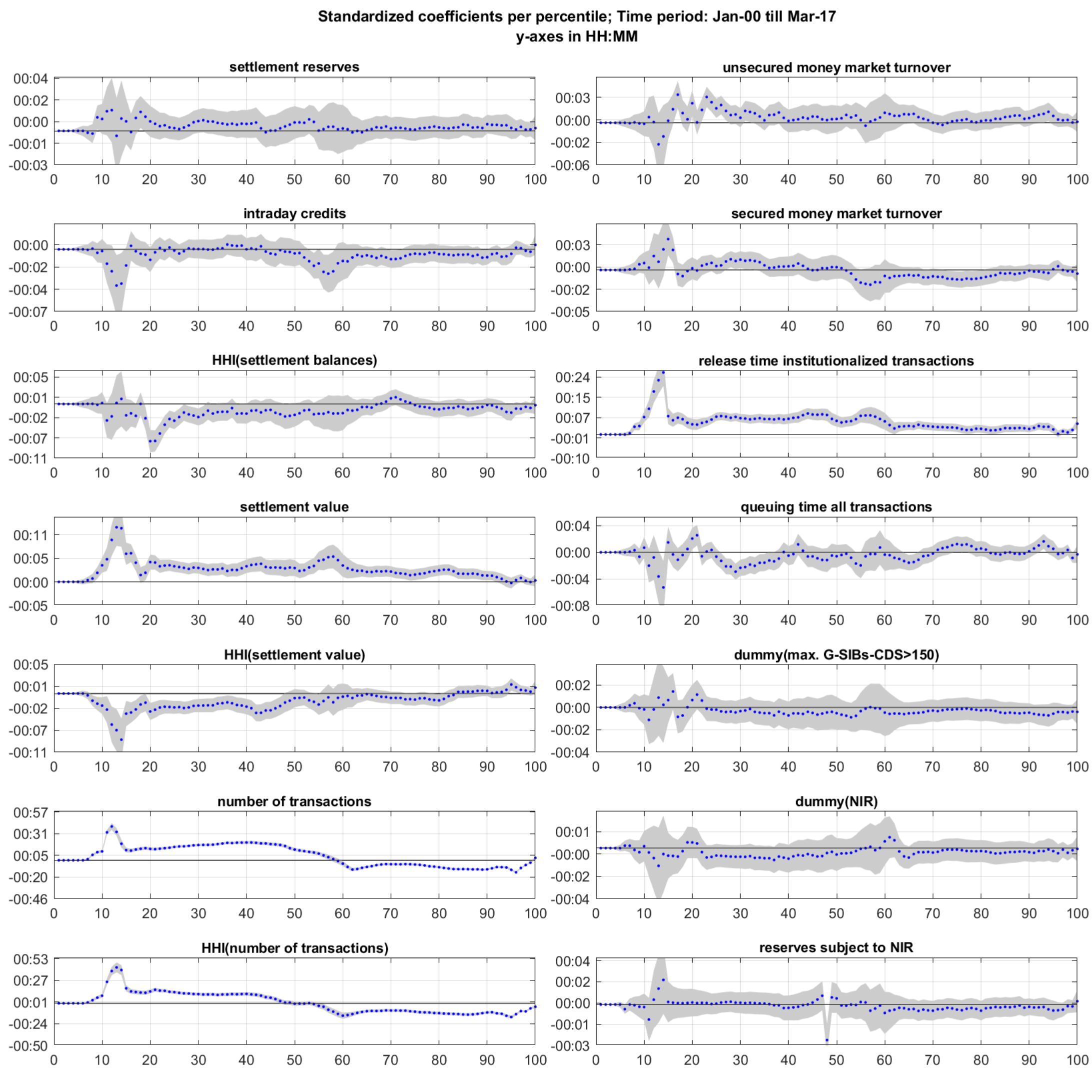
Notes: Blue dots show the point estimate; the grey area the 95% confidence interval; the y-axis shows the impact in hours and minutes. Reported are standardized coefficients and Newey-West corrected standard errors (maximum lag length of 10).

Figure B5.4: Regression results with release time of small non-institutionalized transactions as dependent variable

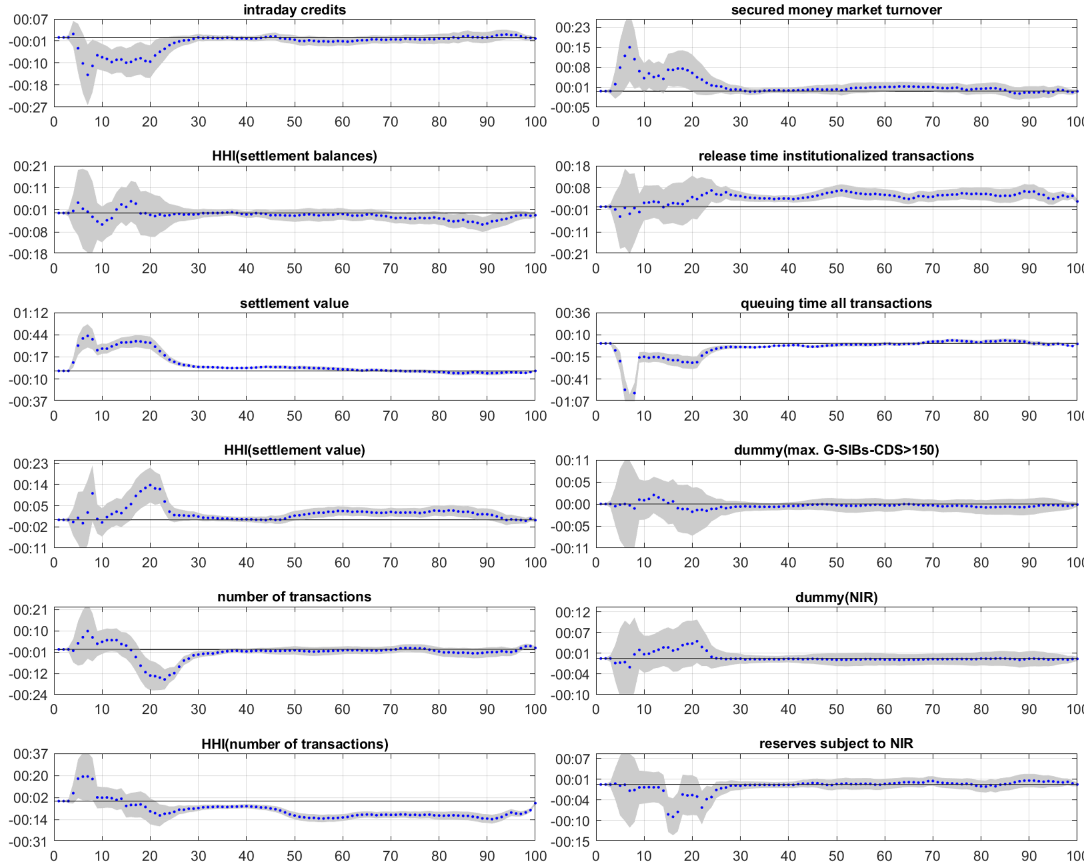


Notes: Blue dots show the point estimate; the grey area the 95% confidence interval; the y-axis shows the impact in hours and minutes. Reported are standardized coefficients and Newey-West corrected standard errors (maximum lag length of 10).

Figure B5.5: Regression results with release time of very small non-institutionalized transactions as dependent variable

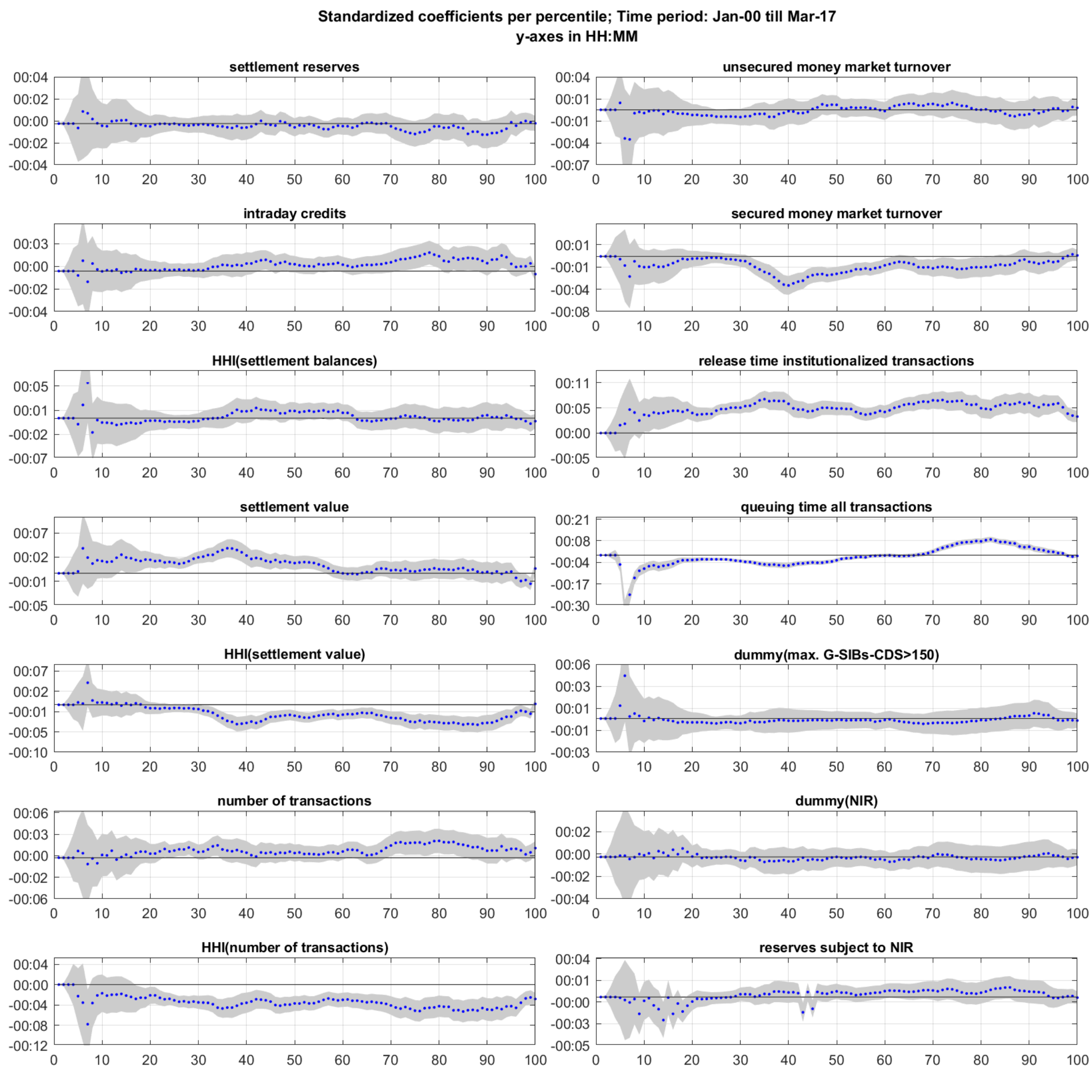


Notes: Blue dots show the point estimate; the grey area the 95% confidence interval; the y-axis shows the impact in hours and minutes. Reported are standardized coefficients and Newey-West corrected standard errors (maximum lag length of 10).



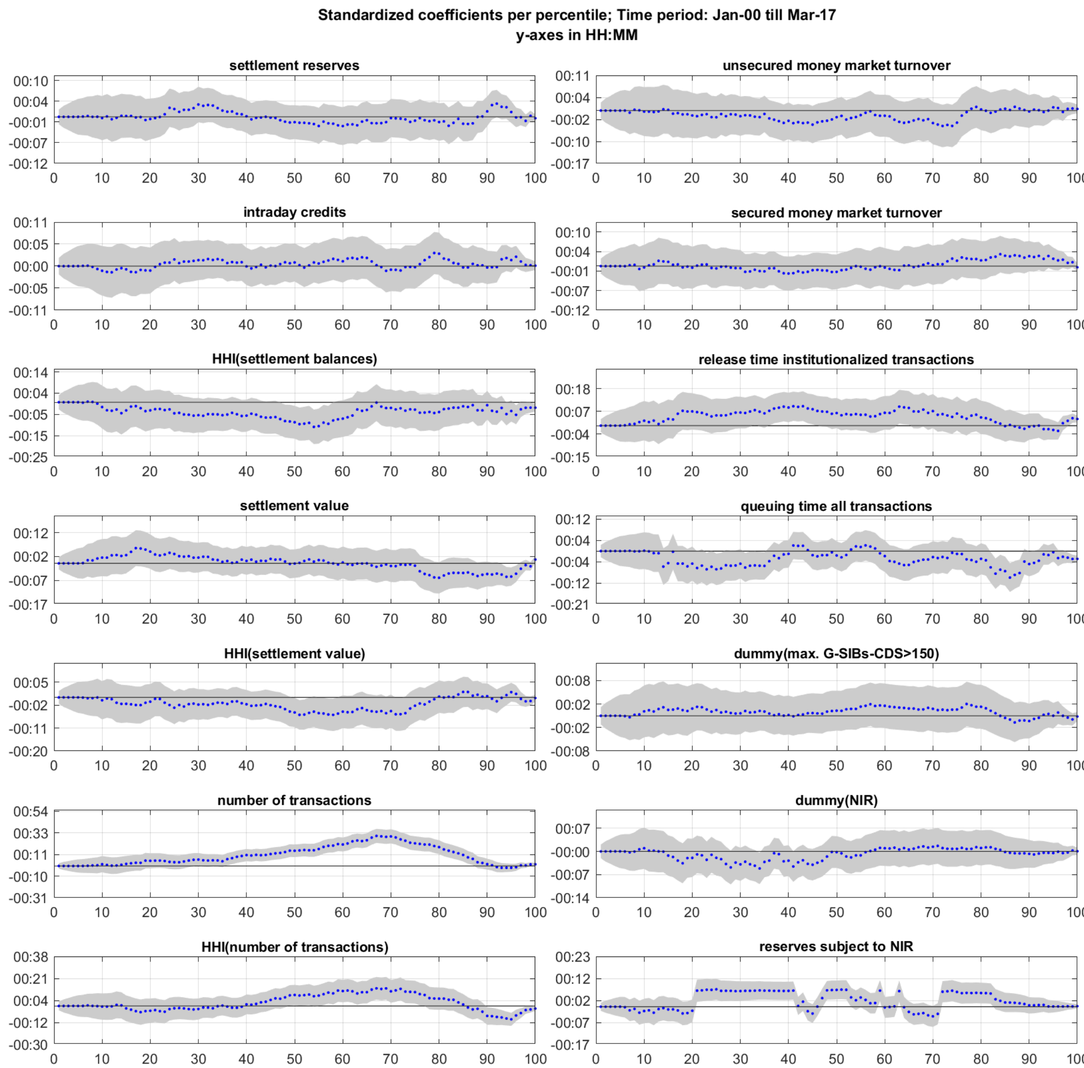
Notes: Blue dots show the point estimate; the grey area the 95% confidence interval; the y-axis shows the impact in hours and minutes. Reported are standardized coefficients and Newey-West corrected standard errors (maximum lag length of 10).

Figure B5.7: Regression results with release time of non-institutionalized b2b transactions as dependent variable



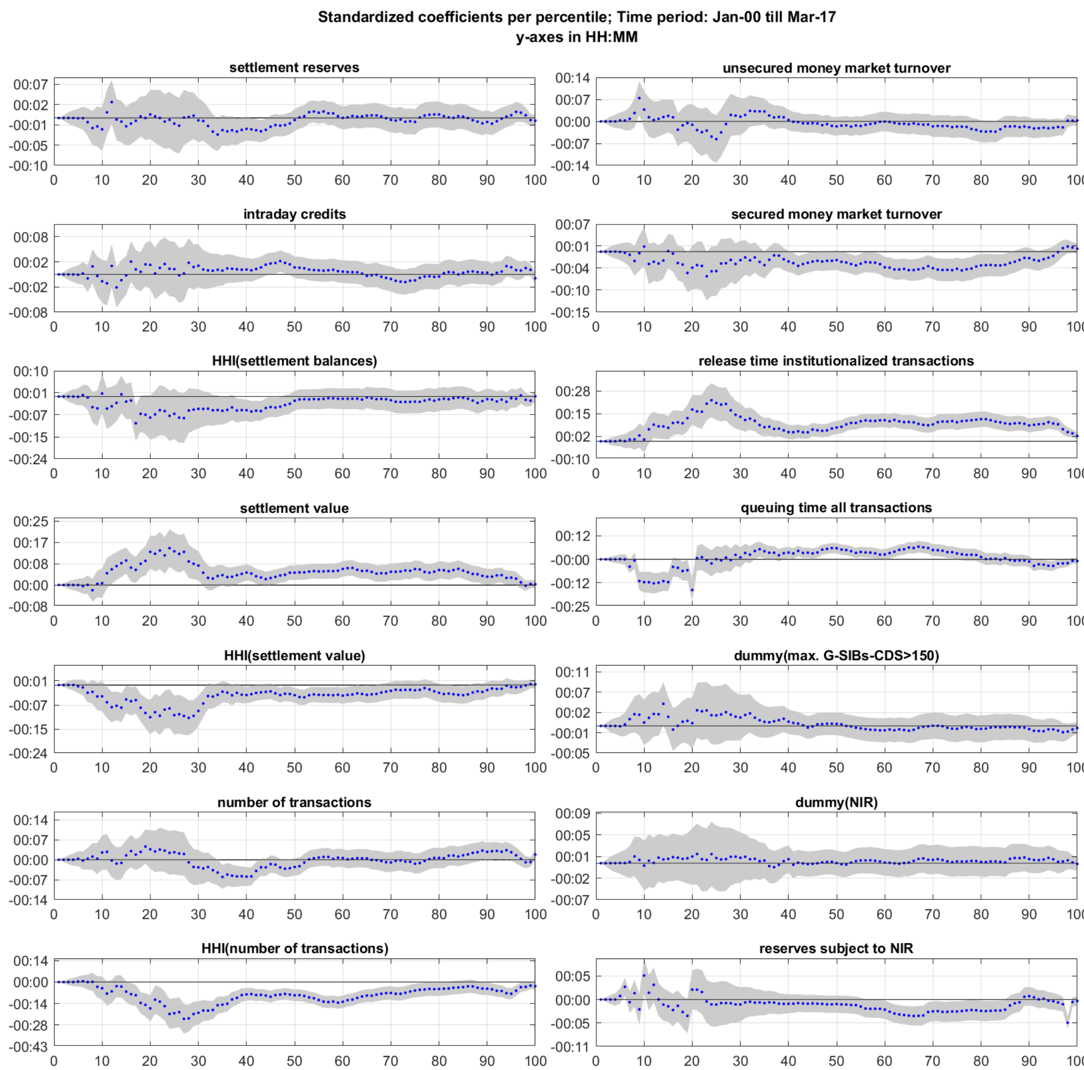
Notes: Blue dots show the point estimate; the grey area the 95% confidence interval; the y-axis shows the impact in hours and minutes. Reported are standardized coefficients and Newey-West corrected standard errors (maximum lag length of 10).

Figure B5.8: Regression results with release time of non-institutionalized urgent (1) transactions as dependent variable



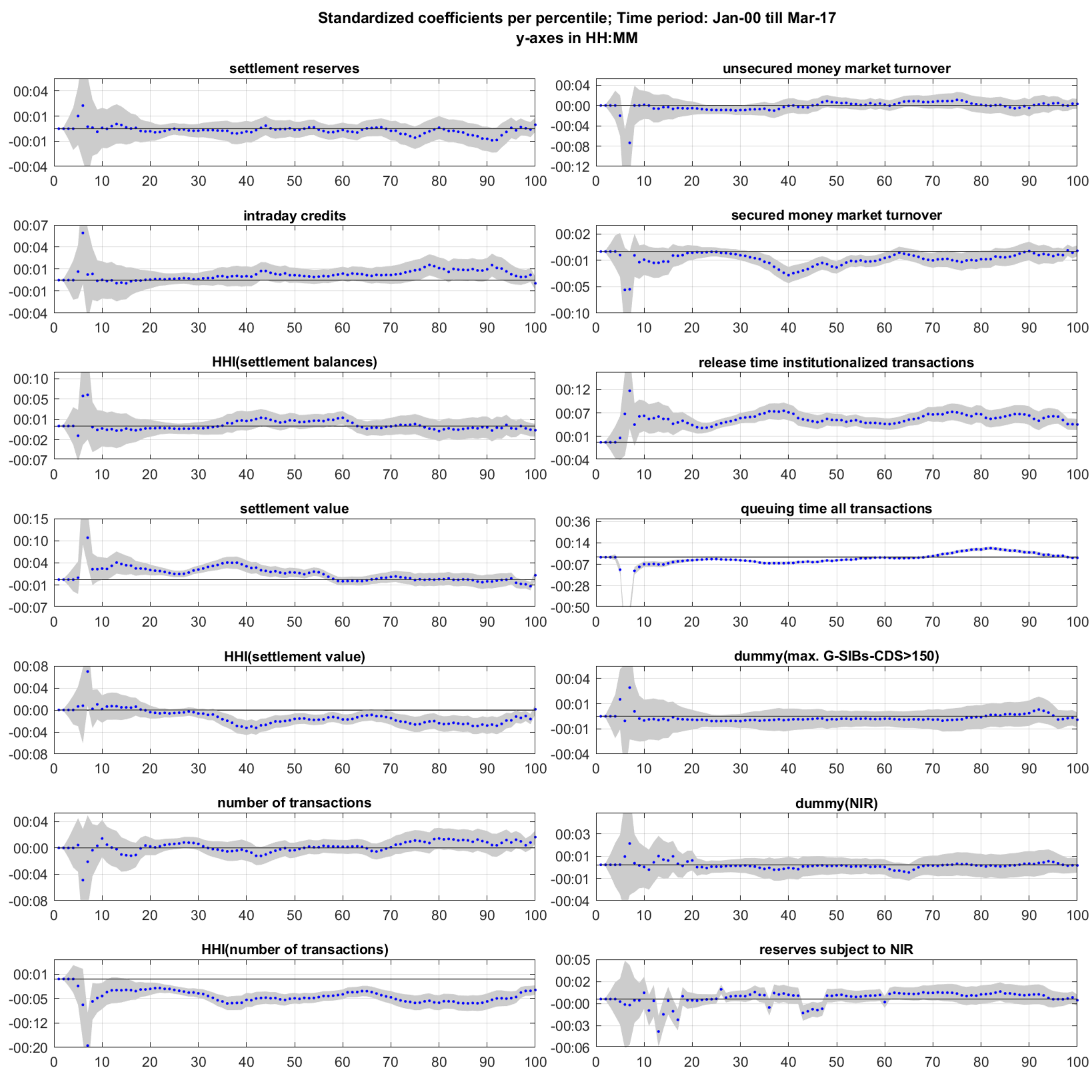
Notes: Blue dots show the point estimate; the grey area the 95% confidence interval; the y-axis shows the impact in hours and minutes. Reported are standardized coefficients and Newey-West corrected standard errors (maximum lag length of 10).

Figure B5.9: Regression results with release time of non-institutionalized less urgent (2) as dependent variable



Notes: Blue dots show the point estimate; the grey area the 95% confidence interval; the y-axis shows the impact in hours and minutes. Reported are standardized coefficients and Newey-West corrected standard errors (maximum lag length of 10).

Figure B5.10: Regression results with release time of non-institutionalized least urgent (3) transactions as dependent variable



Notes: Blue dots show the point estimate; the grey area the 95% confidence interval; the y-axis shows the impact in hours and minutes. Reported are standardized coefficients and Newey-West corrected standard errors (maximum lag length of 10).

References

[1] Auer,Raphael and Sébastien Kraenzlin (2011). International liquidity provision during the financial crisis: a view from Switzerland. Federal Reserv Bank St.Louis Rev. 93 (November/December(6)),409–418.

[2] Berentsen Aleksander, Sébastien Kraenzlin and Benjamin Müller (2015). Exit strategies and trade dynamics in repo markets. SNB Working Paper Series 2015-09.

[3] Christensen, Jens H.E. and Signe Krogstrup (2015). Transmission of Quantitative Easing: The Role of Central Bank Reserves. SNB Working Papers 2015-06, Swiss National Bank.

[4] Grisse, Christian, Signe Krogstrup, and Silvio Schumacher (2017). Lower bound beliefs and long-term interest rates. SNB Working Papers 2017-05, Swiss National Bank.

[5] Guggenheim, B., S. Kraenzlin and S. Schumacher (2011). Exploring an uncharted market: Evidence on the unsecured Swiss franc money market. Aussenwirtschaft, Vol. 66, 59-87.

[6] Kraenzlin, Sébastien, and Thomas Nellen (2010). Daytime is money. Journal of Money, Credit and Banking, 42(8), 1689—1702.

[7] Kraenzlin, Sébastien, and Martin Schlegel (2012). Bidding behavior in the SNB's repo auctions. Journal of International Money and Finance, 31,170–188.

[8] Kraenzlin, Sébastien, and Thomas Nellen (2015). Access policy and money market segmentation. Journal of Monetary Economics, 71, 1-12.

[9] Mirkov, Nikola, Igor Pozdeev and Paul Söderlind (2016). Toward Removal of the Swiss Franc Cap: Market Expectations and Verbal Interventions. SNB Working Paper 2016-10, Swiss National Bank.

[10] Nellen, Thomas (2015). Collateralized liquidity, two-part tariff and settlement coordination. SNB Working Paper 2015-13.

[11] Swiss National Bank (2008). Financial Stability Review. Swiss National Bank.

[12] Swiss National Bank (2009). Financial Stability Review. Swiss National Bank.