Collateralised liquidity, two-part tariff and settlement coordination
Thomas Nellen

Legal Issues

DISCLAIMER

The views expressed in this paper are those of the author(s) and do not necessarily represent those of the Swiss National Bank. Working Papers describe research in progress. Their aim is to elicit comments and to further debate.

COPYRIGHT©

The Swiss National Bank (SNB) respects all third-party rights, in particular rights relating to works protected by copyright (information or data, wordings and depictions, to the extent that these are of an individual character).

SNB publications containing a reference to a copyright (© Swiss National Bank/SNB, Zurich/year, or similar) may, under copyright law, only be used (reproduced, used via the internet, etc.) for non-commercial purposes and provided that the source is mentioned. Their use for commercial purposes is only permitted with the prior express consent of the SNB.

General information and data published without reference to a copyright may be used without mentioning the source. To the extent that the information and data clearly derive from outside sources, the users of such information and data are obliged to respect any existing copyrights and to obtain the right of use from the relevant outside source themselves.

LIMITATION OF LIABILITY

The SNB accepts no responsibility for any information it provides. Under no circumstances will it accept any liability for losses or damage which may result from the use of such information. This limitation of liability applies, in particular, to the topicality, accu‑racy, validity and availability of the information.

ISSN 1660-7716 (printed version)
ISSN 1660-7724 (online version)

© 2015 by Swiss National Bank, Börsenstrasse 15,
P.O. Box, CH-8022 Zurich

Collateralised liquidity, two-part tariff and settlement coordination

Thomas Nellen*
Swiss National Bank†
Bundesplatz 1, P.O. Box, CH-3003 Bern
E-mail: thomas.nellen@snb.ch

October 29, 2015

Abstract

This paper analyses the liquidity management game played in payment systems with free but collateralised intraday credit facilities, under the assumption that settlement risk is the driving force. Settlement equilibria are found to depend on the combination of the intraday liquidity facilities' design and the collateral policy applied by the central bank. The effectiveness of a two-part tariff in coordinating on early settlement depends on the same factors. Model predictions are consistent with stylised facts from a comparison of settlement behaviour in the Swiss Interbank Clearing and Fedwire funds.

JEL classification: E58; G21; G28

Key words: real-time gross settlement; large-value payment systems; intraday liquidity facility; collateralisation; settlement risk

1 Introduction

The liquidity management game played by participants of real-time gross settlement (RTGS) payment systems is analysed here. Settlement in RTGS payment systems requires costly intraday liquidity. To save liquidity, participants delay payments to await incoming funds provided by other participants. Thus, settlement behaviour is determined by a strategic interaction that could result in multiple Pareto-ranked equilibria. Coordination on early settlement is generally

understood as the desired outcome by central banks. For this reason, central banks, as the operators and regulators of such systems, provide incentives by means of various instruments to induce early settlement.

The importance of central bank policies in the resultant settlement behaviour is illustrated here by considering two of the oldest RTGS systems, namely Fedwire funds (Fedwire) and Swiss Interbank Clearing (SIC). The two systems are particularly interesting to compare, as they represent generic RTGS systems that differ in important aspects, namely their intraday liquidity facility, their collateral policy and the application of a two-part tariff to induce early settlement. It is argued here that these differences are crucial in explaining why settlement in the case of SIC takes place substantially earlier than in the case of Fedwire.

To induce earlier settlement, the Swiss National Bank (SNB) introduced a two-part tariff in 1988, and free but collateralised intraday credit in 1999. Intraday credit is actively drawn by participants, is collateralised during the time of usage, and has to be repaid at a prespecified point in time before the end of the settlement day. Banks that establish discount window access can draw intraday credit up to the amount of collateral prepledged at the discount window. Fedwire has provided liquidity via a priced but uncollateralised daylight overdraft facility. Overdrafts are automatically extended to a participant if it has zero balances and releases payments for settlement. Overdrafts are available until the end of the settlement day. Interestingly, in March 2011, the Federal Reserve System (FRS) introduced a new intraday liquidity facility. In addition to priced but uncollateralised overdrafts, the FRS started to offer free but collateralised daylight overdrafts to reduce uncollateralised overdrafts and induce earlier settlement. Participants must prepledge collateral at the FRS and can get overdrafts up to the amount prepledged.

The intraday management game by Mills and Nesmith (2008) (henceforth MN) considers settlement risk as the driving force of the liquidity management game in the context of priced but uncollateralised overdrafts. Their model is adapted to collateralised liquidity facilities, i.e. an intraday credit and a collateralised overdraft facility. The cost of collateral is a decisive factor. Collateral can come at a variable or a fixed opportunity cost, depending on the collateralisation policy. Prepledged collateral naturally results in a fixed cost of collateral, while time of use-dependent collateralisation of intraday credits may result in a variable or a fixed cost of collateral. A variable cost requires valuable intraday opportunities for collateral. A fixed cost may result, despite valuable reuse opportunities, if double duty is allowed for collateral that is required for regulatory or other purposes.

The settlement cost further depends on the intraday liquidity facility. Intraday credit imposes two restrictions that are not present with overdrafts. Intraday credit is actively drawn rather than automatically extended, i.e. the decision to draw an intraday credit goes along with an active collateral management that blocks collateral for some time. Secondly, in SIC, intraday credit is available until some prespecified point before the end of the day, while in Fedwire overdrafts are available until the end of the day. These frictions restrict settlement

off-setting within specific periods and increase demand for costly liquidity.

In the presence of settlement risk, none of the feasible combinations of collateralised liquidity facilities and costs of collateral incentivises coordination on early settlement. As in MN, late settlement equilibria are found to result both for intraday credit facilities with a variable opportunity cost of collateral, and for collateralised overdraft facilities with a fixed opportunity cost of collateral. Interestingly, with an intraday credit facility and a fixed cost of collateral, incentives to coordinate settlement are muted.

Central banks apply additional instruments to incentivise early settlement. Enriching the liquidity management game by a two-part tariff results in valuable insights. While the two-part tariff may help to coordinate on early settlement, its calibration is found to be a difficult task. This is particularly true for payment systems with intraday credit and a variable cost of collateral, but holds true for collateralised overdraft systems with a fixed cost of collateral. For these systems, the central bank would have to be able to condition the two-part tariff at least on payment shocks and settlement risk. In contrast, a system with intraday credits and a fixed opportunity cost of collateral mutes incentives to coordinate payments, allowing any two-part tariff to provide effective incentives to coordinate on early settlement.

The literature mainly relies on the delay cost approach as laid out in Koboyakawa (1997), Angelini (1998), Bech and Garratt (2003), Martin and McAndrews (2009) and Jurgilas and Martin (2013). With settlement risk being the driving force of the liquidity management game, MN focus on priced but uncollateralised overdrafts, while Mills and Husain (2013) analyse links between payment and securities settlement systems. This paper bridges two gaps in the literature by analysing intraday liquidity facilities with free but collateralised intraday liquidity in the context of settlement risk, and by evaluating the effectiveness of a two-part tariff in these setups. This is relevant to policy makers for two reasons. First, according to the World Bank (2010), 109 out of 112 RTGS systems worldwide offer free but collateralised intraday liquidity facilities and 31 out of a sample of 112 central banks provide incentives for early settlement through pricing. Secondly, collateralised overdrafts are granted by 24 central banks. Yet this type of facility has not been dealt with in the literature. Also, while it is meant to reduce settlement delay, it remains an open question whether the new facility offered by the FRS may effectively trigger earlier settlement after reserve levels and interest rates have returned to pre-crisis levels.

Section 2 provides stylised facts on settlement behaviour in SIC and Fedwire. Section 3 introduces the model. Section 4 considers an intraday credit facility with a variable cost of collateral. Section 5 studies an intraday credit facility with a fixed cost of collateral. Section 6 investigates collateralised overdrafts. Section 7 discusses the models in light of SIC and Fedwire. Section 8 concludes.

2 Stylised facts on SIC and Fedwire

A comparison between SIC and Fedwire funds shows that settlement in SIC takes place substantially earlier than in Fedwire funds. This is consistent with the predictions by MN and in this paper. An overdraft system with a variable liquidity cost (priced overdraft) predicts late settlement for Fedwire funds (Proposition 2 in MN), while a model for intraday credits with a fixed opportunity cost of collateral and a two-part tariff predicts early settlement for SIC (Proposition 5 in this paper).[1]

A comparison of settlement times must be limited to non-settlement institutions' payments that are subject to strategic decisions of the sending party. Thus, all institutionalised payments with prespecified settlement times (payments to and from settlement institutions such as CLS for instance) are extracted from the data. Bech, Martin and McAndrews (2012) provide an empirical analysis of the timing of payments in Fedwire funds (see Figure 1) for which they extract institutionalised payments.[2] Similarly, institutionalised payments are removed from SIC data (see Figure 2).[3]

Data available allows us to compare the last 2 1/2 (5 1/2) hours of the Fedwire funds settlement day with the last 2 1/4 (5 1/4) hours of the SIC settlement day.[4] We do so for the period from mid-2003 to mid-2007, i.e. the period after the introduction of Continuous Linked Settlement (CLS) and before the financial crisis starting in 2007.[5] Bech, Martin and McAndrews (2012) show that around 50% of the value is settled 2 1/2 hours before the system closes. Also, 20% of the value is settled 5 1/2 hours before the system closes (see Figure 1). Figure 2 shows that 2 1/4 hours before SIC closes more than 90% of the value is settled. Furthermore, 5 1/4 hours before the system closes around 50% of the value is settled in SIC. The time difference of a 1/4 of an hour lowers SIC's settlement performance in comparison to Fedwire.

A substantial fraction of payments is known ahead of the settlement day. The most relevant in terms of value are interbank payments that originate from any form of interbank trading. Such trades are usually concluded some days ahead of the settlement day, and the resulting payment obligations are well known in advance. Armantier et al. (2008) and Bech, et al. (2012) argue that institutionalised payment times – such as those related to CHIPS and DTC settlement – serve as focal points for other payment activities. While removing institutionalised transactions from the data allows us to focus exclusively on

---

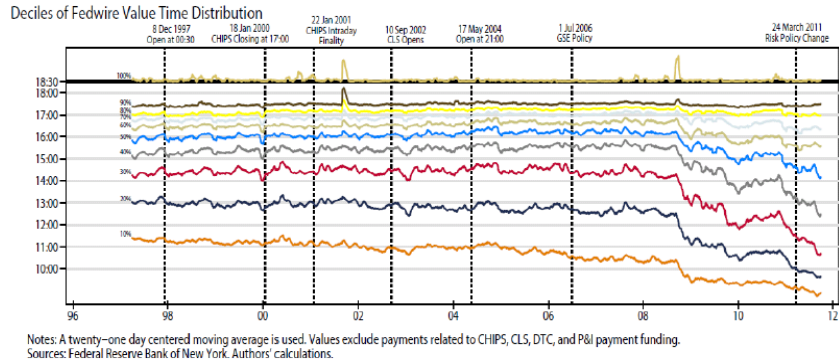[1] See Section 7 on why SIC participants face a fixed opportunity cost of collateral.

[2] The reprint of Figure 2 was kindly permitted by Bech, Martin and McAndrews (2012). For Fedwire funds payments stemming from CHIPS, CLS and the Depository Trust Company (DTC) are excluded.

[3] In the case of SIC, institutionalised payments that stem from CLS, securities settlement and related services, repo transactions and retail clearing houses are excluded.

[4] The SNB's data base on SIC knows hourly data points only. This does not allow to reproduce the analysis for Fedwire funds based on deciles of value time distribution.

[5] CLS reduced settlement volumes and – in the case of SIC – increased demand for intraday liquidity. The financial crisis resulted in unusually high overnight balances (see Figure 7). The period between mid-2003 and mid-2007 is not affected by similarly drastic changes.

Figure 1: Deciles of Fedwire value time distribution

Notes: A twenty-one day centered moving average is used. Values exclude payments related to CHIPS, CLS, DTC, and P&I payment funding.
Sources: Federal Reserve Bank of New York. Authors' calculations.

payments that are subject to strategic delay, it is difficult to account for the effects created by focal points for the settlement of other payments. However, it is consistent with the distinct incentives set by these systems that institution-alised payments in Fedwire take place rather late in the day, whereas in SIC these take place rather early during the day.

Due to the financial crisis, tri-party repo in the US has found special attention. Armantier et al. (2008) find late settlement activity for the secured interbank money market. As pointed out in Kraenzlin and Nellen (2010), tri-party repo transactions in Switzerland are settled during the whole day with substantial volumes already being settled during the morning. This is partly related to monetary policy operations by the SNB taking place early in the morning. However, substantial volumes of interbank repos are settled during the morning, too. These transactions may be considered as semi-institutionalised payments, as the market convention is to trigger high priority payments in SIC immediately after a repo is confirmed by the trading platform. In contrast, US tri-party agents are commercial banks that do not follow a similar institution-alised framework. Thus, repo transactions are deleted from SIC data. Inclusion would further strengthen the comparison in favour of SIC.

While a large fraction of these payments is settled through institutionalised mechanisms (for instance central counterparties), substantial payments volumes remain settled through non-institutionalised mechanisms, i.e. they are subject to strategic delay. MN mention that even though their model qualitatively explains the stylised facts concerning Fedwire, other factors such as payments arriving late may also contribute to the settlement patterns observed. Indeed, another large fraction of payments originates on the settlement date itself. Such payments are related to customer payments and the unsecured interbank money market.

Nellen (2010) reflects on the experience with the introduction of a two-part tariff for SIC in April 1988 and its more progressive application from 1989

Figure 2: Monthly settlement percentage by time of the day from January 1988 to January 2012

Data Source: SNB (author's calculation)
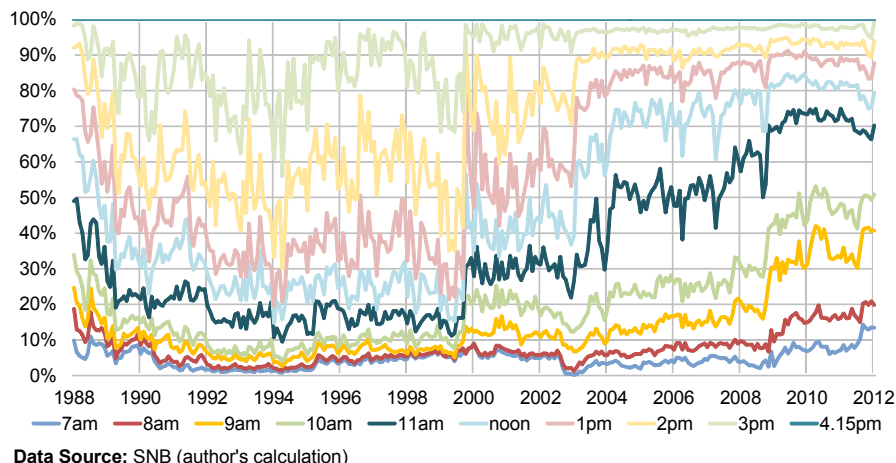
onwards. In terms of the number of payments, many more payments were released earlier than before, as early release and settlement incurs lower fees. However, in terms of the value of transactions, a remarkable move towards later settlement can be noticed from 1990 onwards. Bartolini et al. (2008) find evidence that money market transactions are subject to substantial strategic delay. Both findings suggest that substantial payment management takes place. This is true for pre-known and same-day transactions, which are both subject to strategic delay.

Further evidence on strategic delay has been gained as a by-product of the financial crisis starting in 2007. As reported in Bech, Martin and McAndrews (2012) and Nellen (2010) the period of unconventional monetary policy has provided evidence of strategic delay for both systems. In SIC and Fedwire, a substantial move towards earlier settlement can be observed from the end of 2008 onwards, when unconventional monetary policy started to increase reserve balances to unprecedented levels (see Figures 1 and 2).

To summarise, for both categories of payments – those that are known ahead and those that are generated on the same day – strategic interaction is known to be an issue. While the exact extent is hard to quantify, the phenomenon of strategic delay in RTGS payment systems is real. Since differences in the timing of payments are substantial, SIC data used favours later settlement and both systems' data reflect non-institutionalised payments only, it is justified to perceive the substantial difference in settlement timing as a reflection of fundamental factors.

3 Model

Our model shares many characteristics with MN's model. There are three periods denoted by $t = 0, 1, 2$, for morning, afternoon and end-of-day. Two agents called banks indexed by $i \in \{1, 2\}$ populate the payment system. There is a third institution, the central bank. Banks can send and receive payments by moving balances across accounts that they hold with the central bank.

At the beginning of period 0, with probability p, bank $i \in \{1, 2\}$ receives an instruction to make a payment of value 1 to bank $j \neq i$. The realisation of this payment shock is independent of whether the other bank also receives a payment instruction. Whether a bank receives a payment instruction is private information. MN interpret this as the inability of banks to communicate with one another to cooperatively coordinate payments in order to reduce expected costs. While this looks extreme in the case of two banks, this assumption seems to be justifiable for payment systems with hundreds or thousands of participants.

If bank i receives a payment instruction, it can decide to make the payment either in period 0 or in period 1, i.e. a bank decides to settle in the morning or to delay settlement until the afternoon. As in MN, we assume that a bank does not strategically delay payments until period 2 unless it receives information concerning the ability of the other bank to send payments. That is where settlement risk comes into play.

At the beginning of period 1, with a small probability $\varepsilon > 0$ a bank may receive a settlement shock, i.e. bank i cannot receive a payment from the affected bank j during period 1, but will receive it in period 2. The realisation of the settlement shock is independent across banks, but its realisation is common information. In contrast, whether a bank is to receive a payment from the affected bank with probability p remains private information. If a bank finds out that it cannot receive a payment from the other bank, it can delay any outstanding payments that must be sent to the affected bank until period 2.

The settlement shock represents a certain type of settlement risk to the receiving bank – defined as the risk that a payment is not sent and received as expected, in this case by the end of period 1. Such shocks occur when the sending bank suffers an operational disruption or lacks available liquidity to send a payment at a particular point in time. This restricts the receiving bank's incoming source of liquidity that could offset outgoing payments and reduce its own cost of sending payments. One can think of the settlement shock as a proxy for uncertainty regarding incoming funds.

During period 2 any outstanding payments are settled, i.e. strategic delay beyond intraday is abstracted to focus on the intraday management game. Illiquidity is excluded by assuming banks to hold collateral of value 1. Also, reserve requirements and precautionary motives for banks to hold balances overnight are abstracted. This allows us to let banks start period 0 with a zero account balance. However, banks may end the day holding a positive reserve balance, with an overnight interest rate R attached to it.

Banks need liquidity to settle payments. Liquidity either stems from the central bank or from incoming payments from other banks. Intraday credit must

be actively drawn and is available in periods 0 and 1. In contrast, overdraft is automatically extended if payment instructions are released for settlement. This is also the case during period 2.[6] Posting collateral comes either as a variable, time-of-use dependent opportunity cost ω $(R \geq \omega > 0)$ per period $t \in \{0, 1\}$ or as a fixed cost ψ $(R \geq \psi > 0)$ per settlement day. The variable opportunity cost of collateral is born if an intraday credit is drawn that is collateralised on demand. If no intraday credit is drawn during period 0 or 1, valuable reuse opportunities for collateral allow opportunity costs to be avoided. A daily fixed cost is born if 'prepledged' collateral is used or double duty results in a zero cost (for intraday credit and daylight overdraft). A zero cost and a positive fixed cost turn out to be strategically identical.

In MN, a fee is charged for uncollateralised but priced overdrafts, if and only if the negative account balance remains until the end of period $t \in \{0, 1\}$. In other words, with priced but uncollateralised overdrafts no fee is charged if payments are offset within a period and banks end the period with zero overdraft.[7] In contrast, a similar offset within a period is not feasible for collateralised systems. First, either collateral is prepledged, or making collateral available for valuable reuse opportunities takes time and is costly. Secondly, as banks are assumed to be unable to communicate (remember that p is private information), banks cannot reduce their liquidity needs by coordinating on which bank pays first. Hence, if both banks received a payment shock and decide to settle in the same period, they both draw intraday credits. These features impose a cash-in-advance constraint for intraday credit systems where intraday liquidity is not automatically granted but needs to be actively drawn. The model allows us to mirror these features, assuming an inability to offset payments within a period. While off-setting is not feasible within periods, it remains feasible across them. If a bank receives a payment in period 0, it can use the funds to settle in period 1 to avoid an intraday credit.

Similarly, an overdraft system allows a bank to avoid costly overnight credit if payments are delayed to be settled in period 2. If both banks settle in period 2, they offset negative account balances and avoid drawing an overnight credit. In contrast, intraday credit is not available after period 1. Consequently, to settle in period 2 both banks need to draw an overnight credit. Again, if both banks need to settle, the cash-in-advance constraint requires both banks to provide liquidity.

---

[6]Model differences mirror distinct central bank practices. For instance, the SNB allows intraday credits to be drawn until 2.45 pm, while the settlement day ends at 4.15 pm (the period between 2.45 and 4.15 pm is reflected as period 2 in the model). If intraday credits are not repaid by 3 pm, the repayment of intraday credits is automatically triggered by the system by means of high-priority direct debit payments. Also, after 3 pm only money market transactions are accepted as new payment instructions (however, other instructions may still be pending in a centrally managed queue). After 4 pm only central bank instructions are accepted, i.e. discount window credits. See Heller, Nellen and Strum (2000) for further information on SIC. In contrast, Fedwire allows overdrafts to be drawn until end-of-day, i.e. including period 2 (see Guide to the Federal Reserve's Payment System Risk Policy effective 10 March 2012 and http://www.federalreserve.gov/paymentsystems for further information on the new collateralised overdraft facility).

[7]Fedwire calculates fees on the basis of overdrafts measured at the end of each minute.

If a bank has not repaid intraday credit by the end of period 1, it must borrow overnight from the central bank at interest rate $R \geq \omega, \psi$ to repay it. This is related to the constraint imposed that no intraday liquidity is granted during period 2 and outstanding intraday credits have to be repaid immediately (by means of a high priority direct debit payment). Similarly, if an overdraft is not paid back until the end of the day, it is automatically replaced by an overnight credit.

The two-part tariff is introduced as a late settlement fee $\tau > 0$ if settlement occurs in period 1 or period 2.[8] The central bank charges the late settlement fee whenever settlement occurs during the last two periods.[9]

The bank's objective function is to minimise the expected cost of making a payment. The objective becomes relevant only when a bank receives a payment shock at the beginning of period 0. Thus, we can focus on a bank's payment strategy in the state of the world in which the bank under consideration receives a payment instruction. The analysis is restricted to pure strategies. s_i denotes the strategy of bank i, given that it receives a payment instruction. The set of possible pure strategies is $s_i \in \{m, a\}$, where m denotes a morning payment (period 0) and a denotes an afternoon payment (period 1). A strategy profile is a pair of timing strategies (s_i, s_j) for both banks. Thus, the expected cost c of making a payment is a function of a bank's payment timing strategy s_i, the timing strategy of the other bank s_j. We solve for the Bayesian Nash equilibria (BNE). BNE may depend on the payment shock p, the opportunity cost of intraday liquidity (either a variable cost, ω, or a fixed cost, ψ), the cost of overnight reserves, R, the probability of settlement risk, ε, and the two-part tariff, τ. $c(s_i, s_j)$ denotes bank i's expected cost of making a payment when it plays the timing strategy s_i, while bank j plays the timing strategy s_j. This setup generates four possible realisations of expected costs.

4 Intraday credit with a variable cost

Consider the case when intraday credit is available with a variable cost of collateral. Depending on the strategy pair considered, the game leads to the following four realisations of expected costs $c(s_i, s_j)$:

$$c(m, m) = \omega + (1 - p)(\omega + R) \tag{1}$$

$$c(m, a) = \omega + p(1 - \varepsilon)\omega + p\varepsilon(\omega + R) + (1 - p)(\omega + R) \tag{2}$$

$$c(a, m) = (1 - p)(1 - \varepsilon)(\omega + R) + (1 - p)\varepsilon R \tag{3}$$

$$c(a, a) = p(1 - \varepsilon)\omega + p\varepsilon R + (1 - p)(1 - \varepsilon)(\omega + R) + (1 - p)\varepsilon R \tag{4}$$

---

[8]As set out in Ota (2011), one could well have an early settlement fee τ_m and a late settlement fee τ_a. Assuming $\tau_a - \tau_m = \tau > 0$ makes notation easier without affecting results.

[9]Ota (2011) argues that a negative morning fee $\tau_m < 0$ in combination with a positive evening fee $\tau_a > 0$ allows the implementation of an overall cost-neutral tariff scheme that nevertheless provides strong incentives to settle early. We abstract from these aspects to focus on the intraday liquidity management game.

Figure 3: Intraday credit with a variable opportunity cost of collateral

	m	a
m	$2\omega - p\omega$ $2\omega - p\omega$	$2\omega + p\varepsilon R$ $(1-p)(1-\varepsilon)\omega$
a	$(1-p)(1-\varepsilon)\omega$ $2\omega + p\varepsilon R$	$(1-\varepsilon)\omega + p\varepsilon R$ $(1-\varepsilon)\omega + p\varepsilon R$

Suppose bank i receives a payment order. Then, the first term in equations (1) and (2) mirrors the necessity for bank i to draw an intraday credit to settle early. The last term in equation (1) and (2) reflects the situation when bank j does not receive a payment order. This forces bank i to prolong the intraday credit and, in addition, to draw an overnight loan to bring its account balance back to zero. Even though settlement risk matters in equation (2), this does not affect the case when bank j does not receive a payment instruction. The second term in equation (2) considers the situation when bank i does not suffer from settlement risk and bank j receives a payment. Then, bank i receives a payment by bank j and can bring its account balance back to zero before the end of period 1. The third term describes the realisation of settlement risk if bank j receives a payment shock. This forces bank i to prolong the intraday credit – as it cannot receive any payments – and, additionally, to draw an overnight loan to pay back the intraday credit at the end of period 1. In equations (3) and (4) the cost of bank i is analysed, given that its strategy is to settle late. Therefore, no intraday credit is drawn in the first period. Furthermore, settlement risk may realise. In equation (3), if bank j receives a payment instruction, bank i does not incur a cost to settle its payment in the afternoon as bank j pays in the morning. Consider the first term in equation (3). If bank j does not receive a payment instruction, bank i needs to draw an intraday credit and, obviously, is not able to repay the intraday credit at the end of period 1. Thus, bank i needs to draw an overnight credit. As reflected in the last term, if settlement risk realises, bank i further delays its payment to period 2, avoiding an intraday credit and directly drawing from the overnight facility in period 2. The same goes for the last two terms of equation (4). The two first terms capture the situation of bank i not receiving a payment from bank j in the morning despite the fact that bank j received a payment shock. If settlement risk does not realise, bank i simply draws an intraday credit and pays it back before the end of period 1. If settlement risk realises, both banks delay payments and draw an overnight credit in period 2.

Figure 3 represents the game in normal form with equations (1) to (4) simplified where appropriate.

Proposition 1 *Under a collateralised intraday credit regime with a variable*

opportunity cost of collateral $\omega > 0$ and a settlement shock $\varepsilon > 0$, the strategy profile (a, a) is the unique BNE. Furthermore, a is a strictly dominant strategy for each player.

Proof. *It is easy to see that for bank i $c(a, x) < c(m, x)$ for $x \in \{m, a\}$. Symmetry implies the proposition.* ∎

We call an equilibrium efficient if it minimises the joint expected costs of the two banks. It is easy to show that the joint expected cost for the strategy pair (a, a) is less than for the strategy pair (m, m) if $R > \omega \frac{\varepsilon - p}{p\varepsilon}$. This holds true as we presume ε to be close to zero. Thus, $p > \varepsilon$. Furthermore, (m, a) and (a, m) are less costly than (m, m) if $R > \omega \frac{(1+\varepsilon)(1-p)}{p\varepsilon}$. As $\frac{\varepsilon - p}{p\varepsilon} < \frac{(1+\varepsilon)(1-p)}{p\varepsilon}$, whether or not the former inequality holds true depends on the parameter values. We further find (a, a) to be less costly than (m, a) and (a, m) if $R > \omega \frac{(1+\varepsilon)(1-p)+2p\varepsilon}{p\varepsilon}$. Therefore, even though a is a strictly dominant strategy, (a, a) is not necessarily efficient. This contrasts with Proposition 2 in MN. With $\omega > 0$, (a, a) is found to be always efficient, as late settlement insures against the possibility that incoming payments may not be settled. With free but collateralised intraday credits, late settlement may turn out to be inefficient, as late settlement may necessitate expensive overnight credits. If settlement is not coordinated, this may be avoided.

If $\omega = 0$ and $\varepsilon > 0$, all strategy pairs become BNE. (m, m) is efficient and Pareto-dominates the other strategy pairs. This is in contrast to Proposition 1 in MN with free overdrafts for which (a, a) survives the elimination of weakly dominated strategies, while both (m, m) and (a, a) are efficient. While in MN late settlement insures against the possibility that payments may not settle as expected, with intraday credits banks cannot offset payments in period 2 to avoid expensive overnight credits. In addition to being affected by settlement risk if both banks play a, they are also affected by settlement risk with opposing strategies. Thus, requiring an early repayment of intraday credits makes coordination on late settlement unattractive, as expected costs increase rather than decrease with increasing settlement risk.

If $\omega > 0$ and $\varepsilon = 0$, (a, a) is the unique BNE. (a, a) is also efficient. Banks seek to avoid the cost of intraday liquidity by waiting for incoming payments from the other participants. This is in line with MN. With no settlement risk, early settlement does not insure against the possibility of expensive late settlement.

If $\omega = 0$ and $\varepsilon = 0$, all strategy pairs are BNE and efficient. Again, this is in line with MN.

Consider the game with a two-part tariff. While cost functions (1) and (2) stay the same, cost functions (3) and (4) reflect the additional cost τ for bank i if it settles late.

$$c(a, m) = (1 - p)(1 - \varepsilon)(\omega + R) + (1 - p)\varepsilon R + \tau \qquad (5)$$

$$c(a, a) = p(1 - \varepsilon)\omega + p\varepsilon R + (1 - p)(1 - \varepsilon)(\omega + R) + (1 - p)\varepsilon R + \tau \qquad (6)$$

Proposition 2 *Under a collateralised intraday credit regime with a per period opportunity cost of collateral $\omega > 0$, a settlement shock $\varepsilon > 0$ and a two-part tariff $\tau > 0$, the following strategy profiles emerge as equilibria:*

1. *If $\tau < \omega(1 + \varepsilon - p\varepsilon)$, (a, a) is the unique BNE. Furthermore, a is a strongly dominating strategy for each player;*

2. *If $\tau = \omega(1 + \varepsilon - p\varepsilon)$, (m, m) and (a, a) are BNE. Furthermore, the strategy profile (a, a) survives the elimination of weakly dominated strategies;*

3. *If $\omega(1 + \varepsilon - p\varepsilon) > \tau > \omega(1 + \varepsilon)$, (m, m) and (a, a) are BNE;*

4. *If $\tau = \omega(1 + \varepsilon)$, (m, m) and (a, a) are BNE. The strategy profile (m, m) survives the elimination of weakly dominated strategies;*

5. *If $\tau > \omega(1 + \varepsilon)$, (m, m) is the unique Bayesian Nash equilibrium. Furthermore, m is a strongly dominating strategy for each player.*

Proof.

1. *If $\tau < \omega(1 + \varepsilon - p\varepsilon)$, $\forall\ s \in \{m, a\}$ it holds true that $c(a, s) < c(m, s)$ and $c(s, a) < c(s, m)$;*

2. *If $\tau = \omega(1 + \varepsilon - p\varepsilon)$, for bank i $c(a, m) < c(m, m)$ and $c(a, a) = c(m, a)$ and for bank j $c(m, a) < c(m, m)$ and $c(a, a) = c(a, m)$. Thus, $\forall\ s \in \{m, a\}$ it holds true that for bank i $c(a, s) \leq c(m, s)$ and for bank j $c(s, a) \leq c(s, m)$;*

3. *If $\omega(1 + \varepsilon - p\varepsilon) < \tau < \omega(1 + \varepsilon)$, it is easy to see that for bank i $c(a, a) < c(m, a)$ and $c(a, a) < c(a, m)$ and for bank j $c(m, m) < c(m, a)$ and $c(m, m) < c(a, m)$;*

4. *If $\tau = \omega(1 + \varepsilon)$, it is easy to see that for bank i $c(m, m) = c(a, m)$ and for bank j $c(m, m) = c(m, a)$. Furthermore, for bank i $c(a, a) < c(m, a)$ and for bank j $c(a, a) < c(a, m)$. Thus, for bank i $c(m, s) \leq c(a, s)$ and for bank j $c(s, m) \leq c(s, a)$;*

5. *If $\tau > (1 + \varepsilon)\omega$, $\forall\ s \in \{m, a\}$ it holds true that for bank i $c(m, s) < c(a, s)$ and for bank j $c(s, m) < c(s, a)$.*

∎

The strategy profile (a, a) is efficient if $\tau < (1 + \varepsilon - p)\omega - p\varepsilon R$. (a, a) and (m, m) are both efficient if $\tau = (1 + \varepsilon - p)\omega - p\varepsilon R$. (m, m) is an efficient and Pareto-dominant strategy profile if $\tau > (1 + \varepsilon - p)\omega - p\varepsilon R$. It is easy to see that the following inequalities hold true $\omega(1 - p + \varepsilon) - p\varepsilon R < \omega(1 + \varepsilon - p\varepsilon) < \omega(1 + \varepsilon)$ (as illustrated in Figure 4). Let $s, b, c \in \{m, a\}$. If $\tau > (1 - p + \varepsilon)\omega - p\varepsilon R$, (m, m) is efficient and Pareto-dominant as $c(m, m) < c(b, c)$ for any $(b, c) \neq (m, m)$. If $\tau = (1 - p + \varepsilon) - p\varepsilon R$, both (m, m) and (a, a) are efficient as $c(s, s) < c(b, c)$ for any (b, c) for which $b \neq c$. If $\tau < (1 - p + \varepsilon)\omega - p\varepsilon R$, (a, a) is efficient and Pareto-dominant because $c(a, a) < c(b, c)$ for any $(b, c) \neq (a, a)$.

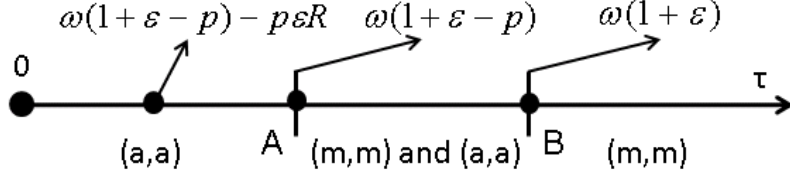Figure 4: BNE for intraday credit with a variable opportunity cost of collateral and a two-part tariff

Figure 4 illustrates Proposition 2. It is evident that steering settlement behaviour is a non-trivial undertaking with a variable opportunity cost of collateral. While the opportunity cost of collateral may be publicly observable, at least on the basis of a market-wide implicit intraday interest rate, other variables may not be so. Both settlement risk and the payment shock may be difficult to infer from payment system data.

Ota (2011) concludes that a two-part tariff is able to reduce the aggregate cost of liquidity if banks incur delay costs. A particular feature of his model is that banks differ in their cost of liquidity but do not face payment uncertainty. For a model with homogenous liquidity costs and no delay costs, we show that if payment uncertainty and settlement risk are present, then the calibration of the two-part tariff must take into account the opportunity cost of collateral, payment uncertainty and settlement risk to be effective. Thus, given a variable opportunity cost of collateral, it is far from evident which two-part tariff implements early settlement and coordinates settlement behaviour.

Comparative statics yields intuitive results. An increase in p does not increase the necessary level of τ to make early settlement the unique equilibrium. However, it widens the area of indeterminacy between points A and B by moving point A to the left. An increase in ε increases the necessary level of τ to make early settlement the unique equilibrium, but leaves the area of indeterminacy the same. An increase in ω increases the necessary level of τ to induce early settlement and widens the area of indeterminacy.

5   Intraday credit with a fixed cost

Banks are assumed to have their collateral of value 1 permanently prepledged at the central bank. According to their settlement strategy, banks use the possibility of drawing intraday credit either in the morning, m, or in the afternoon, a. Still, if a bank's intraday credit has not been paid back by the end of period 1, it has to borrow overnight at a cost R.

The following cost functions result:

$$c(m,m) = \psi + (1-p)R \tag{7}$$

Figure 5: Intraday credit with a fixed opportunity cost of collateral

	m	a
m	0 0	pεR 0
a	0 pεR	pεR pεR

$$c(m,a) = \psi + p\varepsilon R + (1-p)R \qquad (8)$$

$$c(a,m) = \psi + (1-p)R \qquad (9)$$

$$c(a,a) = \psi + p\varepsilon R + (1-p)R \qquad (10)$$

Consider the first term of all four cost functions. Whatever the payment strategy is, bank i incurs opportunity cost ψ since it has to prepledge collateral of value 1. Consider the last term of each cost function. It represents the case when bank j does not receive a payment instruction. Then, bank i draws an overnight credit to repay the intraday credit at the end of period 1. Now consider the cost functions for which bank j's strategy is to pay late. Then, bank i's cost is affected by settlement risk. If bank j receives a payment instruction and settlement risk realises, bank i is urged to draw an overnight loan as it needs to repay the intraday credit at the end of period 1. Otherwise, bank i would repay the intraday credit with bank j's payment. In contrast, if bank j's strategy is to settle early, bank i's cost is not affected by settlement risk.

Figure 5 represents the game in normal form with equations (5-8) simplified where appropriate. By inspecting Figures 3, it is easy to see that this resembles exactly the result obtained for $\omega = 0$ beforehand. Strategically, a fixed opportunity cost of collateral is sunk and mirrors the results obtained if collateral bears no opportunity cost of collateral.

Proposition 3 *Under a collateralised intraday credit regime with a fixed opportunity cost of collateral $\psi > 0$ and a settlement shock $\varepsilon > 0$, all strategy profiles are BNE.*
Proof. *It is easy to see that $c(m,m) = c(a,m)$ and $c(m,a) = c(a,a)$ for bank i and $c(m,m) = c(m,a)$ and $c(a,m) = c(a,a)$ for bank j hold true.* ∎

From Figure 5 it is easy to see that (m,m) is efficient as $c_i(m,m)+c_j(m,m) < c_i(s,s)+c_j(s,s)$ for all possible strategy pairs $(s,s) \neq (m,m)$. Furthermore, the strategy profile (m,m) Pareto-dominates the other strategy pairs as $c_i(m,s) \leq c_i(a,s)$ and $c_j(s,m) \leq c_j(s,a) \ \forall \ s \in \{m,a\}$.

The fixed opportunity cost of collateral leaves all possibilities open because all strategy profiles are BNE. This is an interesting and novel result. Acknowledging the incentive to delay strategically that results from settlement risk, a fixed opportunity cost of collateral neutralises these incentives.

14

Moreover, the strategy profile (m, m) is efficient and, in addition, Pareto-dominates the other strategy pairs. Because all strategy profiles are BNE, it is compelling to assume that (m, m) would be the effectively chosen equilibrium. However, a focal point argument may not convince that early settlement will result. This motivates the use of further instruments to ensure early settlement, such as a two-part tariff to coordinate payment activity in the morning.

It is evident that the above result does not change if $\psi = 0$. In a framework with settlement risk, MN find late settlement to result also with free but uncollateralised overdrafts. Even though we find that a fixed opportunity cost neutralises incentives to delay, (m, m) cannot be established as a unique BNE.

Also, if $\varepsilon = 0$, all strategy pairs remain equilibria. In contrast to before, however, no particular equilibrium is Pareto-dominant. To obtain the same result with priced but uncollateralised overdrafts as in MN, overdrafts must be for free.

Under a fixed cost of intraday credits, early and late settlement are BNE. As argued above, banks choose the Pareto-dominant morning equilibrium. While this may not suffice as an equilibrium selection argument, the situation facilitates the elimination of the late settlement equilibrium. In particular, the introduction of a two-part tariff allows early settlement to be changed into a dominant strategy.

Proposition 4 *Under a collateralised intraday credit regime with a daily fixed opportunity cost of collateral $\psi > 0$, a settlement shock $\varepsilon > 0$ and a two-part tariff $\tau > 0$, (m, m) is the unique BNE. The strategy m is a strictly dominating strategy for each player.*
Proof. *It is easy to see that $c(m, m) > c(a, m)$ and $c(m, a) > c(a, a)$ for bank i and for bank j $c(m, m) > c(m, a)$ and $c(a, m) > c(a, a)$.* ∎

In contrast to a variable opportunity cost of collateral, with a fixed opportunity cost any level of τ allows the elimination of late settlement or areas of indeterminacy. In particular, the effect of the two-part tariff does not depend on payment uncertainty, settlement risk and interest rates, as any $\tau > 0$ makes early settlement a strictly dominating strategy.

6   Collateralised overdraft facility

On 24 March 2011, the FRS introduced free but collateralised overdraft in addition to the priced but uncollateralised overdraft facility. Permanently prepledged collateral involves a fixed opportunity cost ψ. As this new intraday liquidity facility is of interest in its own right, the analysis focuses on priced but uncollateralised overdrafts only. Also, if collateral is insufficient to satisfy the demand for overdrafts, the game analysed in MN is played.

Again, banks are assumed to prepledge the full amount of collateral needed for overdrafts, i.e. 1\$. The crucial difference to the game with intraday credit and a fixed opportunity cost of collateral is that the strategy pair (a, a) does not involve costs related to settlement risk. This is related to the assumption that an

Figure 6: Overdraft with a fixed opportunity cost of collateral

	m	a

m	0
	          0
		pεR
		          0

a	0
	          pεR
		0
		          0

overdraft facility is open until the end of the day. Thus, banks are able to offset payments in period 2 without having to draw overnight loans. This is why banks are only prone to settlement risk if they play differing strategies. This says that $c(a,a)$ changes to $c(a,a) = \psi + (1-p)R$ instead of $c(a,a) = \psi + p\varepsilon R + (1-p)R$. All other cost functions remain the same.

Figure 6 represents the game in normal form with equations (9-12) simplified where appropriate.

Proposition 5 *Under a collateralised overdraft regime with fixed opportunity cost of collateral $\psi > 0$ and a settlement shock $\varepsilon > 0$, the strategy profiles (m,m) and (a,a) are BNE. The strategy profile (a,a) survives the elimination of weakly dominated strategies.*
Proof. *It is easy to see that $c(m,m) = c(a,m)$ and $c(a,a) > c(m,a)$ for bank i and $c(m,m) = c(a,m)$ and $c(a,a) > c(a,m)$ for bank j. Furthermore, it is also easy to see that $c(a,s) \geq c(m,s)$ and $c(s,a) \geq c(s,m)$ hold true $\forall \ s \in \{m,a\}$.* ∎

Because the model setup is identical to MN, it does not come as a surprise that the same results as for free overdrafts (i.e. $\psi = 0$) hold true. As a fixed cost of collateral is sunk, the game is played as if overdrafts are for free. Settlement risk determines the strategy pair (a,a) to be the surviving equilibrium even though a prepledged overdraft facility makes the cost of using intraday liquidity a sunk cost and both BNE – (m,m) and (a,a) – are efficient. (a,a) is the chosen strategy pair because playing morning results in exposure to settlement risk if the other bank pays in the afternoon. Letting $\varepsilon = 0$, it is easy to see that all strategy profiles become BNE and no particular one suggests that it should be chosen.

Again, with the exception that the two-part tariff $\tau > 0$ is added in case of late settlement, the same cost functions result as without the two-part tariff.

Proposition 6 *Under a collateralised overdraft regime with a daily fixed opportunity cost of collateral $\psi > 0$, a settlement shock $\varepsilon > 0$ and a two-part tariff $\tau > 0$, (m,m) is the efficient and Pareto-dominant strategy pair. Depending on τ, the following strategy profiles emerge as equilibria:*

1. if $\tau > p\varepsilon R$, (m,m) is the only BNE. The strategy m is a strictly dominating strategy for each player;

2. if $\tau = p\varepsilon R$, the strategy pairs (m,m) and (a,a) are BNE. The strategy pair (m,m) survives the elimination of weakly dominated strategies;

3. if $\tau < p\varepsilon R$, the strategy profiles (m,m) and (a,a) are BNE.

Proof. It is easy to see that $c(m,m) < c(a,a)$, $2c(m,m) < c(m,a) + c(a,m)$. Furthermore, $c(m,m) < c(m,a)$ and $c(m,m) < c(a,m)$. Therefore, the strategy profile is both efficient and Pareto-dominant.

1. If $\tau > p\varepsilon R$, it is easy to see that for bank i $c(m,m) = c(a,m)$ and $c(m,a) > c(a,a)$ and for bank j $c(m,m) = c(m,a)$ and $c(a,m) > c(a,a)$. Furthermore, $\forall\ s \in \{m,a\}$ it holds true that for bank i $c(m,s) \geq c(a,s)$ and for bank j $c(s,m) \geq c(s,a)$;

2. If $\tau = p\varepsilon R$, for all strategy pairs (s_i, s_j) for which $s_i \neq s_j$ it holds true that $c(s_i, s_j) > c(m,m)$ and $c(s_i, s_j) > c(a,a)$;

3. If $\tau < p\varepsilon R$, it is easy to see that for bank i $c(a,m) = c(a,a)$ and $c(a,a) > c(m,a)$ and for bank j $c(m,a) = c(a,a)$ and $c(m,a) > c(m,m)$. Furthermore, for bank i $c(a,s) \geq c(m,s)$ and for bank j $c(m,s) \geq c(a,s)$ hold true.

∎

The introduction of a two-part tariff makes the strategy pair (m,m) the efficient and Pareto-dominant equilibrium whatever value is chosen for $\tau > 0$. As a consequence, it is compelling to believe in (m,m) as the strategy pair chosen for any $\tau > 0$. Thus, earlier settlement in a collateralised but free overdraft system can be induced by establishing a two-part tariff. However, for $\tau < p\varepsilon R$, (a,a) remains a BNE next to (m,m) and there is no assurance that (m,m) is effectively chosen. In particular, if one tries to move from a well-established late settlement to an early settlement equilibrium, stronger incentives may well have to be provided, i.e. $\tau \geq p\varepsilon R$. Again, the implementation of a two-part tariff requires careful calibration.

7 Discussion

7.1 SIC

When presenting the stylised facts on SIC and Fedwire in Section 2, SIC was claimed to be represented by Proposition 4. Thus, banks are assumed to bear a fixed opportunity cost of collateral despite the fact that the SNB relies on a time-of-use dependent collateralisation of intraday credits. The fixed cost results from the double duty of collateral, i.e. banks can use collateral intraday that they must hold for other purposes overnight. This assertion is backed by

analysing a change in the SNB's collateralisation policy for discount window credits.

In 2005, collateralisation of intraday credit changed with the move from the SNB's old Lombard facility to its new liquidity-shortage financing facility (LSFF). The objective of both facilities is to allow banks to insure against potential liquidity shortages by means of a liquidity facility that is priced above the market's secured overnight interest rate. Also, both facilities require banks to define a credit limit and to pledge collateral accordingly on a yearly basis. The Lombard facility was phased out by the end of 2005. From 2006 onwards, the only facility to insure against liquidity shortages was the LSFF.

The SNB provides free but collateralised intraday liquidity by means of repos. Intraday repos are conducted against the same collateral eligible for overnight or longer-term repo with the SNB. While collateral pledged for the Lombard facility was not made available for drawing intraday credits, collateral pledged for the LSFF is available for that purpose. Accordingly, the period before 2005 should be associated with a variable opportunity cost of collateral because collateral for intraday credits was pledged on demand during the time of use. In contrast, collateral that is prepledged for LSFF is permanently blocked and results in a fixed opportunity cost of collateral.[10]

To assess the potential effects of the change from the Lombard facility to the LSFF, one can draw on Proposition 2 and Proposition 4. Two potential effects are associated with such a policy change: settlement behaviour and intraday liquidity demand may change.

First, with regard to settlement behaviour, Proposition 4 predicts early settlement for a fixed opportunity cost of collateral, while Proposition 2 predicts early or late equilibrium depending on the chosen two-part tariff. If $\tau < \omega(1 + \varepsilon - p)$ the model predicts (a, a), if $\tau > \omega(1 + \varepsilon)$ the model predicts (m, m). To assess whether a change in settlement behaviour can be expected, we need to evaluate the steepness of the two-part tariff. As p and ε are unknown, let us simply consider whether $\tau < \omega$ by a considerable margin. If this is the case, one would expect late settlement to result with a variable opportunity cost of collateral.

Nellen and Kraenzlin (2010) consider the hourly implicit intraday interest rate of repo transactions to mirror the opportunity cost of collateral. They estimate the annualised implicit hourly intraday interest rate to be 0.45bp from the Swiss franc repo market before the financial crisis of 2007. To be indifferent between sending a payment of CHF 4.58 million[11] now or awaiting incoming funds (assuming the bank receives a payment during the coming hour), the two-part tariff has to increase with an hourly rate of CHF 0.57. The effective beginning-of-day fee is CHF 0, whereas the end-of-day fee is CHF 2 from 2pm onwards.[12] However, starting at CHF 0, the end-of-day fee has to be CHF

---

[10] While not all banks establish a limit at the LSFF, the ones that do are responsible for more than 95% of the turnover in SIC.

[11] This is the average payment value for payments exceeding CHF 100,000 in 2006.

[12] The SIC day starts at 5pm (the day before the value date) and ends at 4.15pm. Changes in the two-part tariff occur at 8am, 11am and 2pm. There is an additional release fee increasing

Figure 7: Monthly average of the sum of intraday credits, yearly sum of Lombard / LSFF limits, average monthly reserve balances (CHF Mio) from 2000 to 2014
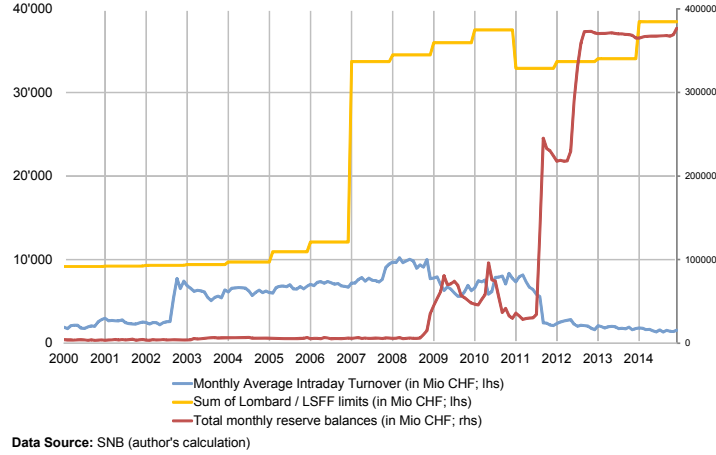
13.17 for a 23-hour settlement day to make banks indifferent to either sending the payment straightaway or awaiting incoming funds. Even though only the nine opening hours of the repo market are considered for calculating the hourly implicit intraday interest rate by Kraenzlin and Nellen (2010), the fee has to raise to CHF 4.58 by the end of the day. As both estimates considerably exceed CHF 2, we infer $\tau < \omega(1 + \varepsilon - p)$. Thus the current two-part tariff does not support early settlement for many large-value payments if the opportunity cost of collateral is variable. This view is validated by the move towards earlier settlement after 2009, when overnight interest rates reached the zero lower bound and reserve balances reached unprecedented levels (see Figure 7).

Thus the equilibrium is predicted to change from (a, a) to (m, m) with the move from the Lombard credit facility to the LSFF. However, inspection of Figure 2 reveals that no change in settlement behaviour took place around 2006.

Secondly, the move from (a, a) to (m, m) is expected to go along with a change in the demand for intraday credit. Let us assign a value of 1\$ for an intraday credit drawn over a single period. Correspondingly, a value of 2\$ for an intraday credit drawn during two periods is assigned. With a variable cost, bank i draws an intraday credit in period 1 with probability $(1 - \varepsilon)$ (remember that bank i receives a payment order for sure). With probability p, bank j also receives a payment instruction. With probability $(1 - \varepsilon)$, bank i receives the payment and draws an intraday credit, while with probability ε it delays the payment until period 2. With probability $(1 - p)$, only bank i receives a payment instruction. Again, with probability $(1 - \varepsilon)$, it draws an intraday credit, while

---

to CHF 1.00 after 2pm. However, the release fee influences incentives to release early rather than to settle early and to provide corresponding liquidity.

with probability ε it delays the payment until period 2 and directly draws an overnight credit. Thus the expected value of intraday credit being drawn over the day equals $1 - \varepsilon$.

With a fixed opportunity cost of collateral, the probability is p that both banks receive a payment instruction and prefund their payments. Then payments are offset in period 0 and banks do not need to draw further intraday credits. The probability is $(1 - p)$ that bank j does not receive a payment instruction. Bank i cannot pay back the intraday credit drawn at the end of period 0 and prolongs it to period 2. Whether settlement risk materialises does not play a role, as bank i will have to pay back the intraday credit at the end of period 1 and needs to draw an overnight credit. Thus the expected demand for intraday credit is $1 + (1 - p)$. Consequently, the demand for intraday credit with a fixed opportunity cost of collateral is greater than with a variable opportunity cost of collateral $(2 - p > 1 - \varepsilon)$.

Intraday credit demand can change in two possible ways. First, the overall demand measured as the sum of all intraday credit drawings over the day changes. Secondly, the sum of all intraday credits can be drawn for a shorter or longer period of time, i.e. outstanding intraday credits can be drawn earlier and be repaid later. None of these effects were observed after the change in collateralisation policy.

Figure 7 shows the sum of intraday credits drawn, the established limit for the LSFF / Lombard facility since 2005[13] when the new facility was introduced and the overnight reserve balance was available to settle in SIC. The demand of intraday credits has steadily increased since mid-2003. However, as reported in Kraenzlin and Nellen (2012), this is related to the increasing number of SIC participants. Only after the second half of 2007 can a pronounced increase be observed. This increase is related to the financial crisis starting in the second half of 2007. Another astonishing fact is that banks drawing intraday credits have never exploited their established limits by a considerable margin. If their demand were not satiated, banks could exploit limits without incurring any substantial extra costs.

Figure 8 shows a value-weighted daily duration of the sum of intraday credit drawings as an average number of hours during which intraday credits were outstanding. Again, we cannot observe a change in the demand for intraday credits.

Thus banks have perceived the opportunity cost of collateral to be fixed both before and after the introduction of the LSFF. This provides evidence for the presumption stipulated by Ball et al. (2011). They claim that the better performance of free but collateralised RTGS payment systems is related to double duty. If banks can use collateral that belongs to their regulatory-required liquidity buffers, double duty allows them to draw intraday credits at no extra cost. This was indeed the case for Switzerland. Both before and after the switch to the LSFF, collateral used to back up intraday credits has been

---

[13]The heavy increase in the sum of LSFF limits from 2006 onwards is related to a Swiss finish of Basle II liquidity regulations for large banks.

Figure 8: Daily value-weighted duration of intraday credit drawing (hours) from 2000 to 2014

Data Source: SNB (author's calculation)
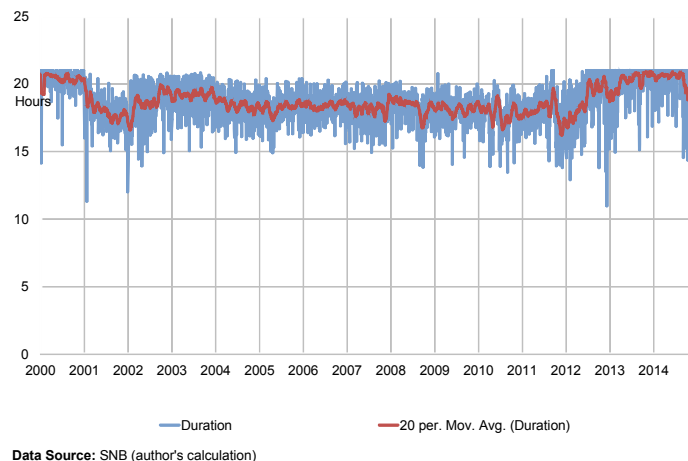
taken into account as liquidity buffers eligible under Basle II.[14]

7.2 Fedwire

The FRS grants free choice of usage of either the uncollateralised or the collateralised overdraft facility. Furfine (2001), Baglioni and Monticini (2008), Kraenzlin and Nellen (2010) and Jurgilas and Zikes (2014) provide evidence that the implicit intraday interest rate as a proxy of the opportunity cost of collateralisation is lower than the overdraft fee charged to cover the credit risk of uncollateralised intraday liquidity.[15] Thus one would expect banks to reduce uncollateralised overdrafts as far as possible because the collateralised overdraft facility provides a less expensive source of intraday liquidity. Even though current numbers on the relative use of the two facilities from 24 March 2011 onwards have to be treated with caution due to the high reserve balances, the choice made by banks seems to be clear-cut. Out of total peak (average) overdrafts, on average 97% (96%) were collateralised from April 2011 to March 2015. Thus the objective of reducing uncollateralised overdrafts was clearly successful.

At the same time, a move towards earlier settlement is observed in Fedwire funds. However, this move towards earlier settlement starts in late 2008 and is related to overnight reserve holdings showing peak values due to unconventional

---

[14]See http://www.snb.ch/en/emi/liqq for a list of collateral eligible as liquidity buffers. See http://www.snb.ch/en/iabout/stat/statpub/bchpub/stats/bankench for statistical evidence on the liquidity regulation. The list of eligible collateral for intraday repos is found on http://www.snb.ch/en/ifor/finmkt/operat/snbgc/id/finmkt_repos_baskets.

[15]Along with the introduction of the new facility, the FRS incentivised the switch from priced to prepledged overdrafts with an increase of the overdraft fee from 36bp to 50bp.

monetary policy (see Bech, Martin and McAndrews, 2012). This is consistent with theory. High reserve balances reduce settlement risk and provides free settlement liquidity. Unsurprisingly, the move to early settlement can be observed for SIC too (see Figures 1 and 2). Whether free but collateralised overdrafts can foster earlier settlement remains an open, empirical question until unconventional monetary policy is neutralised, with reserve levels and interest rates returning to pre-crisis levels.

Arguments provided by Ball et al. (2011) suggest that the introduction of a free but collateralised overdraft facility by the FRS would foster early settlement, as double duty allows for the reduction of settlement costs. While the evidence supports a lowering of intraday liquidity costs, Proposition 5 in this paper suggests that the basic incentive to settle late remains. The coordination later in the day is hard to change, since keeping it assures that settlement risk does not result in higher overnight refinancing needs in an overdraft system. In addition, the effective game played in Fedwire may even be closer to the one analysed in MN, as the FRS continues to provide priced but uncollateralised overdrafts. Thus the introduction of a free but collateralised overdraft facility without the use of further instruments may not affect settlement timing.

8   Conclusions

This is the first paper to apply the settlement risk approach of MN, analysing free but collateralised intraday liquidity facilities, the predominant form of intraday liquidity facilities worldwide. This is done for both collateralised intraday credit and collateralised overdraft facilities. While the literature associates overdraft facilities with priced but uncollateralised intraday liquidity, the FRS joined a group of 25 central banks offering a free but collateralised overdraft facility in March 2011.

The cost of collateral is a determining factor of settlement behaviour. Thus it is important to specify how the chosen liquidity facility and collateral policy affect the cost of collateral. Depending on the choice of the central bank's liquidity facility and collateral policy, multiple equilibria can result and valuable incentives for settlement coordination may be lost. This latter finding motivates the use of further instruments to coordinate payment activity, such as a two-part tariff. While a two-part tariff is usually motivated to promote the implementation of early settlement, in certain setups it is found to facilitate coordination in the first place. Finally, the effectiveness of the two-part tariff in coordinating payments and in inducing early settlement is also found to depend on the combination of the liquidity facility and the collateral policy.

A variable opportunity cost of intraday credit results in late settlement. While the two-part tariff may induce early settlement, it is difficult to implement. To induce early settlement, the tariff has to reflect the cost of intraday liquidity, payment uncertainty and settlement risk appropriately. A fixed cost for intraday credit results in a multiplicity of equilibria and does not allow the choice of early settlement as the Pareto-efficient equilibrium. However, a small

but strictly positive two-part tariff can easily establish early settlement as the unique equilibrium. Thus the two-part tariff is found to be an effective instrument to coordinate payment strategies and implement early settlement for a fixed opportunity cost of collateral. A collateralised overdraft facility results in late settlement and is not able to achieve the FRS's second objective associated with the introduction of this facility, namely imposing early settlement. Even though a two-part tariff is able to induce early settlement, careful calibration is again required to avoid a multiplicity of equilibria.

Model predictions are validated by a comparison between Fedwire funds and SIC. Furthermore, stylised facts from a change in the collateralisation policy of the SNB support the view that permanently prepledged collateral is a sufficient but not a necessary condition to result in a fixed opportunity cost of collateral. The SNB's discount window facility type (LSFF) requires prepledged collateral that can be used to draw intraday credits. Before the introduction of the LSFF in 2005, Swiss banks were able to collateralise intraday credits with assets that at the same time served as regulatory-required liquidity buffers – a practice referred to as double duty. As Ball et al. (2011) point out, if banks are able to draw intraday liquidity at no extra cost, early settlement may result.

Ota (2011) suggests a two-part tariff to be more efficient in comparison to through-put rules in an environment with a delay cost, payment certainty and heterogeneity in liquidity costs. Ota (2011) highlights that his findings may not survive payment uncertainty. This assertion is validated in an intraday liquidity management game driven by payment uncertainty and settlement risk. In particular, payment coordination with a two-part tariff is found to be nontrivial unless the cost of intraday liquidity is fixed. Fixed or sunk costs leave all strategy combinations as equilibria. Thus a small but strictly positive two-part tariff is sufficient to induce early settlement. In contrast, for systems with a variable cost of intraday credit, careful calibration is required, as a wrongly calibrated tariff may destroy settlement coordination. To a somewhat lesser degree, this holds true for systems that offer a collateralised overdraft facility.

While the choice of instrument to coordinate on early settlement seems to be appropriate for SIC, Ota (2011) raises doubts on whether the given calibration of the two-part tariff allows for efficient cost-sharing between banks that are subject to heterogeneous liquidity costs. As outlined in Heller, Nellen and Sturm (2000), one should further consider that some systems settle heterogeneous payments. In particular, SIC serves both as a retail and a large-value payment system. For instance, Rochet and Tirole (1996) and Vital (1990) understand the two-part tariff as an instrument to sequence payments rather than to induce early settlement for all payments. This is in line with the observation by Nellen (2010) that SIC participants released and settled small-value payments earlier, and large-value payments later, after the two-part tariff was introduced in April 1988. These authors perceive sequencing of payments to allow for liquidity-saving settlement.

Indeed, the steepness of the two-part tariff is indicative, as it does not provide strong enough incentives to settle very large payments early, but does so for small-value payments. As MN set out, the effects of settlement risk in coor-

dinating on late settlement are strengthened if one considers counterparty risk. This particularly affects large-value payments, whereas small-value payments bear negligible credit risk. A two-part tariff might have to be extremely steep to induce banks to move large payments to earlier settlement hours.

9   References

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

Armantier, Olivier, Jeffrey Arnold and James McAndrews (2008). Changes in the timing distribution of Fedwire funds transfers. Federal Reserve Bank of New York Economic Policy Review, 14(2), 83-112.

Ball, Alan, Edward Danbee, Mark Manning and Anna Wetherilt (2011). Intraday Liquidity: Risk and Regulation. Bank of England, Financial Stability Papers No. 11.

Bartolini, Leonardo, Spence Hilton and James McAndrews (2010). Settlement delays in the money market. Journal of Banking and Finance, 34, 934–945.

Bech, Morten and Rod Garratt (2003). The intraday liquidity management game. Journal of Economic Theory, 109(2), 198-219.

Bech, Morten, Antoine Martin and James McAndrews (2012). Settlement Liquidity and Monetary Policy Implementation - Lessons from the Financial Crisis. Federal Reserve Bank of New York, Economic Policy Review, Issue March, 3-20.

Federal Reserve System (2011). Guide to the Federal Reserve's Payment System Risk Policy on Intraday Credit. Updated to reflect policy revisions effective March 24, 2011.

Furfine, C. (2001): Banks as monitors of other banks: evidence from the overnight federal funds market, Journal of Business, 74, 33-57.

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

Koboyakawa, Shuji. (1997). The comparative analysis of settlement systems. Centre for Economic Policy Research Discussion Paper No. 1667.

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

Jurgilas, Marius and Antoine Martin (2013). Liquidity-saving mechanisms in collateral-based RTGS payment systems. Annals of Finance, 9(1), 29-60.

Jurgilas, Marius and Filip Zikes (2014). Implicit intraday interest rate in the UK unsecured overnight money market. Journal of Financial Intermediation, 23 ,232–254.

Martin, Antoine, James McAndrews (2009). Liquidity-saving mechanisms. Journal of Monetary Economics, 55, 554–567.

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.

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

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.

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

Rochet, Jean-Charles and Jean Tirole (1996). Controlling Risk in Payment Systems. Journal of Money, Credit, and Banking, 28, 4 (Part 2), 832-62.

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.

Recent SNB Working Papers