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Abstract

Real-time gross settlement (RTGS) systems effect final settlement of payments continuously and on an individual basis. This generates a trade-off between liquidity needs and settlement delay. Against the background of reconstruction discussions, the paper analyses whether more advanced algorithms reduce liquidity needs and settlement delay if applied to the Swiss Interbank Clearing (SIC) system. Simulations run with the BoF-PSS2 simulator show that expected reductions in liquidity needs and settlement delay are modest and should carefully be evaluated against costs. More advanced settlement algorithms improve settlement efficiency only if payment release behaviour is highly aligned.

JEL-Codes: C63, E42, G18

Keywords: payment system, simulation, payment splitting, liquidity-saving mechanisms

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[c] The views expressed in this paper are those of the authors and do not necessary represent those of the Swiss National Bank.

1. Introduction

Technological innovation, globalization and central bank policies have affected the design of payment systems significantly.[1] In the last three decades, real-time gross settlement (RTGS) systems have emerged and replaced deferred net settlement (DNS) systems.[2] This development can be understood as a response to the growing awareness of systemic risk present in DNS systems.[3] In contrast to DNS systems that accumulate incoming and outgoing payments and settle the net amount at a later, predetermined time, RTGS systems effect final settlement of interbank payments continuously and individually throughout the day.

While final intraday settlement reduces credit risks, this comes at the cost of increased liquidity risks. In particular, RTGS systems are more liquidity-intensive than DNS systems. Thus, participants in RTGS systems face a trade-off between the cost of liquidity and the cost of settlement delay. To ease this trade-off, central banks have typically introduced intraday liquidity facilities, meant to provide inexpensive liquidity mostly granted free of interest and on a collateralised basis.[4] Some central banks apply additional measures such as through-put rules or two-part tariffs that incentivise early release and settlement of payments.[5] To further reduce liquidity needs and speed up settlement, central banks have introduced more advanced settlement algorithms - the basic first-in first-out (FIFO) algorithm has steadily been enriched by more sophisticated features ranging from simple queuing, packet building and payment priorities to more advanced features such as payment splitting rules, bilateral and multilateral offsetting.[6]

The Swiss Interbank Clearing (SIC) system went into service in 1987 and has been operating ever since on the basis of central queuing. At first, payments were settled according to a strict FIFO rule and no intraday liquidity facility was provided by the Swiss National Bank (SNB). After minimum reserve requirements were changed in 1988, average reserve balances held by participants overnight dropped dramatically. As a reaction to increased settlement delay, the SNB introduced a two-part tariff and participants together with the SNB agreed to voluntarily split payments that exceed CHF 100 Mio.[7] To allow for faster settlement of time critical payments, priorities can be attached to urgent payments since 1994. While the introduction of priorities was related to the upcoming delivery-versus-payment (DVP) link to the securities settlement system implemented in 1995, the introduction of free and collateralised intraday credit in 1999 was motivated by the planned introduction of Continuous Linked Settlement (CLS) that was expected to require substantial amounts of intraday liquidity during CLS settlement times. In 2001, SIC introduced a gridlock[8]

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[1] For a review on the global trends in large-value payments see Bech, Preisig and Soramäki (2008).

[2] See Bech and Hobijn (2007).

[3] See Bank for International Settlements (BIS) (1997, 2005).

[4] See World Bank (2011) for a survey of RTGS systems worldwide.

[5] Whereas through-put rules stipulate the proportion of daily payments that must be settled by a certain cut-off time, two-part tariffs provide incentive for early release and settlement through time-dependent tariffs.

[6] RTGS systems with bilateral or multilateral offsetting algorithms are sometimes referred to as hybrid payment systems since they combine features of RTGS and DNS systems.

[7] Nevertheless, participants frequently settle payments exceeding CHF 100 million.

[8] Gridlock refers to a situation where all payments in a payment system are blocked due to insufficient liquidity with some participants but where in aggregate there is enough liquidity to settle the end of day net amount.

resolution mechanism that bilaterally offsets payments in case SIC cannot settle for a certain period of time.

At the time of writing, discussions on a reconstruction of SIC take place. One of the issues raised is whether or not the settlement algorithm should be enhanced by liquidity-saving mechanisms. We analyse this question by simulating alternative algorithms based on “Priorities and FIFO”, “Bilateral Offsetting”, “Multilateral Netting” and “Mandatory Splitting”. For the simulations, we rely on real payment data and on the effectively chosen levels of liquidity during February 2007. This allows us to directly compare resulting settlement delay and liquidity usage with the settlement performance of SIC. In doing so, we implicitly assume that participants’ release behaviour and liquidity provision remain constant if a new algorithm is implemented.

We find that more advanced algorithms improve the trade-off between liquidity and settlement delay. In particular, settlement delay is reduced with the same level of available liquidity and, as idle liquidity increases with more advanced algorithms, less reserves are required as precautionary liquidity. However, the reduction of settlement delay is assessed to be economically irrelevant (1.7 minutes per payment) and the potential reduction of idle liquidity holdings (CHF 274 million daily) translates into low cost savings (CHF 73,800 yearly). Thus, development, adoption and operational costs should be carefully weighed against potentially low benefits when considering the introduction of an advanced algorithm. This complements findings of similar studies for other payment systems.

Section 2 sets out the theoretical framework and reviews the literature on payment system simulations. Additionally, we describe SIC’s settlement algorithm in the context of other major RTGS systems. Section 3 provides a descriptive analysis of settlement and liquidity in SIC. Section 4 presents the data and the methodology applied. Based on the simulation results presented in Section 5, a cost-benefit analysis is conducted in Section 6. The last section closes with concluding remarks.

2. Theoretical framework for simulations

2.1 Trade-off between liquidity and settlement delay

A precondition for the settlement of a payment in RTGS systems is sufficient funding. In case of insufficient funds, released payments cannot be settled immediately.[9] However, holding sufficient liquidity is costly. For instance, reserves held overnight on central bank accounts may yield a lower overnight interest rate than if lent or invested. Intraday liquidity is costly too. The central bank determines the cost of intraday liquidity either as an interest rate charged for an uncollateralised overdraft (as applied by the Federal Reserve System) or as the opportunity cost of eligible collateral that has to be pledged for an interest free intraday credit (as applied by the Bank of England (BoE), the Eurosystem and the SNB).[10]

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[9] Depending on the system’s design, payments are either rejected and have to be resubmitted or payments are placed in a queue where they are pending until sufficient funding is provided

[10] Usually, central banks reduce the cost of liquidity by allowing banks as payment system participants to use overnight balances held to fulfil minimum reserve requirements for settlement purposes. The central bank may further seek to reduce the opportunity cost of collateral by accepting a wide range of collateral. Allowing

A participant can reuse liquidity from incoming payments as a free source of funding for its own payments. This incentivises participants to save liquidity costs by delaying their own payments and waiting for incoming payments to fund them. The negative externalities associated with free riding on other participants' liquidity can cause settlement delays. If all participants follow this strategy, they end up delaying payments excessively. As pointed out by Angelini (1998), delayed information on incoming payments increases uncertainty with regard to the end-of-day position and makes liquidity managers hold greater levels of precautionary reserves than they would hold with more precise information on their end-of-day positions. In addition, delayed settlement may involve pecuniary - such as late settlement fees - or non-pecuniary delay costs - such as the deterioration of a participant's reputation as a reliable trading partner. Furthermore, excessive delay increases settlement risks as a consequence, for instance, of an operational incident. Given this trade-off between liquidity and settlement delay, central banks try to induce participants to provide more liquidity and reduce settlement delay by various instruments and policies, such as providing collateralised but free intraday credit, two-part tariffs or through-put rules.[11]

Participants that trade-off the optimal level of liquidity and settlement delay are restricted by the payment system's transformation curve which is determined by the settlement algorithm chosen. The technical transformation curve is represented in part (a) of Figure 1 by the convex curve AA′.[12] Point A represents a DNS system that settles multilaterally netted amounts at the end of day. As such it is defined as the minimum liquidity necessary to settle all payments at the end of the day with maximum possible delay (lower bound liquidity level). In contrast, RTGS systems can reduce the overall settlement delay but require additional (intraday) liquidity. Point A′ represents the necessary liquidity level to achieve immediate settlement of all payments (upper bound liquidity level). RTGS systems usually operate somewhere between the two extremes of the technical transformation curve. Understanding this as a cost minimisation problem, participants try to equilibrate the marginal cost of liquidity and delay (as represented by the dashed slope of liquidity cost over delay cost) with the technical rate of substitution. Suppose participants initially end up at point B. If liquidity costs soar (drop), we would expect participants to reduce (increase) their liquidity holdings leading to more (less) delay, moving away from point B up (down) the technical transformation curve.

By equipping the settlement algorithm with more advanced features such as bilateral or multilateral payments offsetting may improve the trade-off between liquidity and delay - shifting the transformation curve from AA′ to AA″. As a consequence, participants will choose an equilibrium on the new transformation curve AA″. Martin and McAndrews (2008) show that such a change in the settlement algorithms bears feedback effects as a new algorithm affects participants' settlement behaviour. As a consequence, it is difficult to predict what the new equilibrium and its welfare effects may look like if the settlement algorithm is changed. For instance, simply assuming that the

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banks to use liquidity buffers required by bank regulation as eligible collateral for intraday credits – known as double duty – can further reduce the opportunity costs of collateral. See Ball, Denbee, Manning and Wetherilt (2011) and Nellen (2013).

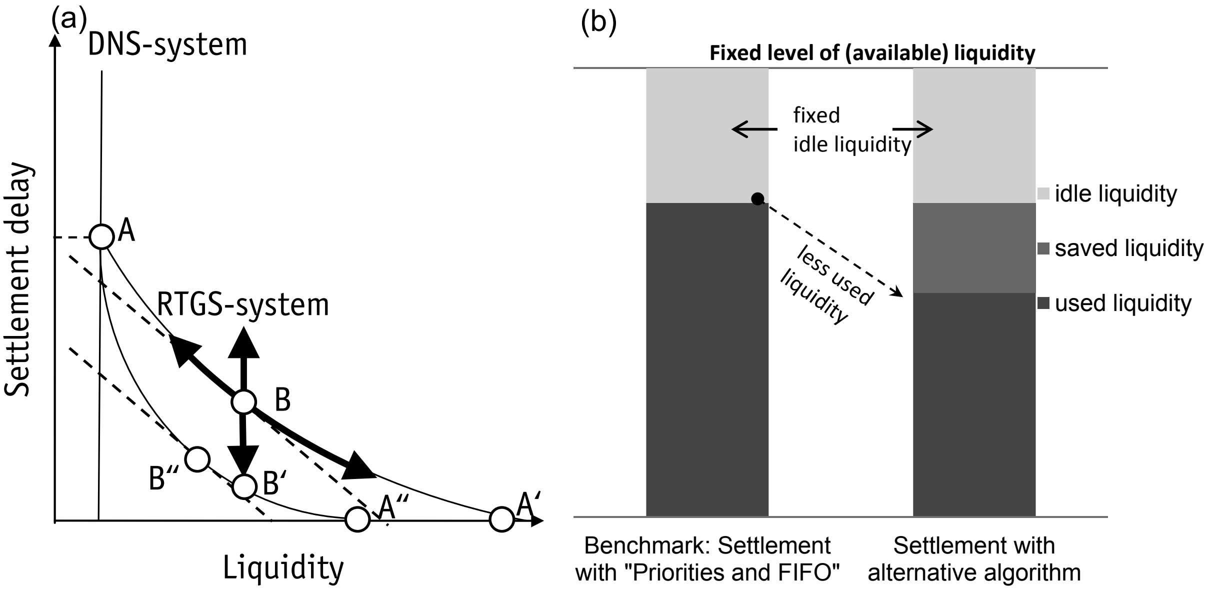
[11] While the SNB fosters early release and settlement in SIC by means of a two-part tariff, the BoE induces early release and settlement in CHAPS, the UK RTGS system, by means of a through-put rule. See Ota (2011) for a theoretical discussion of through-put rules and two-part tariffs.

[12] The convexity of the curve is based on the assumption of diminishing returns. The higher the level of liquidity, the less reduction of settlement delay results from an additional unit of liquidity.

delay and liquidity trade-off remains the same would move us from point B to B″. However, if the trade-off changes, we may end up anywhere on the transformation curve AA″.

The inherent restriction of a simulation study as presented in this paper is that it cannot account for potential changes of participant's behaviour. Furthermore, the sheer number of payments in SIC resulted in extensive computation time for a single simulation. Confronted with a limitation in the number of simulations that can be run, we consider only the effectively chosen levels of liquidity. As a consequence, the effect of a new algorithm is exclusively identified as a reduction in delay. To illustrate this, we measure the effect on delay of a new algorithm by measuring the move from point B to B′, keeping the level of liquidity available and release behaviour identical.

Figure 1: Part (a) technical transformation curve between liquidity and settlement delay (lhs), Part (b) composition of (available) liquidity (rhs)



Sources: Part (a) Leinonen and Soramäki (2005), adapted; part (b) SNB.

Nevertheless, it is possible to identify a proxy for potential liquidity savings. The simulator allows to differentiate available liquidity into used and idle liquidity (see Part (b) on the rhs of Figure 1). Used liquidity is defined as funds that are actually used for settlement (dark grey) whereas idle liquidity denotes reserve that are not used during the whole settlement day, i.e. they lie idle on the reserve accounts of participants (bright grey). Idle liquidity might be held for precautionary motives as such funds would allow participants to cope with unexpected payment shocks. Consistent with the assumption that release behaviour and the provision of (available) liquidity do not change with the introduction of a new algorithm, we assume that participants would keep their liquidity cushions constant. In turn, this allows us to identify potential liquidity savings (blue) should the simulations show that the new algorithm uses less liquidity (dark grey) to settle its payments.

2.2 Simulation results in other countries

Koponen and Soramäki (1998) were the first to conduct simulations with the Bank of Finland-Payment System Simulator (BoF-PSS). Using artificial and real Finnish payment data, they find that settlement delay can be reduced by splitting and netting payments. Splitting is most effective for low levels of liquidity. However, splitting of payments at very low levels of liquidity may not prevent gridlocks and has limited effects on settlement delay.

These results were later confirmed by other simulation studies. For instance, Leinonen and Soramäki (2005) simulate the effects of splitting, bilateral and multilateral netting using real payment data of the Finish RTGS system. They find that settlement delay and the risk of gridlocks can be reduced substantially at low levels of liquidity. Going beyond earlier studies, they model participants as economic agents that minimise their private cost of liquidity and delay. Splitting, respectively netting of queued payments are found to reduce settlement costs up to 10%, respectively 5%. For both algorithms the cost reduction was most pronounced at low levels of liquidity. Denbee and Norman (2010) found that splitting can reduce the duration and value of payments that are queued and that this reduction increases with lower levels of liquidity.

More complex algorithms are, for instance, simulated by Renault and Pecceu (2007). They test the performance of bilateral and multilateral netting algorithms that do not follow the FIFO rule, including the so called GREEDY algorithm proposed by Güntzer et al. (1998). The GREEDY algorithm sorts payments according to value and tries to offset similarly sized payments bilaterally. By using generated as well as real payment data from the Paris Net Settlement System, they show that such algorithms are more efficient than FIFO in terms of unsettled payments for varying levels of liquidity. Also, these algorithms perform better in case of an operational default of a participant. However, Renault and Pecceu (2007) acknowledge that the choice of an algorithm should reflect other consideration too. In particular, an algorithm should be legally sound and match the needs of the users. They conclude that it is difficult to draw definitive recommendation regarding the use of such non-FIFO algorithms in RTGS systems.

Glaser and Haene (2008) simulate the impact on available liquidity if a large SIC participant suffers operational problems and this participant is not able to release further payments but continues to receive payments for a certain period of time. Because the participant suffering operational problems accumulates liquidity from incoming payments on its account, it generates a liquidity sink for the whole system. As a consequence, other participants are hindered to settle their payments.

2.3 Settlement algorithms of SIC and other major payment systems

According to a survey by the World Bank (2011), more than 80% of the large-value payment systems worldwide are RTGS systems. Most of these systems have a central queuing facility where payment orders are pending until conditions for processing are met. An increasing number of countries have enhanced their systems by offsetting mechanisms, with multilateral offsetting becoming ever more widely-used. Thus, offsetting algorithms are gaining ground as a means to reduce settlement delay and to save liquidity in RTGS systems.

Table 1: Settlement algorithms in different countries

System and Country	Basic settlement algorithm	Additional optimisation routines
SIC – Switzerland	Participants can assign priorities to payments. Payments will be ranked according to priority and the first-in first-out (FIFO) principle. Payments are settled in packets, starting with the payments with highest priority.	If no payments can be settled for a certain period (gridlock), a "circles processing" mechanism is triggered automatically that bilaterally offsets payments. In this case, priority and FIFO are bypassed.
Target2 – Eurosystem	Participants can assign priorities to payments. Highly urgent and urgent payments are settled according to FIFO. Other payments are not settled if highly urgent payments are queued (even if entered first), except where an offsetting transaction of non-urgent payments leads to a liquidity increase for a participant with a highly urgent payment.	Each time a payment is released to the system, an offsetting process attempts to bilaterally settle with a payment in the receiving participants queue. Additionally, there are three optimisation routines applied to queued payments. First, an "all-or-nothing" algorithm tries to settle all payments in the queues simultaneously. If this is not possible, a "partial" algorithm removes one payment after the other from queue until the remaining payments can be settled simultaneously. Third, a "multiple" algorithm tries to settle bilateral payments between each pair of participants simultaneously.
CHAPS – United Kingdom	Participants can assign two priorities to payments: urgent and non-urgent. Urgent payments are settled immediately. Non-urgent payments are queued and settled in matching cycles by means of offsetting algorithms.	Every two minutes bilateral and multilateral offsetting algorithms are applied alternately to match non-urgent payments with the aim of minimising the net difference in the value of incoming and outgoing payments. Participants can set bilateral and multilateral limits to assign the maximum value they are ready to send either to one particular participant or to the whole payment system.
BOJ-NET – Japan	Participants can manually reorder their queued payments. Bilateral and multilateral offsetting mechanisms can change this order.	A bilateral offsetting mechanism runs continuously while multilateral offsetting is conducted at given time intervals.
Fedwire – United States	As Fedwire does not support central queuing, payments that do not fulfil funding requirements are rejected. However, collateralised or priced overdrafts are granted to ensure smooth settlement.	-

Sources: Bank for International Settlements (2005, Annex 2), Bank of Japan (2009), European Central Bank (2007).

Table 1 gives an overview of the settlement algorithms of a selection of the world's largest RTGS systems. Even this limited selection shows that a wide range of settlement algorithms exists ranging from Fedwire in the USA featuring a simple FIFO algorithm without central queuing facility to the arguably most complex optimisation routines applied by the Eurosystem's large-value payment system TARGET2. CHAPS, the United Kingdom's (UK) large-value payment system, has introduced in April 2013 a new liquidity saving mechanism. The Japanese system, BOJ-NET, constitutes together with TARGET2 and CHAPS hybrid payment systems featuring bilateral and multilateral offsetting mechanisms. Compared to these systems, SIC uses a rather simple algorithm (see Table 1 and Box 1 for a more detailed description of SIC's settlement algorithm).

Because TARGET2 replaced in 2007 and 2008 many national RTGS systems, the effects of its advanced algorithm cannot be assessed. However, BOJ-Net was upgraded with a bilateral and a multilateral offsetting mechanism in October 2008. The accompanying liquidity savings amounted to 15% and are assessed to be economically relevant by the Bank of Japan (2009). CHAPS actual liquidity savings cannot yet be assessed since banks have just started using it. However, simulations performed by Denbee and McLafferty (2013) suggest community liquidity savings of up to 30% compared to a basic RTGS system.

Box 1: Settlement algorithm in SIC

The exact settlement sequence of payments in SIC is determined by the release behaviour of participants and the settlement algorithm. Payment instructions released by a participant are pending in central queues. If a payment instruction is chosen as settlement candidate and if the participant has sufficient funds, the payment is settled. If cover is insufficient, the payment remains in the queue until sufficient funding is available. Participants can manage the settlement sequence of their queued payments by assigning priorities to payments.

The settlement algorithm determines settlement candidates from payments pending in queues according to priority classes and the first-in-first-out (FIFO) principle. The process is best explained by differentiating between participant and system level:

- Participant level: as a first step, the settlement algorithm determines the next-highest priority payment to be settled for each participant's queue. If a participant has several payment orders with identical priority in the queue, the payment instruction released first will also be first in line for settlement.
- System level: if several participants have queued payments, SIC starts to work off the queue of the participant with the oldest payment, irrespective of the payment's priority.

For reasons of efficiency, SIC tries to settle several consecutive payments in the same queue. However, the interval of release time and the number of payments that can be settled in one packet are restricted. After settlement took place, the algorithm searches for the next settlement candidate.

If no settlement can be initiated for a certain time interval – a system-wide gridlock – SIC automatically activates a bilateral offsetting mechanism. The mechanism searches for off-setting payments from participants that have sufficient funding for settling the net amount of the two payments. Payments are offset simultaneously on a bilateral basis and, returning to its normal routine, the algorithm searches for the next settlement candidate.

3. Settlement and liquidity in SIC

3.1 Network statistics

SIC settles large-value payments together with a substantial volume of retail payments in central bank money. For February 2007, Table 2 shows that retail payments make up the bulk of payments (93%), while large-value payments generate most of the value settled (93%).[13] The average size of a large-value payment was CHF 1.8 million and for a retail payment around CHF 10,000. Overall, the average size of a payment is around CHF 140,000.

Table 2: Daily average volume and value for large-value and retail payments, February 2007

	Volume (in thousand)		Value (in CHF billion)		Average size of payment (in CHF million)
	No.	in %	No.	in %	
Large-value payments	84	7.0	154.8	92.7	1.84
Retail payments	1,108.8	93.0	12.1	7.3	0.01
Total	**1,192.7**		**166.9**		**0.14**

Source: SNB

Out of the 343 participants (*nodes*), on average 305 ± 3.8 (mean ± standard deviation of daily mean over 15 days) settle at least one payment during each of the 15 days considered in February 2007.[14] Participants show an average turnover (or *strength*) of more than CHF 1 billion ± 72 million or 7,800 ± 3,900 payments. These 305 active nodes result in 92,720 directed links (n*(n-1)). Thereof only 7,280 ± 267 links are actually used, resulting in a *connectivity* measure of 7.9% ± 0.3%. The average *degree* of a node has a value of 23.9 ± 0.9, i.e. each node has on average 23.9 links with other nodes. Each link has an average turnover (or *strength*) of CHF 22.6 ± 2.2 million or 164 ± 79 payments. The average *reciprocity* is 50.9% ± 1.4%, i.e. slightly more than half of the links established between two nodes are two-sided (and 49.1% of the links established are one-way). The *path length* measures the shortest distance between two nodes expressed by the number of existing links that must be crossed. The average path length of the network in February 2007 was 2.12.

Considering the *strength* of a node both in terms of number and value of payments and the *degree* of a node reveals that the network is highly concentrated (see

Table 4 below). Also, the statistics characterise a network that makes no use of most of the possible links between SIC participants (92.1%). However, the "sub-network" of those links that are activated is extremely compact with a high turnover and a high likelihood of mutually exchanged payments.

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[13] Large-value payments are defined as bank-to-bank payments, payments resulting from trip-party repo transactions, and payments triggered from securities settlement systems or central counterparties. Retail payments are defined as direct debit, credit transfer payments, and payments resulting from batch settlement of retail transactions.

[14] Network topology measures are marked in *italic*. For definitions of the measures used see Soramäki et al. (2007).

Table 3: Network statistics for SIC, February 2007

Network statistic	Daily average	Standard deviation
Size (number of nodes)	305	3.8
Average strength of node		
Value^{+}	1,089	72.2
Number of payments	7,809	3892.1
Number of links between nodes (directed)	7,281	267.1
Average strength of link		
Value^{+}	22.6	2.2
Number of payments	164	78.8
Connectivity	7.9%	0.3%
Reciprocity	50.9%	1.4%
Average degree of a node (number of links)	23.9	0.9
Average path length	2.1	0.02

Source: SNB; + In CHF million.

Table 4: Concentration of Degree and Strength (directional), February 2007

	Strength (number)	Strength (value)	Degree
Top 3 participants	52.2%	58.7%	8.1%
Top 5 participants	62.1%	66.7%	12.0%
Top 10 participants	73.7%	76.8%	19.6%
Skewness	9.2	11.8	2.6
Kurtosis	89.8	148.8	9.4

Source: SNB

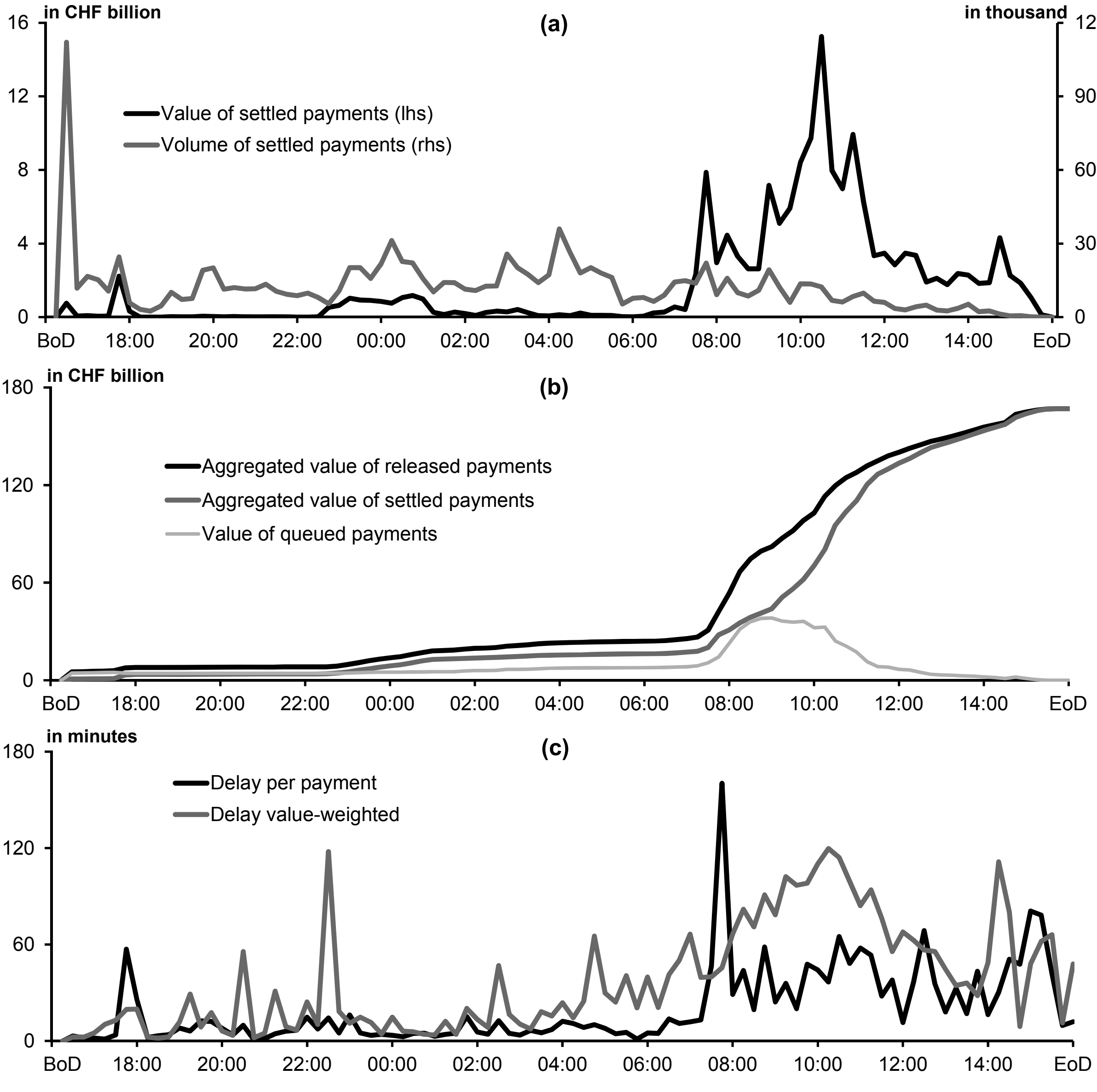
3.2 Timing of payments and delay

The daily release, settlement and queuing of payments depicted in Figure 2 characterizes payment activity throughout the SIC settlement day. Panel (a) plots the daily average value and volume of payments settled in SIC within a 15-minute interval for February 2007. Most of the low value payments are settled in SIC overnight (between 17:00 the preceding day and 07:00 in the morning of the value day), while most high value payments are subsequently released in the morning from 07:00 onwards. Panel (b) depicts the aggregated value of released, queued and settled payments. The value of queued payments increases in tandem with released payments and starts decreasing after persisting on a high level for around two hours. This is a result of temporary discrepancies between the released and settled value of payments: participants start to release large-value payments shortly before 08:00 but are not able to settle all of them immediately. However, settlement catches up after 10:00 so that the level of queued payments steadily decreases and almost vanishes until 14:00. Panel (c) tracks the average delay per payment as well as the value-weighted delay within a 15-minute interval. Obviously, the longest delays are observed from 08:00 onwards when participants begin to release large-value payments.

3.2 Sources of liquidity

From the viewpoint of a participant, two main sources of liquidity can be distinguished. The first source of liquidity are incoming payments from other participants. Incoming payments can be used immediately by the receiver for the settlement of its own payments. The second source of liquidity is the SNB. Each transaction between the SNB and a participant results in a change of the liquidity available to the respective participant and to the payment system as a whole. The more important transactions between the SNB and participants can be differentiated into open market operations and standing facilities. Open market operations influence the level of overnight reserve balances that participants require to fulfil minimum reserve requirements and that can be used to settle.

Figure 2: Daily average of (a) value and volume of payments settled, (b) aggregated value of payments released, settled and queued, and (c) 15-minute interval average values of delay per payment and value-weighted delay, February 2007

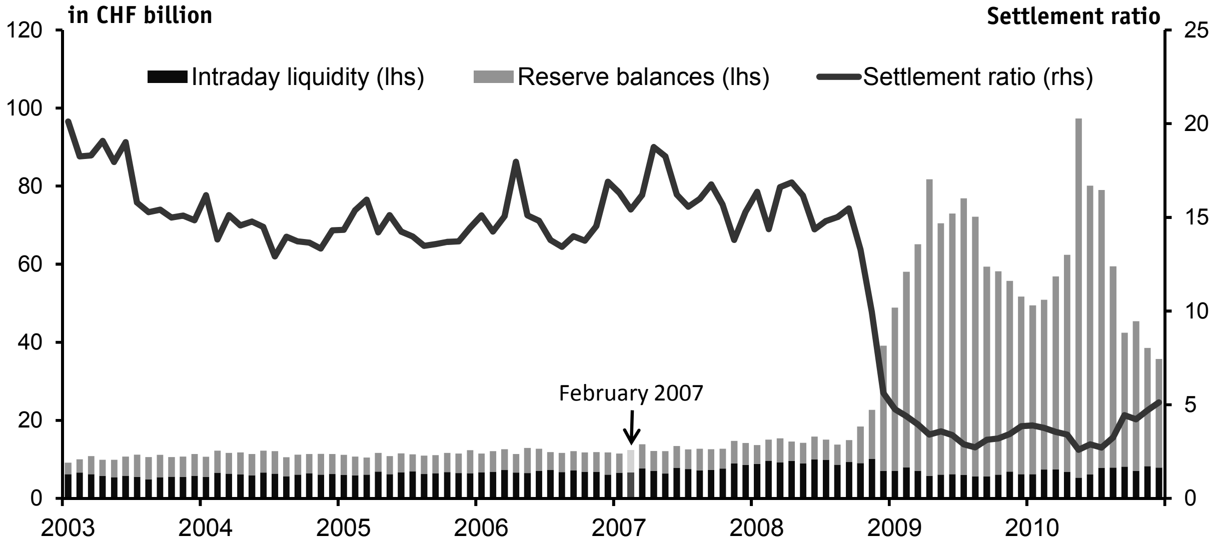


Source: SNB

Standing facilities are of importance for settlement purposes and include the intraday credit facility and the liquidity-shortage financing facility. The intraday credit facility provides SIC participants with interest rate free but collateralised intraday credits during the settlement day. The liquidity-shortage financing facility enables participants at a penalty interest rate to bridge overnight short-term liquidity bottlenecks up to a pre-collateralised limit.[15]

Figure 3 depicts monthly averages of total intraday credits drawn, overnight reserve balances and the settlement ratio (SR) that corresponds to the ratio of settlement value to available liquidity (defined as the sum of maximum value of intraday credits and end-of-day reserve balances). It shows that the level of intraday liquidity, reserve balances and the resulting settlement ratio were relatively stable until the second part of 2008 when unconventional monetary policy measures increased reserve balances to an unprecedented level. February 2007 is highlighted in Figure 3.

Figure 3: Monthly average of intraday liquidity, reserve balances and settlement ratio, 2003 - 2010



Source: SNB

4. Data and simulation methodology

This section describes the data used, the simulation algorithms applied and the methodology for measuring liquidity and settlement delay.

4.1 Data sample

We conduct simulations on the basis of real payment data from February 2007 when transaction volumes and values represent average SIC activity. Furthermore, February 2007 is a pre-crisis month that represents an average level of liquidity in normal times (see Figure 3). The sample covers 15

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[15] See http://www.snb.ch/en/iabout/monpol/id/monpol_instr for further information on the SNB's monetary policy instruments.

business days with an average daily number of 1.2 million transactions and an average daily settlement value of CHF 167 billion.

The BoF-PSS2 Simulator works on the basis of a 24 hour settlement day. Because SIC starts the settlement day with value-date Monday on Friday 5 p.m. and ends it – with two interruptions on Saturday and Sunday – on Monday 4.15 p.m., we exclude Mondays from the sample. We further exclude 28 February because the volume was exceptionally high, leaving the simulator with insufficient processing capacity.

We further extract CLS related transactions because these payments are settled on specifically dedicated subaccounts that do not influence settlement on the main accounts. This is also related to the funding of these subaccounts that is done exclusively via intraday credits. However, we account for liquidity movements that take place between main accounts and CLS subaccounts as they affect settlement performance on the main accounts.[16]

4.2 Alternative settlement algorithms

Given the variety of settlement algorithms in use, we focus on generic algorithms with features that are most often applied (see Table 5):

- The first algorithm "Priority and FIFO" serves as a reference case. It is the BoF-PSS2 algorithm that represents the closest available approximation of the algorithm currently applied in SIC.
- Based on "Priority and FIFO", the second algorithm applies a continuous "Bilateral Offsetting" mechanism. This additional mechanism checks – for each new payment released – whether the payee has an approximately offsetting payment waiting in the queue that is directed towards the payor. If positive, the payments are offset by the settlement of the net amount.
- The third algorithm complements the second algorithm with a "Multilateral Netting" every 60 minutes. It tries to settle all payments in the queue simultaneously. If the multilateral net settlement does not succeed, it reverts to "Bilateral Offsetting" (all-or-nothing).
- The fourth algorithm improves the first algorithm by introducing "Mandatory Splitting" of payments larger than CHF 100 million. While other amounts could be chosen, in the case of SIC it is most interesting to analyse a limit of CHF 100 million. This allows us to evaluate the effects if the currently applied voluntary splitting is made mandatory.

The basic settlement algorithm of the BoF-PSS2 Simulator "Priority and FIFO" resembles the SIC settlement algorithm. However, three differences cannot be replicated with the BoF-PSS2 simulator:

- Selection of a participant's queue: If there are several participants with pending payments and sufficient funds to settle, the SIC algorithm starts settling the queue first which contains the payment that has been released first, irrespective of its priority. In contrast, "Priority and FIFO" settles the queue first which contains the payment with the highest

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[16] See Appendix B for a detailed description of how these transactions were excluded and how liquidity movements between CLS subaccounts and main accounts are taken into account.

priority. "Priority and FIFO" resorts to FIFO only in case several queues with identical priorities exist.

- Packet building: Once SIC has chosen a queue, it continues to settle all payments within the same priority until one of the following conditions are met: the participant's queue is empty, the maximum volume of payments within a given limit is settled (one packet should not contain more than 150 payments), the maximum time lag between the first and last payment is reached (currently set at one minute) or cover becomes insufficient. In contrast, "Priority and FIFO" settles as many payments as the given level of funds permits.
- Gridlock resolution mechanism: In case no queued payments can be settled for a certain period of time, SIC activates the gridlock resolution mechanism. "Priority and FIFO" does not have such a gridlock resolution algorithm in place.

Table 5: Simulation algorithms

Number and label	Basic settlement algorithm	Additional optimisation routine
1. "Priority and FIFO"	Payments are queued if liquidity is insufficient. Payments are released according to priority and FIFO if liquidity becomes available.	-
2. (1.) + "Bilateral Offsetting"	Same basic settlement algorithm as "Priority and FIFO".	Continuous bilateral offsetting is applied that can bypass strict system level priority FIFO order transactions.
3. (1.)+(2.)+ Full "Multilateral Netting" every 60 minutes	Same basic settlement algorithm as "Priority and FIFO".	In addition to continuous bilateral offsetting, complete multilateral netting takes place every 60 minutes on the basis "all or nothing".
4. (1.) + "Mandatory Splitting" of transactions greater than CHF 100 million	Same basic settlement algorithm as "Priority and FIFO".	Transactions larger than CHF 100 million are split.

Source: SNB.

To compare the simulation results of the four alternative algorithms described above with the SIC algorithm, we report delay and liquidity indicators for SIC too. Applied liquidity and delay indicators are described in the following subsection.

4.3 Measuring liquidity and delay

Available liquidity in the SIC system is equal to the liquidity provided by the SNB. We define available liquidity (LA) to be equal to the sum of overnight balances at the end of the day plus the sum of all intraday credits drawn during the day. Participants can draw and pay back intraday liquidity at any time after 7.30 am. Thus, LA could vary during the day. Also, the repurchase leg (purchase leg) of open market operations take place after 08.00 (09.00). However, the suggested definition for LA is reasonable for the following two reasons. First, participants almost don't vary their holdings of intraday credits during the day.[17] Second, available overnight balances at end of day reflect available overnight liquidity during the hours of the greatest settlement activity. Thus, we define LA as follows:

(1) $LA = B(t_M) + \sum_i d^i(t_0, t_M)$

where i=1,2,…,N (number of participants) and m=0,1,2,…,M (number of time intervals);
$B(t_M)$ represents the balance of all participants at the end of day (t_M); and
$d^i(t_0,t_M)$ represents the sum of intraday credits drawn by participant i between beginning (t_0) and end of day (t_M).[18]

Available liquidity can be divided into liquidity that is actually used to effect settlement (used liquidity, LU) and liquidity that remains idle on the accounts of participants (idle liquidity, LI). LI can be derived via simulation. It is defined as the sum of reserves that lie idle on the accounts of participants, i.e. the sum of the minimum account balances in the course of the settlement day.[19] Thus, LU is the difference between LA and LI:

(2) $LU = LA - LI$

Independent of the reasons why individual participants hold more liquidity than they actually use to effect settlement of their payment obligations (such as precautionary reserve holdings to cope with payment shocks), we treat the observed level of idle liquidity in SIC as a minimum level that is not further reduced even if more advanced algorithms would allow to do so. As a consequence, if advanced settlement algorithms result in an increase of idle liquidity, the difference between idle liquidity for SIC and idle liquidity for a more advance algorithm could be eliminated and represents potential liquidity savings.

For each measure of liquidity a ratio can be calculated, dividing the respective measure of liquidity by the settlement value. The available liquidity ratio (ALR) is of particular interest as it is often used as a reference for the liquidity efficiency of a payment system:

(3) $ALR = \frac{LA}{Settlement\ Value} = \frac{1}{SR}$

Even though we do not artificially change the level of available liquidity, natural day to day fluctuations of available liquidity and settlement value allow us to investigate the effects of changing levels of liquidity to a certain degree. During the observation period the ALR varied between 0.059 and 0.074 (see Figure 4).

We measure delay with two standard settlement delay indicators[20] supported by the BoF-PSS2 Simulator:

(4) $Settlement\ Delay\ Weighted\ (SDW) = \frac{\sum_k^K q_k \times a_k}{\sum_k^K p_k \times a_k},$

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[17] See Nellen (2012).

[18] See Appendix A for a more detailed description and derivation of liquidity measures.

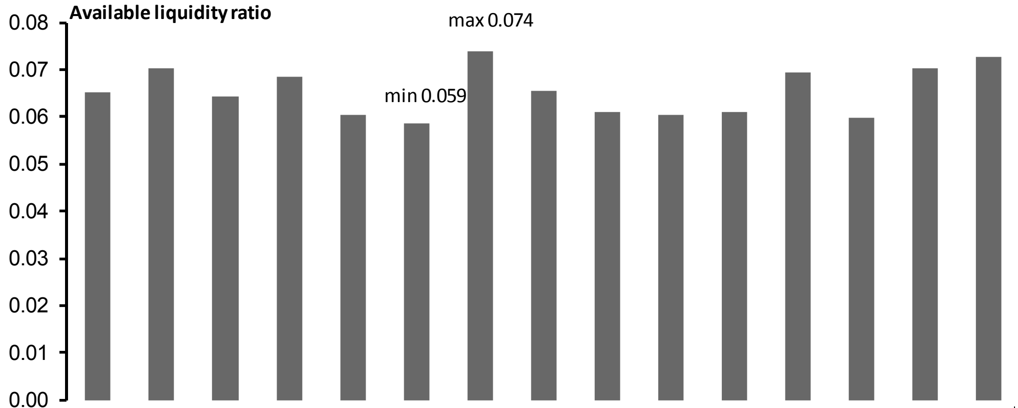
[19] Some algorithms end the day with pending payments (see Table 4). In order to make the levels of idle liquidity comparable, the value of unsettled payments (if any) is always deducted from idle liquidity.

[20] For a detailed description consult the BoF-PSS User Manual (User Manual: Databases and Files, Annex 1).

$$(5)\ Settlement\ Delay\ Unweighted\ (SDU) = \frac{\sum_k^K q_k}{K},$$

where k represents the number of payments of all participants k=0,1,2,...,K;
q_k represents queuing time for payment k;
a_k represents value of payment k; and
p_k represents maximum settlement delay, i.e. the time difference between release time and end of day of payment k.

Figure 4: Available liquidity (CHF billion) and available liquidity ratio in SIC, February 2007



Day in Feb 2007	01.	02.	06.	07.	08.	09.	13.	14.	15.	16.	20.	21.	22.	23.	27.
Balance End-of-Day	4.7	5.6	5.1	5.8	5.4	5.7	5.8	5.5	5.4	5.6	6.0	6.6	6.1	6.3	5.9
Intraday Repos	5.7	5.8	4.5	4.7	5.4	4.1	5.6	5.1	5.6	4.8	5.1	4.9	5.2	5.7	5.6
Available Liquidity	10.4	11.4	9.6	10.5	10.8	9.7	11.4	10.6	10.9	10.4	11.1	11.5	11.3	12.1	11.5
Idle Liquidity	1.2	1.0	1.2	1.2	1.0	0.9	1.1	1.2	1.2	1.1	1.1	1.2	0.9	1.0	1.2
Available Liquidity Ratio	0.07	0.07	0.06	0.07	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.07	0.06	0.07	0.07

Source: SNB.

While the indicator "settlement delay weighted" (SDW) weighs queuing time with the value of each payment, the indicator "settlement delay unweighted" (SDU) simply represents the average queuing time of all payments irrespective of their value. Furthermore, SDW assigns queued payments a higher weight the later in the day they are queued. This comes as a result of the divisor weighing a payment according to its potential queuing time which is defined as end of day time minus release time. To illustrate the difference between the two indicators, consider a payment system that runs for 23 hours. A single payment of one unit of money is to be settled. If the payment is released to the system at the beginning of the day and is queued for one hour, the weighted settlement delay indicator for t equals 1/23 = 0.043. In contrast, the weighted settlement delay indicator equals 1/1 = 1 if the payment is queued for one hour but released at t=22. For comparison, the SDU of both payments' is equal to 60 minutes. Therefore, SDU is neutral with regard when the payment is queued. In contrast, SDW assigns more weight to payments with higher values and delays taking place later in the day.[21]

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[21] One may interpret a SDW of 0.11 as follows: on average each Swiss franc was queued 11% of the time between release and end-of-day.

5. Simulation results

The results of the four simulated algorithms ("Priorities and FIFO", "Bilateral Offsetting", "Multilateral Netting" and "Mandatory Splitting") for 15 days in February 2007 are summarised in Table 6 below. Comparing these simulation results with real settlement delay and used liquidity observed in SIC, we identify the following key findings (detailed statistics are reported in Annex C).

On average, additional liquidity reduces settlement delay. The indicators for settlement delay unweighted (SDU)[22] and settlement delay weighted (SDW)[23] exhibit negative correlations with the available liquidity ratio (ALR) and used liquidity ratio (ULR). While the correlations are low for SDU, correlations for SDW are higher. Thus, additional liquidity mainly reduces delay of large-value payments and/or payments that are released later in the day.

The SIC algorithm seems to be on average superior in speeding up settlement of small-value payments (retail payments) compared to any other simulated algorithm with the same level of available liquidity. While we observe a slightly higher level of SDW for the SIC algorithm compared to all other simulated algorithms, the SIC algorithm is superior in terms of SDU. This suggests that the SIC algorithm is better at settling the high share of small-value payments than any other algorithm simulated in this study. This, however, comes at a cost of higher volatility: for both delay measures the SIC algorithm exhibits a higher standard deviation than the simulated algorithms (see Tables 6 and 7 in Appendix C). In terms of liquidity used, the SIC algorithm manages to settle its payments with less liquidity (and higher levels of idle liquidity) compared to "Priorities and FIFO". Overall, we conclude that "Priorities and FIFO" seems to be an acceptable albeit not perfect approximation of the original SIC algorithm. For the remaining part of this section we will compare the simulation results to the baseline scenario „Priorities and FIFO" (and not to the original SIC algorithm). This is due to the fact that – in the simulation – any additional features of the algorithm are built on "Priorities and FIFO" and not on the original SIC algorithm which – due to its specific characteristics described in Subsection 2.3 – cannot be simulated.

The simulations show that compared to "Priorities and FIFO" more advanced settlement algorithms do not allow to reduce settlement delay substantially. "Bilateral Offsetting" reduces average SDU by 1.7 minutes (9%) and average SDW by 0.018 points (12%). Likewise, the number and value of queued payments is reduced by less than 5,000 payments (3%) and CHF 640 million (1%) respectively. At first glance, this is surprising given the concentration of payment activity among a few participants and the high level of reciprocity in the payment network (see Section 3). One would expect that bilateral and multilateral off-setting can help to overcome delay more effectively. A closer look at the timing of delay reveals discrepancies in the timing of queued payments which reduce the potential for bilateral and multilateral offsetting. Panel (a) in Figure 5 depicts the value of queued payments of the four major participants (as a percentage of total value settled). Queuing peaks are spread over a period spanning 3 hours. Panel (b) looks at a particular bilateral relationship and shows that there is limited overlap between values queued (which is representative for several major bilateral links). This reduces the potential for bilateral and multilateral offsetting of payments and explains why more advanced algorithms have a limited effect on delay. While a better aligned

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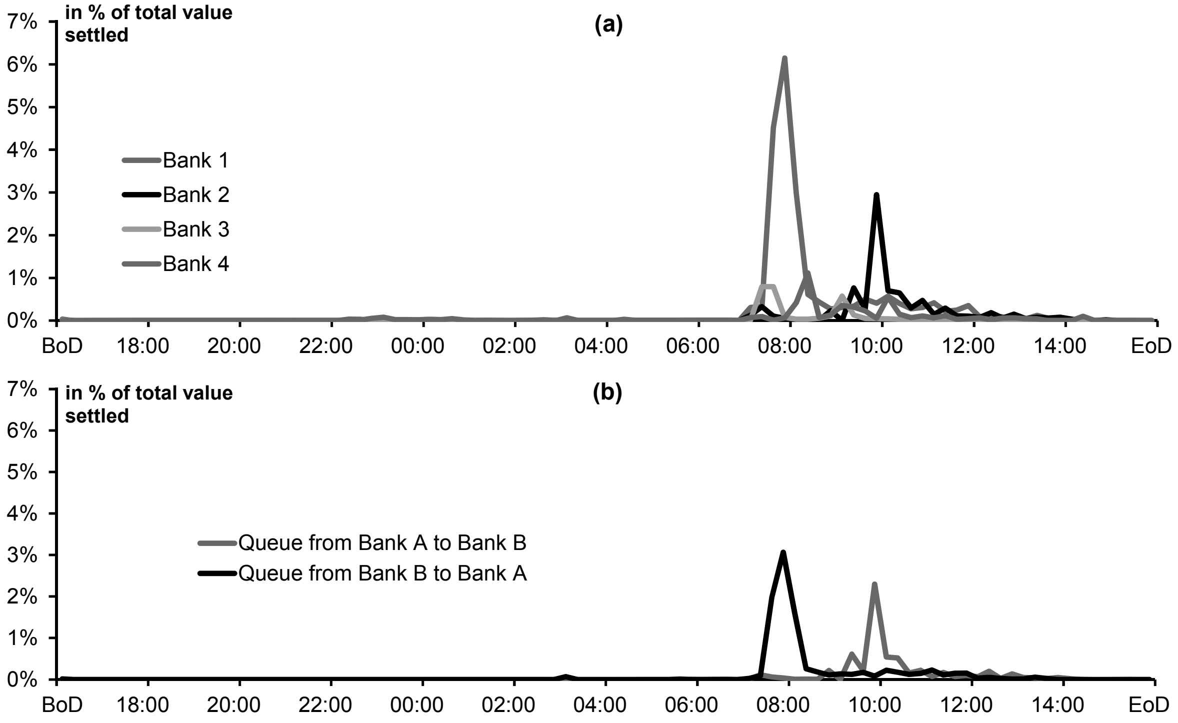
[22] Settlement delay unweighted (SDU) measures the average queuing time of a payment (in minutes).

[23] Settlement delay weighted (SDW) measures the value-weighted queuing time of a payment and gives higher weight to payments queued later in the day (with values between 0 and 1).

payment release behaviour might generally help to reduce settlement delay, the effect might be more pronounced if more advanced algorithms are applied.

Figure 5: Daily value of (a) queued payments of the four participants with the largest settlement value, (b) queued payments in a bilateral relationship, February 2007



Source: SNB.

We found no added-value of "Multilateral Netting" compared to "Bilateral Offsetting" since it had no effects on delay or used liquidity. The "Multilateral Netting" algorithm which works on the basis "all-or-nothing" seems to contain requirements that turned out to be too stringent: If the algorithm cannot settle all queued payments at once, it reverts to the "Bilateral Offsetting" modus. Even if one payment cannot be settled (for example because there are no reciprocal payments to be netted against) the whole multilateral netting will fail. Based on the fact that the simulation results for "Bilateral Offsetting" and "Multilateral Netting" are exactly the same, we conclude that there were no (or only a few) situations where multilateral netting of all queued payments succeeded. This is again related to the heterogeneous release behaviour. Were payments better aligned, multilateral netting would be more likely to be effective. In future one might try to simulate multilateral netting for a subset of participants.

"Mandatory Splitting" (with a limit of CHF 100 million) reduces settlement delay compared to "Priorities and FIFO" to a negligible extent (1.3% reduction for SDW and 0.3% reduction for SDU). This is surprising given a daily average of more than 140 transactions that exceed this threshold and account for CHF 24.8 billion of turnover (15% of the overall settlement value). In addition, close examination of the SIC data shows that these payments remain in the queue on average for more than one hour. It remains an open question whether a lower threshold would have a greater impact on settlement delay.

For “Bilateral Offsetting” and “Multilateral Netting” no unsettled payments remain pending at the end of the day, unlike for “Priorities and FIFO” and “Mandatory Splitting” where payments are left unsettled. “Priorities and FIFO” exhibits on average 35 payments with a value of almost CHF 300 million unsettled. “Mandatory Splitting” ends the day on average with 14 unsettled payments with a value of CHF 250 million. In comparison to an average settlement value of CHF 167 billion and average volume of 1.2 million payments (without CLS payments), pending payments at the end of the day remain negligible. Therefore, indicators of delay are not materially affected by the value and volume of pending payments.

Table 6: Simulation results and comparison to SIC, February 2007

	SIC		**Simulation results**		
	Original	1. Priorities and FIFO Benchmark	2. Bilateral Offsetting	3. Multilat. Netting	4. Mandatory Splitting
Average SDW[#]	0.157	0.153	0.135	0.135	0.151
Corr SDW/ALR	-0.28	-0.54	-0.44	-0.44	-0.50
Corr SDW/ULR	-0.30	-0.54	-0.33	-0.33	-0.39
Average SDU[##]	15.18	19.40	17.70	17.70	19.35
Corr SDU/ALR	-0.21	-0.28	-0.22	-0.22	-0.28
Corr SDU/ULR	-0.21	-0.22	-0.19	-0.19	-0.27
Average Available Liquidity[+]	10,884	10,884	10,884	10,884	10,884
Average Used Liquidity[+]	9,778	9,882	9,608	9,608	9,799
Average Idle Liquidity[+]	1,106	1,002	1,275	1,275	1,085
Liquidity safed[+]	104	-	274	274	83
Number of queued payments	192'586	169'304	164'788	164'788	168'882
Value of queued payments[+]	87'217	84'621	83'986	83'986	83'445
Number of unsettled payments	nap[§]	35	0	0	14
Value of unsettled payments[++]	nap[§]	296	0	0	248

[#] An interpretation of the settlement delay weighted (SDW) with value 0.16 is that each Swiss franc was on average in the queue 16% of the time between its release and end-of-day. ALR stands for available liquidity ratio and ULR for used liquidity ratio.

[##] Settlement delay unweighted (SDU) measures the average queuing time of a payment (in minutes).

[+] In CHF million.

[++] Benchmark is the settlement algorithm “Priorities and FIFO”. Higher levels of idle liquidity indicate, that less liquidity was used for actual settlement (in CHF million).

[§] Number and value of unsettled payments is by definition zero, since SIC system deletes all payments that remain in the queue by the end of the day. Details of deleted payments are not recorded in the database.

The level of available liquidity (LA) as effectively observed in February 2007 is used for the simulations. While LA is the same for all algorithms, differences in idle liquidity (LI) and the level of used liquidity (LU) can arise due to the varying efficiency of the algorithms considered.[24] Compared to “Priorities and FIFO”, all simulated settlement algorithms are more liquidity efficient since they all have higher levels of idle liquidity and show lower delay indicators. Participants use CHF 274 million less liquidity in case of continuous “Bilateral Offsetting” and “Multilateral Netting”, while “Mandatory Splitting” increases idle liquidity to a much lower extent.

6. Cost-benefit analysis

A comprehensive cost-benefit analysis is beyond the scope of this study. However, we are able to identify some sources of benefits and costs associated with introducing a new algorithm.

Potential benefits include the reduction of delay and liquidity needs. The simulation reveals that - in comparison to “Priorities and FIFO” - “Bilateral Offsetting” allows to reduce both settlement delay weighted (SDW) by 0.018 points (on a range between 0 and 1 or by 9 % in relative terms) and settlement delay unweighted (SDU) by 1.7 minutes per payment (or by 12% in relative terms). The relatively small reduction of delay suggests that benefits are economically insignificant. The results further suggest that SIC is able to accommodate the need to timely settle large-value payments as well as to cope with a large volume of retail payments.

The reduction of liquidity holdings associated with an increase in idle liquidity is the second source of benefits. Assuming that participants – for precautionary motives – hold the same level of idle liquidity as in February 2007, they can save liquidity if the level of idle liquidity increases as a result of the introduction of a new algorithm. Liquidity savings are, thus, defined as the level of idle liquidity with the old algorithm minus the level of idle liquidity with a new algorithm. Using “Priorities and FIFO” as the benchmark algorithm and assuming that adding “Bilateral Offsetting” to the SIC algorithm reduces liquidity needs by the same margin as introducing “Bilateral Offsetting” to “Priorities and FIFO”, we find that “Bilateral Offsetting” reduces liquidity needs of participants by around CHF 274 million. As reserve balances in normal times are mainly held to fulfil minimum reserve requirements and for other structural reasons, participants would reduce liquidity by means of lowering their demand for intraday credits. Since intraday credits are free but collateralised, the potential cost savings are calculated by multiplying the average liquidity saving with the implicit intraday interest rate. For the period after the introduction of CLS in 2002 and before the financial crisis starting 2007, Kränzlin and Nellen (2010) estimate the implicit intraday interest rate to be around 2.7 basis points. Therefore, yearly cost savings due to a lower provision of intraday credits would amount to CHF 73,800 (CHF 274 Mio x 2.7 basis points). This estimate is based on the assumption that participants do not change their payment behaviour. However, there is room for more liquidity savings given that a better alignment of release behaviour – especially in the morning hours – helps to improve bilateral netting and, thus, the efficient usage of liquidity.

The introduction of a new algorithm involves costs related to its development and implementation. In case of SIC – settling both large-value and retail payments – an off-the-shelf algorithm may not be the appropriate choice. However, a customised solution increases development costs. In addition,

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[24] In order to make the levels of idle liquidity comparable, the value of unsettled payments (if any) is always deducted from idle liquidity.

a new algorithm may give rise to substantial adaption costs for participants. For instance, adaption costs could be caused by the need to rearrange internal payment processing arrangements. Besides these sunk costs, a new algorithm may have to be carefully designed to avoid higher variable costs related to an increased demand for processing capacity and management attention.

7. Conclusions

The paper investigates whether the trade-off between delay and liquidity in SIC can be improved with the introduction of more advanced algorithms.

We find that compared to “Priorities and FIFO”, “Bilateral Offsetting” is able to modestly reduce delay and liquidity usage. “Multilateral Netting” – which is built on top of “Bilateral Offsetting” – provides no value added due to its stringent settlement criteria, neither in terms of delay nor liquidity savings. Also, “Mandatory Splitting” reduces settlement delay and liquidity usage to a negligible degree.

Potential reductions of settlement delay are assessed to be economically insignificant. Furthermore, we find potential yearly costs savings of around CHF 73,800 as a result of a reduced intraday liquidity demand. Thus, the costs associated with the introduction of a new algorithm such as investment, adaption and running costs must be carefully weighed against potentially low benefits.

Furthermore, we provide evidence that participants could reduce settlement delay and liquidity needs solely by aligning their release behaviour. We identify a better alignment of release behaviour as a precondition for bilateral off-setting to be more effective. While SIC prices release and settlement by means of a two-part tariff already, one might think of further elements to better align payment behaviour. Also, it may well be possible that more advanced algorithms might actually provide such incentives.

Our findings are in line with other studies. Sophisticated settlement algorithms reduce delay and liquidity usage substantially only if the level of liquidity is low. The level of available liquidity in SIC is sufficient to ensure smooth settlement and does not leave much room for sophisticated algorithms to take effect.

Overall, the current SIC algorithm performs comparatively well. Alternative algorithms offer only very modest improvements. Potential benefits are, thus, likely to be outweighed by the costs associated with the development, adaption and operation of a new algorithm.

Appendix A: Measures for available, used and idle liquidity

Let B^i (t_m) represent the balance of participant i at time t_m. The balance is equal to the balance at the beginning of day (BoD), plus the difference between the cumulative value of outgoing and incoming payments until t_m from and to other participants (s), overnight repos and any other flows between participant i and central bank (o) or intraday repos received from or paid back to the central bank (d).

(1)

$$B^i(t_m) = BoD^i + \sum_{j \neq i}\left[(s^{ji}(t_0, t_m) - s^{ij}(t_0, t_m)\right] + \left[o^{ci}(t_0, t_m) - o^{ic}(t_0, t_m)\right] + \left[d^{ci}(t_0, t_m) - d^{ic}(t_0, t_m)\right],$$

where i=0,1,2,…,N (number of participants) and m =1,2,…,M (number of time intervals).

s^{ij} (t_0,t_m) = settled payments from participant i to participant j between t_0 and t_m

o^{ci} (t_0,t_m) = settled overnight or longer repos and other flows from central bank c to participant i between t_0 and t_m

d^{ci} (t_0,t_m) = settled intraday repos from central bank c to participant i between t_0 and t_m

The liquidity available (LA) in the payment system at time t_m equals the sum of balances of all system participants. Note that interbank payments cancel out, thus LA is defined as:

(2) $LA(t_m) = B(t_m) = \sum_i BoD^i + \sum_i\left[o^{ci}(t_0, t_m) - o^{ic}(t_0, t_m)\right] + \sum_i\left[d^{ci}(t_0, t_m) - d^{ic}(t_0, t_m)\right],$

The maximum available liquidity is defined as:

(3) $MaxLA = \max_m(B(t_m)),$

Maximum available liquidity as defined in equation (3) is not easily detectable as participants can draw and pay back intraday liquidity at any time during the day (but latest by the end of the day). Participants have to settle the repurchase leg of maturing overnight repos before they can draw new ones, which takes place at around 9 a.m. Assuming that participants typically pay back their intraday liquidity holdings after conducting their overnight repo transactions, maximum liquidity available can be approximated by the sum of the end-of-day balance and the peak intraday liquidity position:

(4) $Max\ LA_{approx} = B(t_M) + \sum_i d^{ci}(t_0, t_M),$

with

(5) $B(t_M) = \sum_i BoD^i + \sum_i\left[o^{ci}(t_0, t_M) - o^{ic}(t_0, t_M)\right] = Balance\ end\ of\ day$

Liquidity available in a system can be divided into liquidity used (LU) and liquidity that has been lying idle on the account and has not been used for making payments (LI). Therefore we have:

(6) $LA(t_M) = LU(t_M) + LI(t_M)$

By definition, an individual participant's LI is the stock of funds on its settlement account that could be siphoned off without any effect on the participant's payment performance at any time of the day. Overall, the system can settle each participant's payments in exactly the same manner with or without participants' individual shares in LI on their accounts. Given this definition, LI in a system can be defined as the sum of idle liquidity holdings over all participants:

(7) $LI(t_M) = \sum_i(\min_m(B^i(t_m)))$

Inserting (4) and (7) in (6) we get a measure for maximum liquidity used in the system:

(8) $Max\ LU(t_M) = B(t_M) + \sum_i d^{ci}(t_0, t_M) - \sum_i(\min_m(B^i(t_m)))$

Appendix B: Ancillary systems and treatment of CLS-payments

SIC is linked to the securities settlement system SECOM, to the central counterparty Eurex Clearing and to the foreign exchange settlement system CLS. The payments resulting from SECOM and Eurex Clearing are left unaltered for the purpose of the simulation analysis. A few other ancillary systems settle in participants' main accounts on the basis of direct debit payments. These are left unaltered too. CLS-related transactions are removed as such payments settle in dedicated CLS sub-accounts and do not affect delay or liquidity needs on the main accounts. However, transactions between main accounts and CLS sub-accounts are replaced by SNB related payments in order to replicate liquidity implications for the participants. If cash is transferred from a participant's main account to CLS, a corresponding payment debiting the participant's main and crediting the SNB's account is created. If cash is transferred from CLS to a participant's main account, a corresponding payment crediting the participant's main account is created. All other CLS related payments are removed from the transaction data. Figures 4 and 5 illustrate the procedure.

Figure 6: Transactions with CLS sub-account

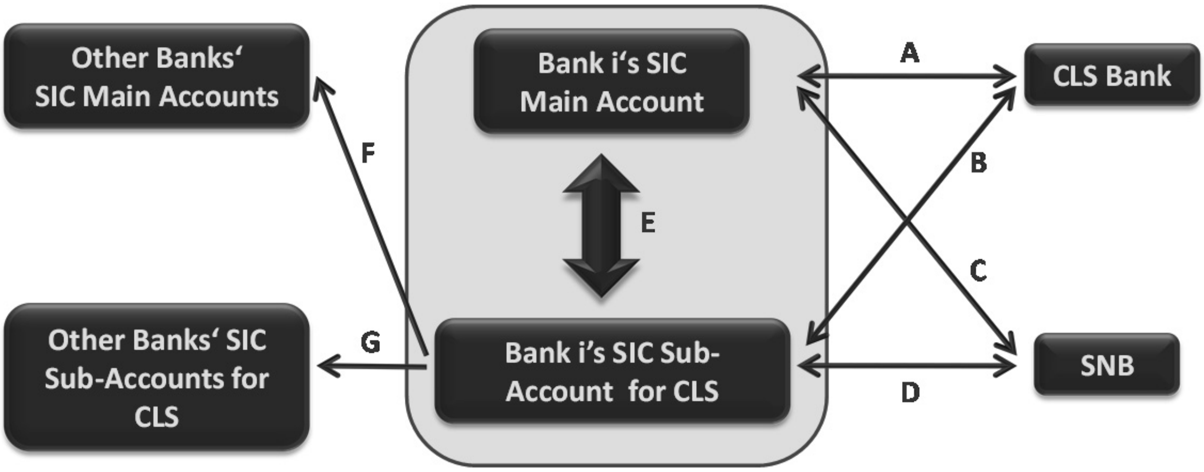
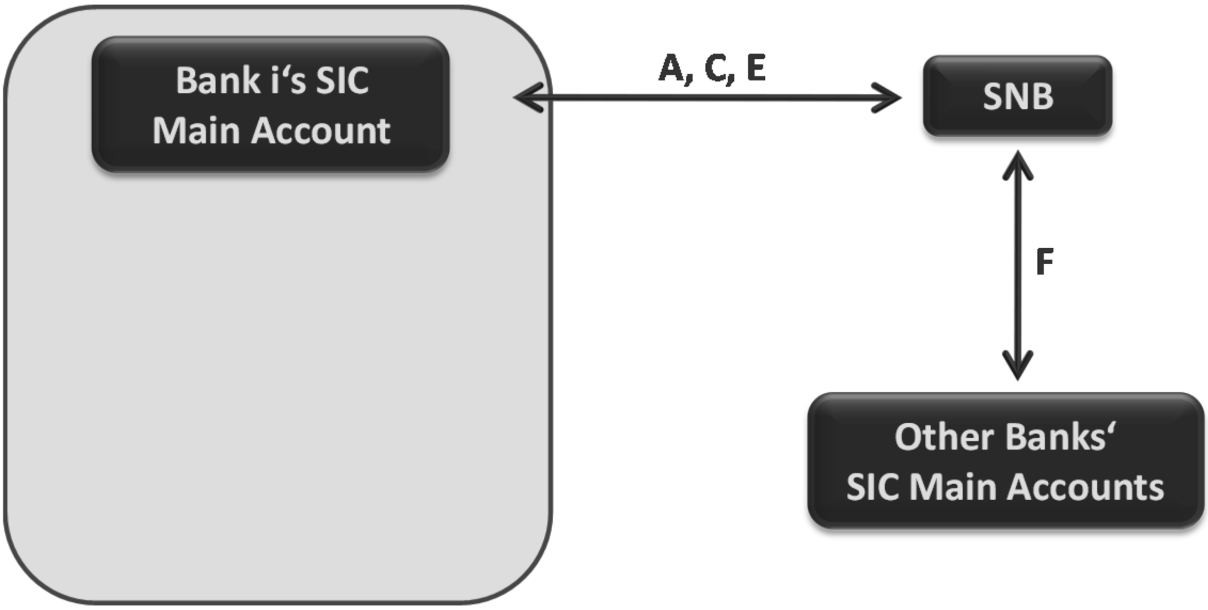


Figure 7: Transactions without CLS sub-account



Appendix C: Data

Table 7: Value and volume of transactions for days used in simulation[*]

Date	Value of transactions (in Mio CHF)	Volume of transactions
01.02.2007	160,219	2,549,714
02.02.2007	162,082	1,527,960
06.02.2007	149,469	1,150,163
07.02.2007	152,838	1,008,863
08.02.2007	179,214	844,145
09.02.2007	166,378	986,297
13.02.2007	154,112	808,995
14.02.2007	161,266	772,400
15.02.2007	179,153	869,732
16.02.2007	172,167	795,222
20.02.2007	182,239	818,271
21.02.2007	165,385	718,179
22.02.2007	189,285	837,156
23.02.2007	171,289	2,197,914
27.02.2007	158,349	2,006,079
Average	**166‘896**	**1,192,739**

[*] CLS-Transactions and beginning of day transactions are not included.

Table 8: Simulation results – settlement delay weighted

Day	Available Liquidity Ratio	Settlement Delay Weighted				
		SIC	Priorities and FIFO	Bilateral Offsetting	Multilateral Netting	Mandatory Splitting
01.02.2007	0.066	0.20	0.16	0.14	0.14	0.16
02.02.2007	0.070	0.17	0.15	0.14	0.14	0.15
06.02.2007	0.065	0.15	0.14	0.12	0.12	0.14
07.02.2007	0.069	0.17	0.17	0.15	0.15	0.17
08.02.2007	0.061	0.17	0.17	0.15	0.15	0.17
09.02.2007	0.058	0.14	0.14	0.12	0.12	0.14
13.02.2007	0.074	0.14	0.14	0.12	0.12	0.14
14.02.2007	0.065	0.17	0.17	0.15	0.15	0.17
15.02.2007	0.061	0.18	0.18	0.16	0.16	0.17
16.02.2007	0.060	0.14	0.16	0.13	0.13	0.16
20.02.2007	0.060	0.13	0.15	0.13	0.13	0.14
21.02.2007	0.070	0.13	0.13	0.12	0.12	0.12
22.02.2007	0.060	0.18	0.18	0.16	0.16	0.18
23.02.2007	0.070	0.15	0.15	0.13	0.13	0.15
27.02.2007	0.072	0.11	0.11	0.10	0.10	0.11
Average	**0.065**	**0.155**	**0.153**	**0.135**	**0.135**	**0.151**
St. deviation	**-**	**0.026**	**0.020**	**0.017**	**0.017**	**0.020**

Table 9: Simulation results – settlement delay unweighted, in minutes

Day	Available Liquidity Ratio	Settlement Delay Unweighted				
		SIC	Priorities and FIFO	Bilateral Offsetting	Multilateral Netting	Mandatory Splitting
01.02.2007	0.066	30.44	25.50	24.77	24.77	25.45
02.02.2007	0.070	21.47	20.33	18.60	18.60	20.28
06.02.2007	0.065	8.93	13.07	12.15	12.15	13.05
07.02.2007	0.069	10.61	13.68	11.83	11.83	13.12
08.02.2007	0.061	17.15	22.75	21.10	21.10	22.77
09.02.2007	0.058	9.62	14.93	13.78	13.78	14.70
13.02.2007	0.074	7.80	15.93	16.10	16.10	15.72
14.02.2007	0.065	13.69	27.88	21.23	21.23	28.03
15.02.2007	0.061	21.30	26.58	24.55	24.55	26.52
16.02.2007	0.060	13.88	17.38	16.22	16.22	17.38
20.02.2007	0.060	16.77	21.50	18.12	18.12	21.87
21.02.2007	0.070	13.73	14.72	13.55	13.55	14.70
22.02.2007	0.060	17.02	21.42	19.48	19.48	21.43
23.02.2007	0.070	11.77	15.13	14.28	14.28	15.13
27.02.2007	0.072	13.53	20.22	19.70	19.70	20.12
Average	**0.065**	**15.18**	**19.40**	**17.70**	**17.70**	**19.35**
St. deviation		**5.89**	**4.86**	**4.17**	**4.17**	**4.96**

Table 10: Simulation results – number of queued payments

Day	SIC*	Priorities and FIFO	Bilateral Offsetting	Multilateral Netting	Mandatory Splitting
01.02.2007	704,878	455,021	454,784	454,784	454,439
02.02.2007	294,541	251,449	239,939	239,939	251,239
06.02.2007	133,729	121,787	117,007	117,007	121,033
07.02.2007	196,492	120,855	111,817	111,817	119,583
08.02.2007	132,803	131,504	130,652	130,652	131,503
09.02.2007	75,082	113,030	110,687	110,687	112,792
13.02.2007	78,735	95,613	95,264	95,264	94,570
14.02.2007	73,852	113,228	109,271	109,271	113,375
15.02.2007	194,571	158,607	155,596	155,596	158,581
16.02.2007	68,048	98,212	95,459	95,459	98,214
20.02.2007	103,401	123,180	120,237	120,237	123,186
21.02.2007	131,947	92,040	85,227	85,227	91,856
22.02.2007	98,702	130,111	125,827	125,827	129,987
23.02.2007	305,767	300,052	292,636	292,636	300,056
27.02.2007	296,244	234,876	227,416	227,416	232,820
Average	**192,586**	**169,304**	**164,788**	**164,788**	**168,882**

* Due to the design of the SIC settlement algorithm nearly all payments remain for a view seconds in the queue. Therefore payments with a negligible settlement delay were removed from the statistics.

Table 11: Simulation results – value of queued payments, in CHF million

Day	SIC*	Priorities and FIFO	Bilateral Offsetting	Multilateral Netting	Mandatory Splitting
01.02.2007	102,500	90,438	90,093	90,093	89,297
02.02.2007	91,640	79,188	77,830	77,830	77,186
06.02.2007	71,710	72,868	73,181	73,181	71,730
07.02.2007	91,080	86,108	82,591	82,591	84,212
08.02.2007	94,130	88,499	92,053	92,053	87,464
09.02.2007	93,830	96,481	96,108	96,108	94,123
13.02.2007	79,040	74,108	74,593	74,593	72,459
14.02.2007	77,840	80,674	79,384	79,384	80,381
15.02.2007	107,200	104,698	104,358	104,358	103,890
16.02.2007	79,820	79,442	78,671	78,671	79,053
20.02.2007	95,620	94,592	92,981	92,981	94,092
21.02.2007	69,930	72,223	71,330	71,330	70,336
22.02.2007	89,880	93,491	91,466	91,466	92,602
23.02.2007	86,790	82,459	80,914	80,914	82,359
27.02.2007	77,250	74,042	74,239	74,239	72,495
Average	**87,217**	**84,621**	**83,986**	**83,986**	**83,445**

* Due to the design of the SIC settlement algorithm nearly all payments remain for a view seconds in the queue. Therefore payments with a negligible settlement delay were removed from the statistics.

Table 12: Simulation results – number of unsettled payments

Day	SIC*	Priorities and FIFO	Bilateral Offsetting	Multilateral Netting	Mandatory Splitting
01.02.2007	nav	0	0	0	0
02.02.2007	nav	11	0	0	11
06.02.2007	nav	0	0	0	0
07.02.2007	nav	7	0	0	7
08.02.2007	nav	14	0	0	14
09.02.2007	nav	30	0	0	30
13.02.2007	nav	0	0	0	0
14.02.2007	nav	23	0	0	23
15.02.2007	nav	61	0	0	61
16.02.2007	nav	14	0	0	14
20.02.2007	nav	17	0	0	17
21.02.2007	nav	4	0	0	4
22.02.2007	nav	7	0	0	7
23.02.2007	nav	19	0	0	19
27.02.2007	nav	314	0	0	10
Average	**0**	**35**	**0**	**0**	**14**

* Unsettled payments in SIC are removed from the payment statistics and hence not available.

Table 13: Simulation results – value of unsettled payments, in CHF million

Day	SIC*	Priorities and FIFO	Bilateral Offsetting	Multilateral Netting	Mandatory Splitting
01.02.2007	nav	0	0	0	0
02.02.2007	nav	393	0	0	393
06.02.2007	nav	0	0	0	0
07.02.2007	nav	1	0	0	149
08.02.2007	nav	266	0	0	266
09.02.2007	nav	403	0	0	403
13.02.2007	nav	0	0	0	0
14.02.2007	nav	393	0	0	393
15.02.2007	nav	311	0	0	311
16.02.2007	nav	569	0	0	569
20.02.2007	nav	348	0	0	348
21.02.2007	nav	45	0	0	45
22.02.2007	nav	83	0	0	83
23.02.2007	nav	386	0	0	386
27.02.2007	nav	1241	0	0	379
Average	**0**	**296.04**	**0**	**0**	**248.42**

* Unsettled payments in SIC are removed from the payment statistics and hence not available.

References

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

Ball, Alan, Edward Denbee, Mark Manning and Anne Wetherilt (2011). Intraday liquidity: Risk and regulation. Bank of England, Financial Stability Paper, No. 11.

Bank for International Settlements (1997): Real-time Gross Settlement Systems. Bank for International Settlements, Basel.

Bank for International Settlements (2005): New developments in large-value payment systems. BIS/CPSS, Basel.

Bank of Japan (2009): BOJ-Net funds transfers after the implementation of phase 1 of the next generation RTGS project. Bank of Japan Review, July 2009.

Bartolini, Leonardo, Spence Hilton and James McAndrews (2008): Settlement delays in the money market. Federal Reserve Bank of New York Staff Report no. 319.

Bech, Morten and Bart Hobijn (2007): Technology diffusion within central banking: the case of real-time gross settlement. International Journal of Central Banking, Vol. 3 No. 3, p.147-181.

Bech, Morten, Christine Preisig and Kimmo Soramäki (2008): Global trends in large-value payments. Federal Reserve Bank of New York Economic Policy Review, September 2008, 59-81.

Denbee, Edward and Johanna McLafferty (2013): Liquidity saving in CHAPS: a simulation study. In: Simulation in computational finance and economics: tools and emerging applications. Business Science Reference, 120–42.

Denbee, Edward and Ben Norman (2010): The impact of payment splitting on liquidity requirements in RTGS, Bank of England, Working Paper No. 404.

European Central Bank (2007): Guideline of the European Central Bank of 26 April 2007 on a Trans-European Automated Real-time Gross settlement Express Transfer system (TARGET2).

Glaser, Martina and Philipp Haene (2008): Liquidity effects of a participant-level operational disruption in the Swiss Interbank Clearing System.

Güntzer, Michael M., Dieter Jungnickel and Matthias Leclerc (1998): Efficient algorithms for the clearing of interbank payments. European Journal of Operational Research, Volume 106, Issue 1, 1 April 1998, 212-219.

Koponen, Risto and Kimmo Soramäki (1998): Intraday Liquidity Needs in a Modern Interbank Payment System - A Simulation Approach. Bank of Finland Studies E:31, 73-116.

Kränzlin, Sebastian and Thomas Nellen (2010): Daytime is money. Journal of Money, Credit and Banking, Vol. 42, No. 8.

Leinonen, Harry and Kimmo Soramäki (2005): Optimising Liquidity Usage and Settlement Speed in Payment Systems. Bank of Finland Studies E:31, 117-150.

Martin, Antoine. and James McAndrews (2008): Liquidity-saving mechanisms. Journal of Monetary Economics 55, no. 3 (April): 554-67.

Nellen, Thomas (2013): Double duty and two-part tariff. Forthcoming, Swiss National Bank Working Paper.

Newman, M. E. J. (2006): Power laws, Pareto distributions and Zipf's law. cond-mat/0412004v3, 29 May 2006.

Ota, Tomohiro (2011). Intraday two-part tariff in payment systems. Bank of England Working Paper No. 428.

Renault, Fabien and Jean-Baptiste Pecceu (2007): From PNS to TARGET 2: cost of FIFO in RTGS payment systems. Bank of Finland, Scientific monographs, E:39, 41-85.

Soramäki, Kimmo, Morten L. Bech, Jeffrey Anrold, Robert J. Glass and Walter E. Beyeler (2007): The topology of interbank payment flows. Physica A, 317-333.

World Bank (2011): Payment systems worldwide. A snapshot. Outcomes of the global payment systems survey 2011. Financial Infrastructure Policy and Research Series.

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