Intraday Liquidity Around the World*

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September 13, 2021

Abstract

We study intraday liquidity usage and its determinants using a unique cross-country data set on large-value payments. We document that the amount of intraday liquidity that depository institutions around the world use *each day* equals, on average, 15% of their total daily payment values or 2.8% of their countries' GDP. We then define and calculate system-level measures of liquidity efficiency and inequality in liquidity provision. We show that these measures vary systematically with participants' degree of payment coordination, the quantity and opportunity cost of central bank reserves and institutional characteristics such as incentives for early payment submissions and Liquidity Saving Mechanism (LSM) design features. Our results are consistent with payment system participants actively managing intraday liquidity and acting strategically

*Among the authors of this paper are members/alternates of the user groups with access to TARGET2 data in accordance with Article 1(2) of Decision ECB/2017/2080 of 22 September 2017 on access to and use of certain TARGET2 data. The European Central Bank, the Deutsche Bundesbank, the Market Infrastructure Board (MIB) and the Market Infrastructure and Payments Committee (MIPC) have checked the paper against the rules for guaranteeing the confidentiality of transaction-level data imposed by the MIB pursuant to Article 1(4) of the above mentioned issue. The views expressed in the paper are solely those of the authors and do not necessarily represent the views of the authors' affiliations, listed below, or any other person associated with these institutions. The authors wish to thank Derek Brito, Adam Epp, Othón Moreno González, Aldo Juárez Acevedo, Carlos León-Rincón, Clara Machado-Franco, Carlos Navarro Ramirez, Kristian Nørgaard Bentsen, Fabio Ortega-Castro, Patrick Papsdorf, Michael Pywell, Matthieu Rüttimann, Teresa Samuel, Takeshi Shirakami and Flurina Strasser for their contributions to the project.

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in order to do so. System participants also appear to condition their payment behavior on specific LSM characteristics, which may weaken some of the LSMs' intended effects.

1 Introduction

Financial institutions manage their intraday liquidity to meet obligations that arise during the day. These obligations are typically associated with (large) payments that financial institutions make to one another, in central bank money, using dedicated electronic networks collectively referred to as large-value payment systems (LVPSs). LVPSs in most jurisdictions settle their participants' payments on a gross basis, meaning that any payments need to be pre-funded.[1] While settlement of transactions on a gross basis helps to reduce credit risk [Bech and Hobjin (2007), Kahn and Roberds (1998)] it is also liquidity-intensive with intraday liquidity needs arising whenever there are timing mismatches between same-day incoming and outgoing payments. These intraday liquidity needs can be sizeable and usually much larger than banks' net daily obligations, especially during times of stress. This became evident during the financial crisis of 2008-09 by the collapse of Lehman Brothers.[2] In response, regulatory reforms since the financial crisis of 2008-09 have sought to address risks arising from intraday liquidity shortfalls.[3]

This paper is the first to measure intraday liquidity usage across multiple jurisdictions over a long period of time and study its determinants. For this purpose, we use proprietary data on individual LVPS transactions, between financial institutions and other payment system participants, in each jurisdiction. This data is used to measure, for each jurisdiction and on a daily frequency, the aggregate amount of liquidity that institutions use to cover their intraday obligations and also to describe overall payment activity. Our data spans several major economies, which account collectively for more than 45% of the world's GDP and as such is highly representative of global payment activity and intraday liquidity usage. The jurisdictions in our sample vary with respect to such institutional arrangements as the terms under which the central bank provides intraday credit, the presence of incentives for banks to settle their payments earlier in the day, as well as the presence and the particular design features of liquidity saving mechanisms (LSMs).[4] This allows us to compare and

[1] For this reason such payment systems are also referred to as Real-Time Gross Settlement (RTGS) systems.

[2] According to the examiner's post-mortem for Lehman, the company had a total liquid asset pool of $25 billion as of September 12, 2008. Of this, $16 billion was pledged as collateral with clearing and custodian banks with the exclusive purpose of covering intraday liquidity needs. This meant that a substantial fraction of Lehman's liquid assets were encumbered and unavailable to meet other obligations, which on that day exceeded Lehman's available liquidity and led to its demise. See Valukas (2010).

[3] Intraday liquidity risk is directly addressed by the "Principles for Sound Liquidity Risk Management and Supervision" issued by the Basel Committee on Banking Supervision [BIS (2008)]. For instance, Principle 8 states that "A bank should actively manage its intraday liquidity positions and risks to meet payment and settlement obligations on a timely basis under both normal and stressed conditions and thus contribute to the smooth functioning of the payment and settlement systems". For an overview of intraday liquidity regulation see Ball et al. (2011).

[4] LSMs are mechanisms that offset or net payments on a frequent basis during the day. As such, they allow payment system participants to economize on intraday liquidity. The exact payment offsetting/netting criteria may vary across LSMs. We provide more details on LSM design characteristics in Section 4.4.

contrast their impact on intraday liquidity usage. Furthermore, our data spans an eventful 17-year period (2003-20) that includes the financial crisis of 2008-09 and the subsequent central bank interventions that took place in several of the jurisdictions of our sample.

We start our analysis by measuring, for each jurisdiction, aggregate amounts of liquidity used by banks and other participants to cover their payment obligations during the day. Participants can meet their obligations by either using their own reserves balances, or by obtaining intraday credit from the central bank, or by recycling incoming payments from other system participants.[5] We find that the amounts of intraday liquidity that participants use by tapping their reserves or by borrowing from the central bank, is economically significant. For example, in the US, participants (mostly banks) with Fed reserve accounts collectively use, during our sample period, on average, $630 billion *each day*, with a maximum value of about $1 trillion. For the Eurosystem, the daily average and maximum values are $443 billion and $800 billion, respectively. On average, across jurisdictions and over our entire sample period, participants use, each day, the equivalent of 15% of aggregate daily payment values or about 2.8% of their countries'/jurisdictions' GDP in order to cover their intraday liquidity needs. These numbers are large and highlight the financial stability relevance of intraday liquidity.

Given that participants often choose when to settle their payments on a given day, and given that incoming payments can be used to fund outgoing ones, LVPSs may give rise to strategic effects since recycling incoming payments allows participants to economize on their own liquidity usage [Bech and Garratt (2003)]. For this reason, we calculate, for each jurisdiction, a liquidity efficiency measure as in Benos et al. (2014), defined as the ratio of aggregate payment values to aggregate intraday liquidity used. This measure captures the degree to which intraday liquidity needs are met by payment recycling in a given LVPS. We show that this ratio varies substantially across systems and over time. For example, for every unit of intraday liquidity used, UK participants make on average 13 units worth of payments, whereas participants in Denmark make 2.5 units worth of payments.

Similarly, given that payments are, to some extent, recycled in an LVPS, we examine whether liquidity is provided by system participants in a manner proportional to their own payment obligations, or whether most participants rely on just few other ones to make payments first and supply liquidity to the LVPS for the rest to (re)use. This matters for financial stability because a high degree of inequality in liquidity provision could mean that the LVPS is reliant on just a few participants to function smoothly. Should these liquidity-supplying participants choose to hoard on liquidity or otherwise not be able to supply it, during times of stress, this could potentially affect the ability of the other participants to meet their obligations. As such, we calculate a Gini coefficient of relative liquidity provision as in Denbee et al. (2015) and show that this coefficient also varies over time and across jurisdictions. Why do such differences in efficiency and inequality in liquidity provision arise? This motivates the rest of our analysis.

Since intraday liquidity usage is a direct function of participant activity in an LVPS, we construct two additional variables to capture key elements of this activity, namely the timing and degree of coordination of payments. As such, we calculate, for each jurisdiction, the value-weighted average settlement time as well as a measure of payment dispersion

[5] This includes cases where participants obtain credit from one another.

across system participants. In panel regressions, estimated across days and jurisdictions, we condition these activity variables on a number of regressors that include both time-varying factors, such as the total amount of reserves available each day and the opportunity cost of holding them, as well as time-invariant institutional characteristics, such as the presence of incentives to settle payments early, the central bank intraday credit regime and the various LSM design features, which pertain to the criteria and algorithms used to offset payments.[6] Our cross-system data includes different combinations of LSM design characteristics which allows us to compare them and assess their impact on intraday liquidity usage.

We find that participant activity correlates significantly with most of these variables in a manner mostly consistent with theoretical predictions. For example, higher levels of reserves balances are associated with earlier settlement times and reduced payment coordination both of which are consistent with reduced participant incentives to economize on liquidity.[7] On the other hand, increases in the opportunity cost of reserves are associated with later settlement times as well as reduced payment coordination, which is consistent with liquidity hoarding, particularly at times of stress.

Regarding institutional characteristics, although incentives to settle payments early are associated with earlier settlement times, as one might expect, the rather unexpected and thus most interesting finding here is that there is a stronger statistical correlation with payment coordination. A potential explanation for this is that the incentives to pay early also increase the incentives for payment coordination as participants may not wish to deviate too much from average behavior, as this might stigmatize them. This might be especially true if the incentives for early payment submission take the form of penalties to which deviating participants might be liable to. The possibility to obtain intraday credit from the central bank at a lower collateral cost is associated with reduced payment coordination, also consistent with fewer incentives to economize on liquidity but paradoxically this is also associated with later settlement times. This is surprising, as one might expect that a lower collateral cost for central bank liquidity would decrease participants' incentives to delay their payments.

We also explore how our activity (i.e. payment timing and coordination) variables are related to LSMs. Overall, the presence of an LSM queue correlates only weakly with these variables; and while the effects are in a direction consistent with theoretical predictions they are not statistically significant. However, specific LSM design features are strongly correlated with our activity variables. For example, liquidity saving features of LSMs (such as the ability of LSMs to bypass the priority of payments in the queue in order to maximize offsetting benefits and also the ability to offset payments on a multilateral basis) are both associated with earlier settlement times. This is consistent with theoretical predictions (Martin and McAndrews (2008)) suggesting that LSMs reduce banks' incentives to delay their outgoing payments in anticipation of incoming ones. Some of our results also suggest that system participants could potentially be conditioning their behavior on these LSM features in a way that reduces (or negates) their intended effect. For instance, we find that the FIFO bypass functionality, which allows LSMs to more flexibly offset payments, is associated with reduced

[6] For more details, see BIS (1997) and BIS (2005).

[7] This is also consistent with the findings of Bech et al. (2012) who look at the impact of reserve balances on settlement times in the US Fedwire system.

payment coordination. One potential explanation of this is that, in its presence, participants have less of an incentive to coordinate their payments.

In the last part of our analysis, we use our activity variables as regressors in specifications where the dependent variables are our our measures of liquidity efficiency and inequality in liquidity provision. Given that our activity variables may not capture all aspects of LVPS participant behaviour, we also include in these specifications as regressors the same time-varying and institutional variables described above. Consistent with theory, our results show that efficiency is strongly and positively correlated with the degree of payment coordination. This provides empirical support to the literature that casts LVPS interactions in a game-theoretic setting (e.g. Bech and Garratt (2003)). Our results also suggest that the amount of available liquidity as well as its opportunity cost affect intraday liquidity efficiency primarily via their effect on payment coordination.

Institutional characteristics also matter for intraday liquidity efficiency. Incentives for early settlement help banks economize on liquidity, largely by inducing them to coordinate the timing of their payments. Thus, if payment incentives have the effect of inducing coordination, as discussed above, this results in a clear improvement in liquidity efficiency. Our results also show that intraday liquidity usage is correlated with the collateral costs of central bank intraday credit. In regimes where intraday credit can be obtained on an uncollateralized basis, or where the cost of collateral is lower, intraday liquidity efficiency is also lower and this is almost entirely driven by the reduced coordination among participating institutions that was also discussed earlier. Finally, the presence of an LSM in an LVPS is statistically uncorrelated with our liquidity efficiency measure. This is consistent with our earlier finding that LSMs are overall also uncorrelated with our activity variables. There are a couple of potential non-exclusive explanations for this. First, a large segment of our data overlaps with periods of ample reserves balances in many jurisdictions, as a result of central bank QE programs. This means that incentives to economize on liquidity have likely been lower in these jurisdictions with LVPS participants using LSMs less intensively as a result.[8] Alternatively, different LSM features are influencing participant behavior and liquidity usage in different ways, thus potentially minimizing the overall intended effect of LSMs. For example, in addition to our finding that participant payment coordination is negatively correlated with the FIFO bypass functionality, we also find that it is positively correlated with the multilateral offsetting one. Given that payment coordination strongly correlates with liquidity efficiency, this suggests that the two LSM functionalities could be related with coordination and liquidity efficiency in opposite ways, thus weakening the overall relationship between the LSM and liquidity efficiency.

Regarding our measure of inequality in liquidity provision, we find that the Gini coefficient is lower when the opportunity cost of liquidity increases, when reserves balances are higher and when there are incentives for early payments in place. These results are consistent with the idea that some participants may choose to hoard on liquidity when liquidity is expensive and that an abundance of reserves alongside requirements for early payments mitigate this problem.

Overall, our paper is the first to study, on a cross-LVPS basis, the relation between intraday liquidity and institutional arrangements such as the central bank's intraday credit

[8] Unfortunately, we do not observe LSM usage and as such, we cannot empirically verify this.

regime, the presence of incentives for early payment submissions and the design of LSMs. Such an empirical test requires data from multiple jurisdictions and our cross-country data allows us to do precisely that.

The rest of the paper proceeds as follows: In Section 2 we review the literature; in Section 3 we describe the data. In Section 4 we define and measure intraday liquidity usage as well as payment system activity variables. This is followed in Section 5 by our empirical analysis and results. We conclude and discuss future work in Section 6.

2 Literature review

The literature on intraday liquidity is relatively scarce not least because there are no explicit intraday money markets and banks typically obtain intraday credit from the central bank at a low cost. This is in contrast to overnight liquidity where in most jurisdictions, central banks primarily rely on the overnight market to supply and allocate reserves. This discrepancy, however, has motivated a number of theoretical studies on whether it is optimal to supply liquidity via a market mechanism or via the central bank at a pre-determined, fixed price. Freeman (1999) sets up a model where the asynchronous presence of borrowers and lenders in the money market creates a need for liquidity which can be met by the central bank either via a standing facility (at a pre-determined price) or by open market operations. Abstracting from moral hazard, Freeman (1999) shows that open market operations enable better risk sharing. Chapman and Martin (2013) extend this model to account for moral hazard and show that open market operations continue to yield more efficient outcomes as long as the central bank interacts with a select subset of banks that are themselves unaffected by moral hazard. That way, the price of liquidity reflects information available to market participants. While these arguments suggest that an explicit market for intraday liquidity might be desirable, there are also arguments in favor of the current regime: A lower cost of intraday liquidity, as typically provided by most central banks, reduces banks' incentives for delaying their payments and also protects them from costly intraday overdrafts that banks could have faced in an explicit intraday money market. Martin and McAndrews (2010) provide a comprehensive overview of these arguments. The unique data across jurisdictions that our paper utilizes, allow us to directly test some of these theoretical predictions.

Although no explicit intraday money markets exist, a number of papers have looked at whether such markets nevertheless implicitly exist through differentiated prices of overnight loans with different settlement times. Studies that use data prior to the 2007-08 financial crisis generally find small but positive implied intraday rates. For example, Furfine (2001) estimates the hourly intraday unsecured rate in Fedwire to be around 0.9 bps whereas Kraenzlin and Nellen (2010) estimate the Swiss hourly repo rate to be around 0.43 bps. Similarly, Baglioni and Monticini (2008) detect economically small intraday rates in the unsecured Italian e-MID market. However, these implied rates significantly increased during the financial crisis. Baglioni and Monticini (2010) and Jurgilas and Zikes (2014) both report more than ten-fold increases in implied unsecured intraday rates in the Italian e-MID and Sterling markets respectively during the crisis. They argue that these rises reflect the increased opportunity costs of pledging collateral with the central bank. While our paper does not estimate implied intraday rates, it complements this literature by calculating the aggregate quantities of intraday liquidity deployed in each jurisdiction and by examining their determinants.

Our paper is also closely linked to the literature of payment system design, of strategic behavior of participants within payment systems and of central bank policies regarding the provision of intraday credit. On the theoretical side, Kahn and Roberds (2009) compare and contrast the properties of pure RTGS systems with those that settle payments on a net basis (also known as deferred net settlement or DNS systems). Their paper formalizes the key tradeoff between RTGS and DNS systems, namely that while the latter are more liquidity-efficient, they also give rise to intraday credit exposures among system participants which may create moral hazard.

Given the prevalence of RTGS systems around the world, Bech and Garratt (2003) describe the incentives and equilibrium strategies of their participants. Their key intuition is that since incoming payments can be recycled in order to fund outgoing ones, this creates a rich set of possible interactions between system participants, the nature of which depends on the conditions under which the central bank provides intraday liquidity. Bech and Garratt (2003) show that in a collateralized (and free of fees) credit regime, the strategies and payoffs faced by RTGS system participants are those of a "prisoner's dilemma" whereas in a priced (and uncollateralized) credit regime, they are those of a "stag hunt". The authors make the key assumption that in a collateralized credit regime participants always bear a collateral opportunity cost, whereas in a priced credit regime they only do so when their payment requests are not coordinated and therefore not offset. Under this assumption, delaying payments is always socially inefficient when credit is collateralized because the cost of collateral is sunk. On the contrary, when credit is uncollateralized and priced, delays can be efficient if they lead to liquidity savings. In all cases, Bech and Garratt (2003) consider single-stage games, meaning that in the repeated versions of the "prisoner's dilemma", one might expect efficient (cooperative) equilibria to arise. Building on their approach, Mills and Nesmith (2008) study payments equilibria when participants strategically interact both in payment and security settlement systems. Their analysis suggests that settlement risk may lead to late-day concentration of payments and, moreover, in the presence of settlement risk, an overdraft fee can have a greater impact on the concentration of transactions. Nellen (2019) also studies the intraday liquidity management game in the presence of credit regimes with fixed and variable cost focusing on different designs of intraday liquidity facilities provided by a central bank and associated incentives (or disincentives) for early settlement. In his model, a variable cost credit regime leads to late settlement as it is assumed to have a positive marginal cost, in contrast to a regime with fixed credit cost which has zero marginal cost. A fixed cost credit regime then eliminates incentives to coordinate payments provided that intraday liquidity borrowed is available until the end of the day. In that scenario, a strictly positive transaction fee for late settlement will incentivize early settlement. Finally, Bech and Garratt (2012) theoretically show that a wide-scale disruption (caused either by operational outages or credit events) can lead to a breakdown in coordination among RTGS system participants and thus lead to an increase in the amount of intraday liquidity used.

The empirical evidence from a number of different jurisdictions suggests that banks coordinate their payments to some extent in order to economize on intraday liquidity. For instance, McAndrews and Rajan (2000) and Becher et al. (2008) show that in the US and UK RTGS systems respectively, banks use incoming payments to fund outgoing ones. Becher et al. (2008) attribute the high level of payment recycling in the UK system to its small membership and the throughput rules that are in place which require banks to make a certain amount of payments by various points of time during the day. However, payment coordination between RTGS system participants is not always a given and can break down due to some external event. Several papers have examined actual coordination failures and their impact. McAndrews and Potter (2002) document that in the days following the September 11, 2001 terrorist attacks, payment coordination between Fedwire participants dropped substantially, resulting in increased liquidity usage and triggering a short-term liquidity injection by the Fed.[9] Bech and Garratt (2012) and Benos et al. (2014) document coordination failures in the wake of Lehman's default, in the US and UK RTGS systems respectively. In both cases, payments were delayed with the evidence from the UK RTGS system further suggesting that these delays were targeted at banks with perceived higher credit risk.

Finally, our paper is also related to the literature on liquidity saving mechanisms (LSMs). This literature generally examines theoretically how the presence of an LSM affects the tradeoff between the cost of delaying payments and the cost of obtaining intraday liquidity in order to settle payments early. This typically involves a game-theoretic setup which captures the impact of an LSM on RTGS system participants' incentives. In this respect, Martin and McAndrews (2008) show that an LSM reduces banks' incentives to delay payments and this leads to payments being made earlier on average which, in turn, improves liquidity efficiency and welfare. However, there can also be instances where welfare is reduced in the presence of an LSM. This happens because LSMs reduce the degree of strategic complementarity relative to a pure RTGS system, since its offsetting functionality reduces participants' incentives to coordinate their payments. When a high degree of payment coordination is desirable (e.g. when a few participants have to make large payments that are urgent and cannot be queued) welfare is reduced because banks are forced to obtain intraday liquidity from the central bank at a cost. Jurgilas and Martin (2013) argue that such cases do not arise in collateral-based credit regimes where it is assumed that the opportunity cost of pledging collateral with the central bank is low. Evidence of strategic complementarity is also provided by Nellen et al. (2018) who show that as LSM queuing times in the Swiss RTGS were reduced, as a result of higher settlement balances, payment submissions into the queue were delayed thus offsetting the reduced queuing time. Our paper complements this literature by studying the impact of particular LSM design features on the incentives and behavior of RTGS system participants and how these features ultimately affect intraday liquidity usage.

3 Data

The primary source of data in our paper are payment messages from the large-value payment systems (LVPSs) of nine different jurisdictions: Brazil, Canada, Colombia, Denmark, the Eurosystem, Mexico, the United Kingdom, the United States and Switzerland. The payments in our data are typically large in value and are made among financial and other

[9] For instance, McAndrews and Potter (2002) report that the ratio of daily payment values to reserve balances dropped from more than 100 before September 11 to only 18 on September 14, 2001.

institutions with access to central bank reserve accounts. As such, they are made using central bank reserve balances in the local currency and, once processed, are final and irrevocable. Typical payments that are settled via LVPSs include unsecured wholesale money market loans and foreign exchange transactions. Many LVPSs also settle the cash legs for wholesale repo and securities transactions. LVPS systems are also regularly used to settle margin payments to clearing houses and support other payment systems to settle net obligations. These payments can be made or received either on the system participants' own account or on behalf of their customers. Furthermore, some LVPSs are also used to settle retail transactions.[10]

These data are available to central banks operating and/or overseeing their respective payment systems and contain information on the identities of payers and payees as well as the value, date and settlement time of the payments being made.[11] These granular data are confidential and for this reason are aggregated, in this study, across LVPS participants and used to construct, on a daily frequency, the variables described in Section 4. Since the aggregated data do not contain participant-specific information, they can be shared and put together to form a panel data set. Our data cover the period from 2006 to 2018 but data from some systems cover only sub-periods within this time range, due to availability constraints. Table 1 shows the data time range available for each jurisdiction, along with the number of daily observations and the local currency of payment denomination. Our final panel consists of 21,544 observations.

Table 1: Payment data sources. This table shows the large-value payments systems included in our study, their jurisdiction, their number of daily observations, their data range as well as the currency in which payments are denominated.

System name	Jurisdiction	N	First date	Last date	Currency
CHAPS	United Kingdom	3148	2006-01-03	2018-06-18	GBP
CUD	Colombia	2444	2008-07-01	2018-06-29	COP
Fedwire	United States	2523	2008-06-02	2018-06-26	USD
Kronos	Denmark	3120	2006-01-03	2018-06-29	DKK
LVTS	Canada	3170	2006-01-03	2018-07-31	CAD
SIC	Switzerland	2568	2008-06-03	2018-07-30	CHF
SPEI	Mexico	1967	2008-06-02	2016-06-29	MXN
STR	Brazil	4650	2003-01-02	2020-12-31	BRL
TARGET2	Eurosystem	2604	2008-06-02	2018-07-31	EUR

[10]One such system is the Swiss SIC. Nellen et al. (2018) show that retail payments in SIC help recycle settlement balances thus contributing to increased liquidity efficiency.

[11]In the presence of an LSM, payment settlement times are different from payment submission times. The latter refers to the point in time that a payment is submitted to the LSM queue. Banks receiving instructions by clients to make payments on their behalf, may also choose to settle these payments at a later time during the day. In both cases, we only use in our analysis settlement times as only these are consistently observed across systems.

To construct our variables of interest, we apply a set of filters on the raw payments data in a consistent manner across systems. Given our focus on intraday liquidity, we only use, as a general rule, transactions that affect a participant's liquidity position, that is, the funds available across a participant's accounts to make RTGS payments at a given time. This includes all interbank payments between settlement banks, payments that banks settle on behalf of their customers, as well as liquidity transfers to and from accounts reserved for ancillary systems.[12] Similarly, central bank transactions with system participants are included if they alter the participants' liquidity position, but are excluded if they are purely administrative or technical in nature.[13] Finally, central banks and ancillary systems such as CLS and securities settlement systems are out of scope of our analysis, as stand-alone entities, since they do not behave strategically as credit institutions may do. For this reason, we do not count them as system participants and do not examine their activity, although their interactions with the other system participants are within scope and included in our data.

Finally, we complement our payments data with information on the number of participants active in each RTGS system, the aggregate value of central bank reserve balances and the overnight unsecured interbank borrowing rate (or alternatively the central bank policy rate) as a proxy for the opportunity cost of liquidity.

4 Variables and summary statistics

4.1 Payment system activity and intraday liquidity

We start our analysis by calculating, for each system, the aggregate value of payments made and the amount of intraday liquidity used. Let $t \in \{1, 2, ..., T\}$ be a time partition of the daily business hours of each payment system. Let also $x_s^{i,j}(t)$ be the value of payments sent by participant i to participant j on day s and in time interval t. Then, the total value of payments made in that system on day s, is:

$$P_s \equiv \sum_{i,j,t} x_s^{i,j}(t) \tag{1}$$

Given a participant's incoming and outgoing payments, the amount of intraday liquidity used by that participant is equal to the amount of liquidity that the participant needs to have in place, in the form of reserves or intraday credit from the central bank, in order to meet its payment obligations for the day. This is the maximum cumulative net debit position that this participant attains during the day. Using the above notation, the net debit position of participant i, on day s and at time t is:

$$N_s^i(t) \equiv \sum_{k=1}^{t} \sum_{i \neq j} x_s^{i,j}(k) - x_s^{j,i}(k)$$

[12] Additional information on the ancillary systems linked to the LVPS in each jurisdiction, is provided in the Appendix.

[13] For example, a repayment of an overnight central bank loan is included whereas a liquidity transfer between two central bank reserve accounts held by the same participant is excluded.

and therefore the amount of intraday liquidity used by this participant for the day is:

$$L_s^i \equiv \max_t \{N_s^i(t), 0\}$$

The aggregate amount of intraday liquidity used in the payment system is then the sum, across system participants, of the individual amounts of own liquidity used:

$$L_s = \sum_i L_s^i \tag{2}$$

Figure 1 plots the aggregate values of payments made and liquidity used for each system in our sample. To facilitate comparison across systems, all values are reported in USD. Daily aggregate payment values are large and measured in the trillions of USD for the larger systems (Fedwire and TARGET2) and in the tens or hundreds of billions for the other systems. It is notable that payment values are elevated at times and in jurisdictions experiencing financial stress. This is evident, for example, in Fedwire (US), CHAPS (UK) and Kronos (Denmark) during the financial crisis of 2007-09 and in TARGET2 (Eurozone) during the European sovereign debt crisis of 2011-13. This likely reflects increased activity in financial markets as a result of higher market volatility. For instance, some LVPSs settle the cash leg of security transactions which tend to increase in volatile conditions, while LVPSs may also facilitate margin payments, either between market participants directly or via a clearing house, which also increase with market volatility.

The amount of intraday liquidity used in each system is also economically significant. For instance, in the US, the amount of intraday liquidity used in Fedwire fluctuates around \$630 billion daily with values reaching as high as \$1 trillion. The corresponding values for Eurozone's TARGET2 are \$443 and \$800 billion respectively. Across systems and over our sample time, daily intraday liquidity usage accounts for about 2.8% of GDP.

It is also evident that the amount of liquidity used is invariably lower than the total value of payments made as system participants may use incoming payments to fund outgoing ones, thus forgoing the need to use their own liquidity for this purpose. Although in all systems intraday liquidity used is highly correlated with the value of payments, as one would expect, the ratio of the two varies substantially across systems and over time. This motivates our measure of intraday liquidity efficiency.

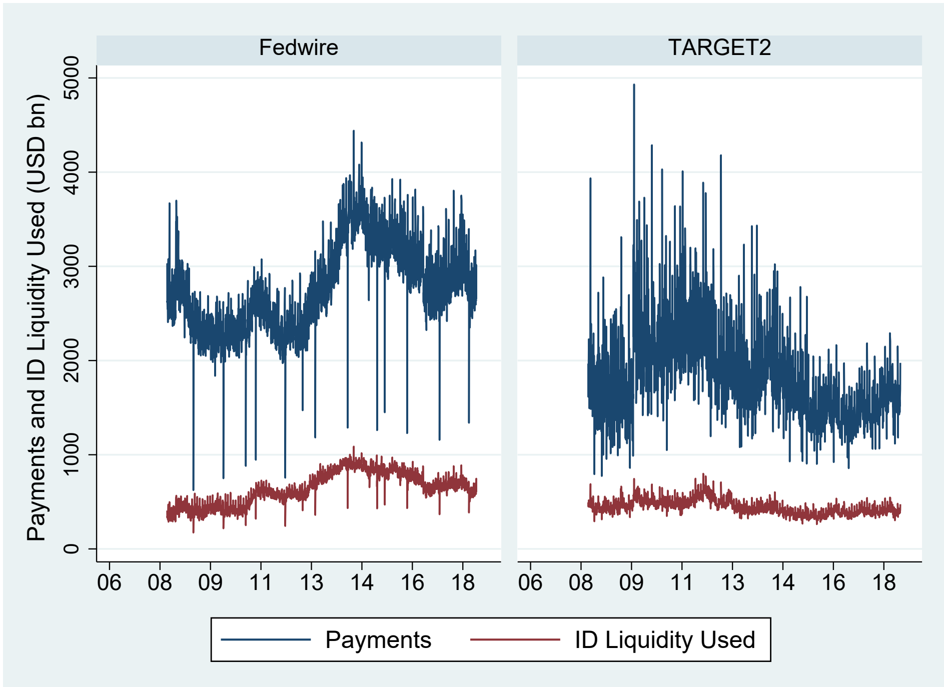
4.2 Efficiency and inequality in intraday liquidity usage

Following Benos et al. (2014), we define intraday liquidity efficiency, at the system level, to be the ratio of aggregate payment values over aggregate intraday liquidity used. In terms of our notation this is expressed as:

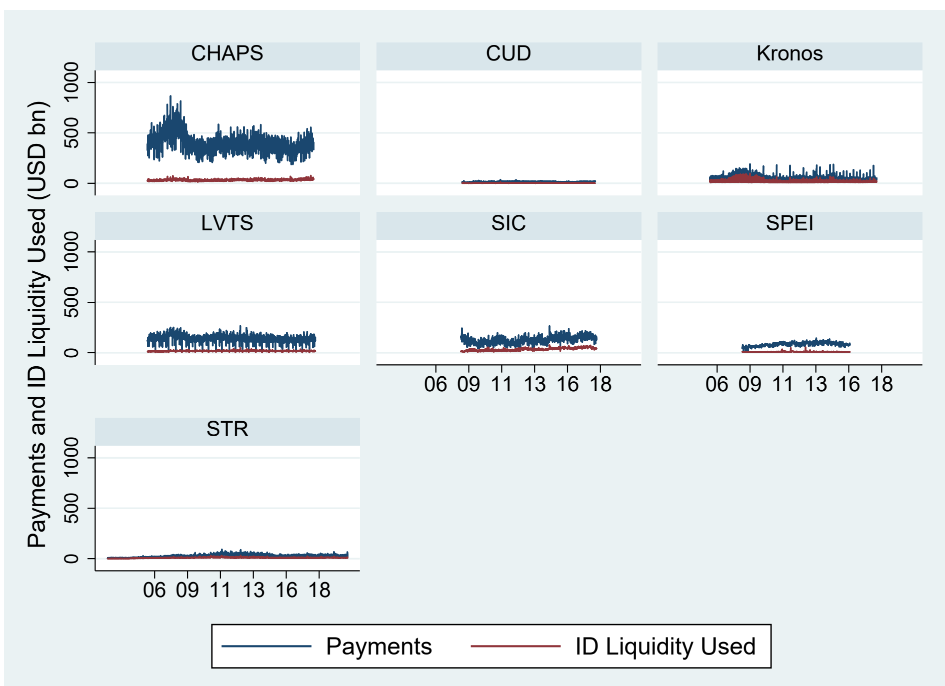
$$Q_s \equiv \frac{P_s}{L_s} \tag{3}$$

This ratio captures the value of payments that are made for each unit of intraday liquidity used. If system participants can meet their daily payment obligations with minimal liquidity usage, the ratio takes on higher values and the system is considered to be more liquidity-efficient. As mentioned earlier, liquidity efficiency will depend on the degree to

Figure 1: Daily aggregate values (in USD billions) of payments made (P) and liquidity used (L) by payment system. The two variables are defined in equations (1) and (2) respectively.



(a) "Large" systems



(b) "Smaller" systems

which payments are recycled as well as on the extent to which payment obligations are matched and offset via an LSM.[14] Figure 2 plots daily values of this measure for each system. For most systems (CUD, Fedwire, SIC, TARGET2) liquidity efficiency takes on values between four and six whereas CHAPS and Kronos appear to have higher and lower values, than the other systems, respectively. In all cases, there is variation over time with some systems (e.g. CHAPS, SIC) exhibiting higher variability than others. A key goal of our study is to understand why this variability arises and what makes systems more or less liquidity efficient.

Given that payments settle on a gross basis in all systems, liquidity efficiency is ultimately determined by the extent to which payments are coordinated and thus recycled in each system and over time. This assumes that system participants have the option to time and coordinate their payments and thus economize on liquidity. Whether they choose to do so should, in turn, depend on the cost of liquidity usage as well as the easiness of coordinating their payments. The former will likely depend on the unit opportunity cost (and available quantity) of reserves balances whereas the latter could depend on the presence of an LSM which is intended to incentivize the early submission of payments.

In our empirical analysis we explore these potential determinants of cross-sectional and time variability in liquidity efficiency. Our prior is that liquidity efficiency will increase with payment coordination and that payment coordination will itself depend on participants' incentives to coordinate. For instance, we expect that an increase in reserves balances will tend to reduce participants' incentives to coordinate their payments and thus negatively affect liquidity efficiency. Given that several jurisdictions in our sample engaged in quantitative easing programs that drastically increased the amount of aggregate reserves, it could be for this reason that efficiency is trending downward in the UK, the US and the Eurozone.

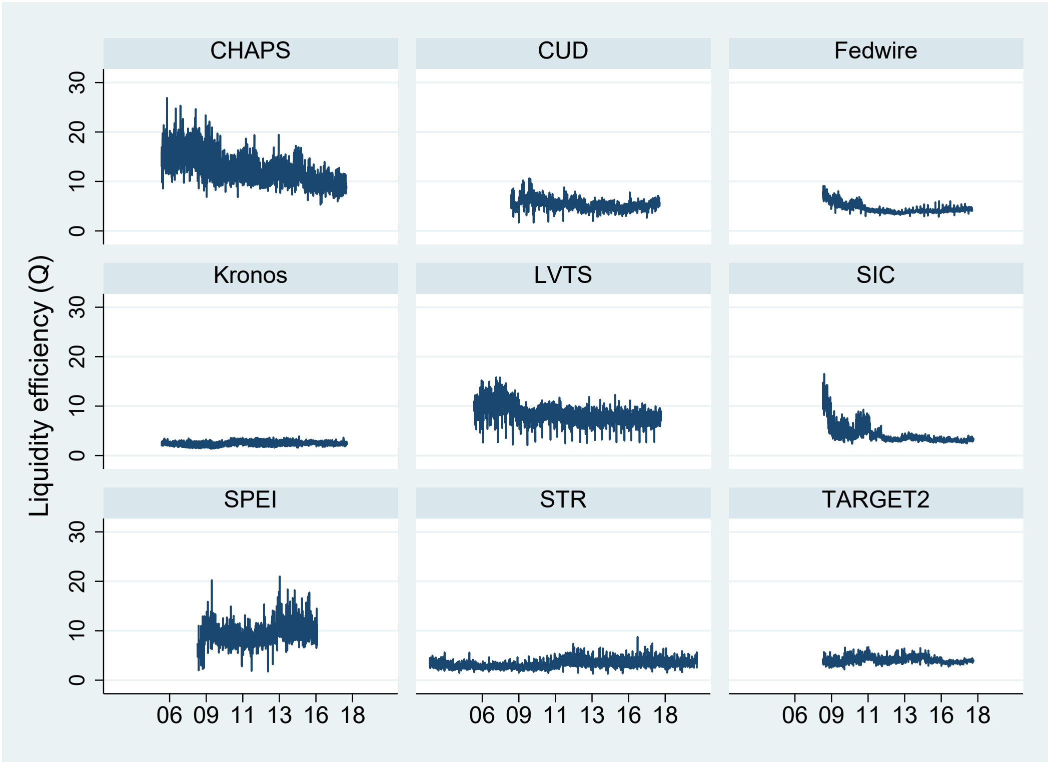
The opportunity cost of reserves is another potential determinant of efficiency though it is not a-priori clear what its effect could be. On the one hand, a higher opportunity cost could incentivize system participants to coordinate their payments, leading to higher liquidity efficiency. On the other hand, it could incentivize them to hoard on liquidity which could lead to a breakdown of coordination and a drop in efficiency.

Finally, we expect that payment coordination and efficiency will likely also depend on a number of institutional features such as incentives to submit payments early, the collateral cost of obtaining intraday credit from the central bank, the degree of tiering and the presence of an LSM with its various design features. As such, we expect that a lower collateral cost of intraday credit will dis-incentivize payment coordination (and reduce efficiency) whereas incentives for early payments will likely have the opposite effect. We are otherwise agnostic as to what is driving the sizeable time and cross-sectional variation in liquidity efficiency shown in Figure 2.

Finally, we measure how intraday liquidity usage is distributed across payment system participants and in particular whether it is proportional to the value of payments made by each participant. This is our measure of inequality in intraday liquidity usage. For this, we follow Denbee et al. (2015) and calculate the Gini coefficient over relative liquidity usage

[14] A system with a higher value for liquidity efficiency, as defined in this paper, does not imply that this system is overall "superior" to one with a lower value. This is because there are additional LVPS features that matter (e.g. settlement times) that are not captured by the liquidity efficiency measure.

Figure 2: Liquidity efficiency (Q) across systems. Liquidity efficiency is defined in equation (3).



(or liquidity cost) across participants in each jurisdiction. Let $P_s^i \equiv \sum_{j,t} x_s^{i,j}(t)$ be the total value of payments made by participant i on day s and let L_s^i be the participant's amount of intraday liquidity used (as defined above). Then, we define the relative liquidity usage (or liquidity cost) of that participant to be:

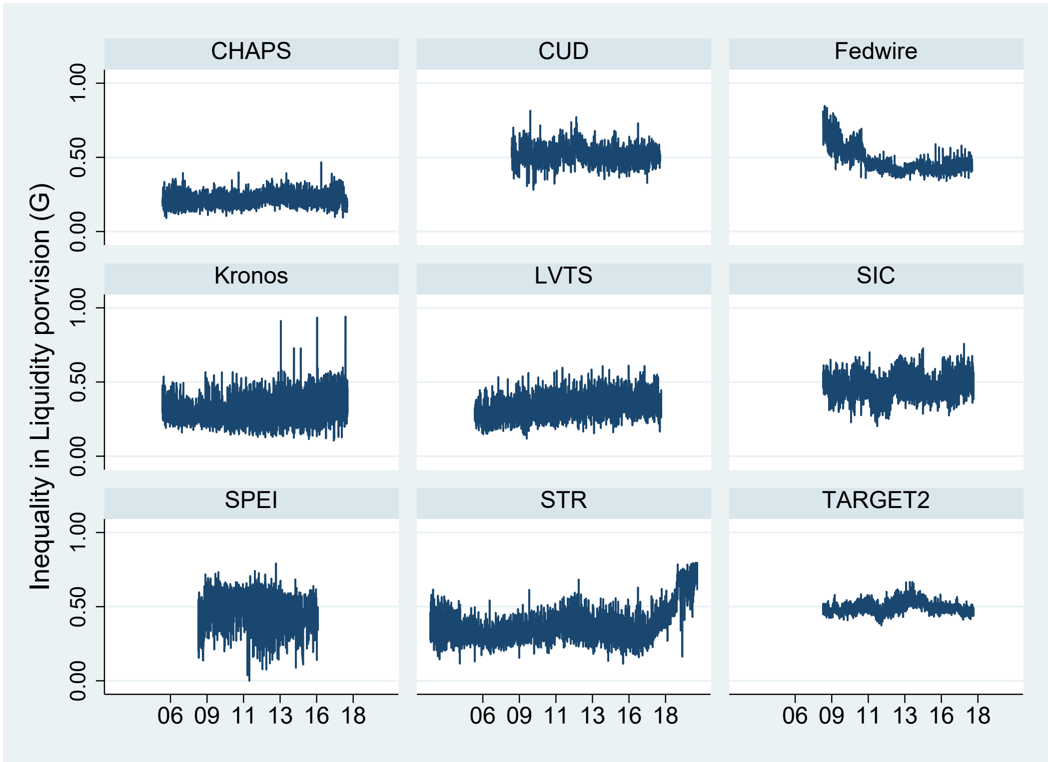
$$l_s^i \equiv \frac{L_s^i}{P_s^i}$$

and the Gini coefficient of relative liquidity usage across participants is then the volume-weighted average of the pairwise differences in relative liquidity usage:

$$G_s = \frac{1}{2M^2\mu}\left(\sum_i \sum_j m^i m^j |l_s^i - l_s^j|\right) \tag{4}$$

where m^j is the number of payments made by participant j, M is the total number of payments made by all participants, μ is the average relative liquidity cost of all payments and l^j is the relative liquidity usage of participant j. The Gini coefficient takes a minimum value of zero when each participant uses the same amount of intraday liquidity relative to their payments. On the other extreme, it takes a value of one when all of the intraday liquidity cost is incurred by a single participant. In Figure 3 we plot daily values of the Gini coefficients, over our sample period, for each jurisdiction. The Gini coefficient varies substantially over time and also across systems. In our empirical analysis we explore the determinants of this variability.

Figure 3: Inequality in intraday liquidity usage (G) across systems. Inequality is captured by the Gini coefficient of relative liquidity usage defined in equation (4).



4.3 Payment timing and dispersion

Given that intraday liquidity usage depends on the degree of payment recycling which, in turn, depends on payment timing, we construct two additional variables to capture the value-weighted average settlement time and the degree of payment coordination or, inversely, dispersion. Let $P_s(t)$ be the aggregate value of payments made on day s and in time interval t. Then the value-weighted average settlement time on that day is:

$$T_s \equiv \frac{\sum_{t=1}^{T} tP_s(t)}{\sum_{t=1}^{T} P_s(t)} \tag{5}$$

where the denominator is the total value sent through the system on day s. To quantify payment coordination, we first calculate, for a given system, the ten deciles of daily payment timing. Payment decile $D_s(d)$ on day s is defined as:

$$D_s(d) \equiv \arg\min_k \frac{\sum_{t=1}^{k} P_s(t)}{\sum_{t=1}^{T} P_s(t)} - d \geq 0$$

which is the earliest point in time during the day by which a fraction d of total daily payment value has been made.[15] Our measure of payment dispersion is then defined as:

$$Tdiff_s \equiv \frac{1}{2}[D_s(0.7) + D_s(0.8) - D_s(0.2) - D_s(0.3)] \quad (6)$$

This variable can be interpreted as a proxy for system participants' degree of payment coordination with higher values implying a smaller degree of coordination and vice versa. Since it is based on payment value deciles, our dispersion measure does not depend on the time of the day that coordination in payments might take place. However, since we only observe payment settlement times and not payment submission times, this variable is a noisy proxy of the degree to which payment submission is coordinated among participants.

Both the value-weighted average settlement time and payment dispersion are plotted, for each system, in Figures 4 and 5. Average settlement time is relatively stable for most systems over the longer run and centered around the middle of each system's business hours.[16] However, there appears to be a downward trend for some systems (LVTS, Fedwire, SIC). Our prior is that payment timing will mainly be influenced by the quantity and opportunity cost of reserves. The more reserves are available and/or the lower their opportunity cost, the earlier payments will be settled as participants will have less of an incentive to delay their payments to economize on liquidity. The increase in reserves balances as a result of quantitative easing programs in Canada, the US and Switzerland may be the reason for the downward trends in timing that we observe in their systems.

Regarding our dispersion measure, this too varies substantially across systems and over time. We hypothesize that dispersion will generally increase with the quantity of reserves balances as in those cases there will be less of a need for system participants to economize on liquidity by coordinating their payment submission times. On the other hand, it is less clear what the relationship between dispersion and the opportunity cost of reserves should be. An increase in the opportunity cost could incentivize participants to coordinate their payments more or it could incentivize them to hoard on liquidity thereby increasing dispersion. Finally, while payment dispersion will depend to some degree on participants' incentives to coordinate their payments, it will also be influenced by exogenous factors beyond the control of participants. For example, payments to and from ancillary systems (e.g. securities settlement systems) often take place at pre-determined times.

[15] These deciles are similar to Table 1 and Chart 6 in Armantier et. al. (2008). This would be the system equivalent to Intraday throughput [C(i) of table 1 in BCBS (2013)]

[16] The only exception to that is SIC where average settlement time appears to be later in the day. This happens because SIC has much longer business hours with the system opening in the afternoon of the previous business day.

Figure 4: Value-weighted average settlement time (T) across systems. Value-weighted average settlement time is defined in equation (5).

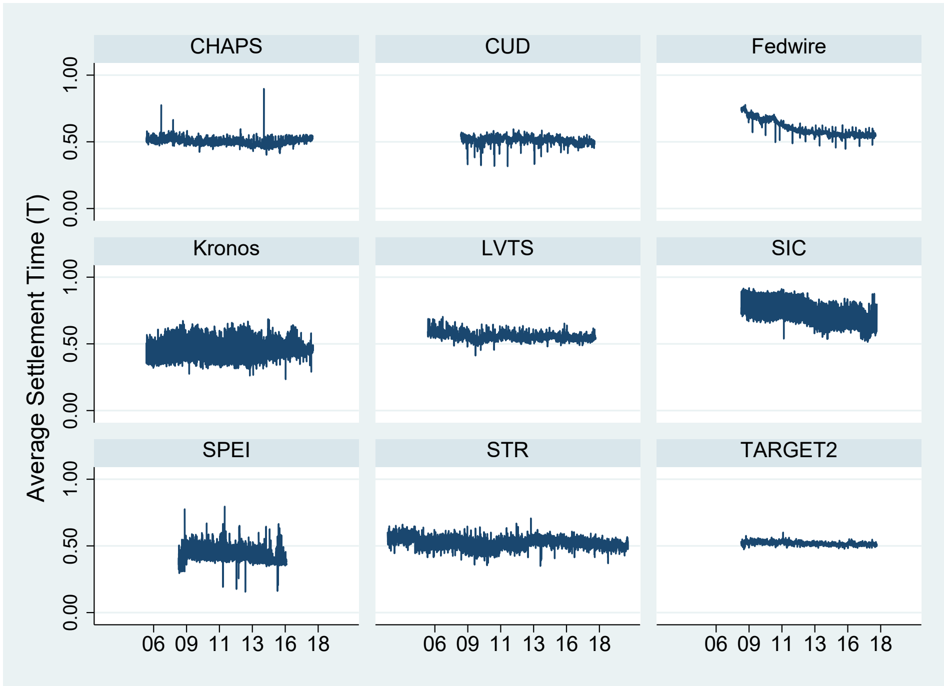


Figure 5: Payment dispersion ($Tdiff$) across systems. Payment dispersion is defined in equation (6).

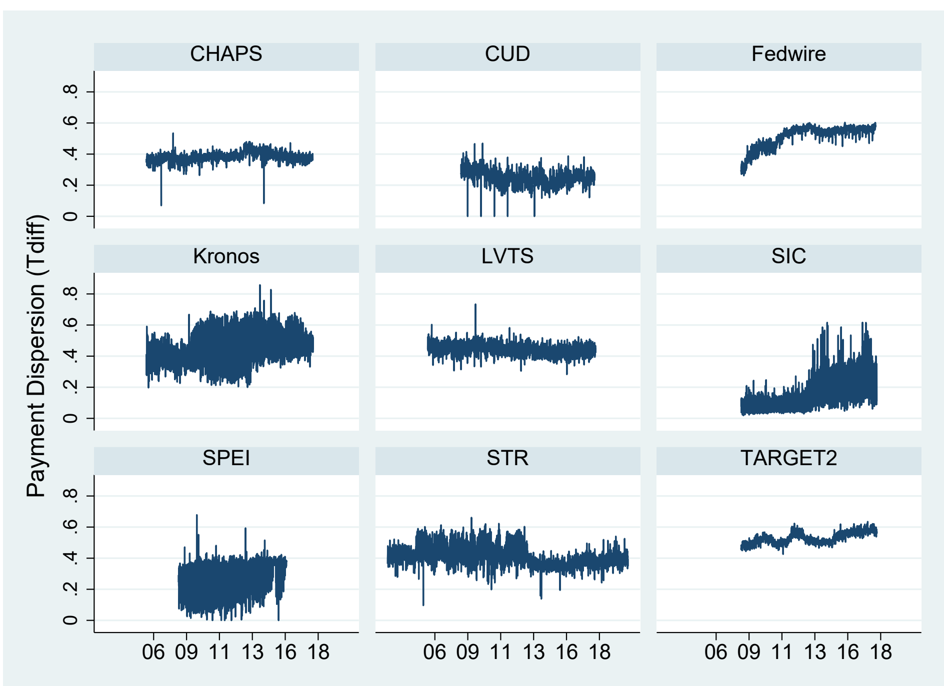


Table 2: Summary statistics. This table shows summary statistics, by payment system, for the key variables of interest. The sample properties for each system are summarised in Table 1. Variables P (in USD bn), L (in USD bn), Q, G, T and *Tdiff* are defined in equations (1)-(6). *IBOR* (in %) is either the unsecured overnight interbank rate or the central bank policy rate. *Reserves* (in $ bn) is the total size of reserve balances held with the central bank by payment system participants. The table continues on the next page.

	CHAPS (UK)				**Fedwire (US)**			
	mean	sd	min	max	mean	sd	min	max
P (USD bn)	388.33	80.45	186.45	867.14	2734.88	460.16	624.01	4440.73
L (USD bn)	31.81	6.98	11.96	77.34	629.54	172.47	173.26	1087.55
Q	12.55	2.78	5.30	26.90	4.55	0.98	2.84	9.10
G	0.22	0.04	0.09	0.47	0.48	0.09	0.34	0.85
T	0.50	0.03	0.40	0.90	0.60	0.06	0.45	0.78
Tdiff	0.38	0.03	0.07	0.53	0.51	0.07	0.26	0.60
Members	17.42	3.64	13	28	5628.18	340.23	4800	6184
IBOR(%)	1.53	1.97	0.16	6.49	0.39	0.50	0.04	2.97
Reserves (USD bn)	241.10	100.13	62.40	450.42	1718.59	690.37	1.88	2699.97
	LVTS (Canada)				**Kronos (Denmark)**			
	mean	sd	min	max	mean	sd	min	max
P (USD bn)	139.21	28.10	4.44	267.66	43.76	21.64	14.48	192.16
L (USD bn)	16.73	3.56	1.67	47.79	18.71	13.21	6.01	97.95
Q	8.46	1.77	2.09	15.84	2.52	0.40	1.35	3.90
G	0.33	0.07	0.12	0.61	0.31	0.09	0.1	0.94
T	0.55	0.03	0.41	0.70	0.43	0.08	0.23	0.69
Tdiff	0.45	0.03	0.28	0.73	0.42	0.10	0.20	0.86
Members	15.91	0.80	15	17	109.01	15.04	86	130
IBOR(%)	1.51	1.35	0.23	4.55	1.09	1.71	-1.98	6.97
Reserves (USD bn)	240.67	49.58	119.07	570.97	10.02	10.86	-20.46	61.45
	CUD (Colombia)				**TARGET2 (Eurosystem)**			
	mean	sd	min	max	mean	sd	min	max
P (USD bn)	16.36	3.43	0.22	36.63	1835.55	444.71	774.12	4931.80
L (USD bn)	3.14	0.85	0.13	12.37	442.63	74.03	261.98	799.14
Q	5.36	1.04	1.64	10.65	4.13	0.56	2.17	6.71
G	0.52	0.06	0.28	0.82	0.49	0.04	0.37	0.67
T	0.51	0.03	0.32	0.60	0.52	0.01	0.47	0.60
Tdiff	0.25	0.05	0.00	0.47	0.53	0.04	0.43	0.63
Members	132.55	8.81	12	161	969.13	99.04	747	1076
IBOR(%)	5.02	1.82	2.95	10.05	0.36	0.97	-0.37	4.60
Reserves (USD bn)	8.99	2.04	4.14	14.37	545.11	417.41	88.34	1718.05

4.4 Institutional characteristics and LSM design features

Payment systems around the world have in place different institutional arrangements that can affect intraday liquidity usage. In this paper we study two key arrangements: the presence of incentives for LVPS participants to settle their payments early and the conditions under which central banks provide intraday liquidity. The details of these are as follows:

- *Early payment incentives*: Incentives to pay early may affect payment timing and intraday liquidity usage. Incentives to settle payments earlier rather than later are

Table 2 continued

	SIC (Switzerland)				SPEI (Mexico)			
	mean	sd	min	max	mean	sd	min	max
P (USD bn)	122.65	31.05	41.48	266.26	84.79	16.99	16.14	145.18
L (USD bn)	6.60	6.88	1.12	53.74	9.51	2.65	3.12	55.36
Q	4.31	1.97	2.40	16.51	9.22	2.05	1.75	21.00
G	0.47	0.08	0.20	0.76	0.48	0.11	0.00	0.79
T	0.69	0.08	0.51	0.92	0.43	0.06	0.16	0.80
Tdiff	0.19	0.12	0.02	0.62	0.30	0.10	0.00	0.68
Members	363.92	14.44	331	387	49.84	2.26	48	53
IBOR(%)	-0.17	0.61	-1.58	3.00	4.46	1.37	3.00	8.25
Reserves (USD bn)	274.63	174.04	3.07	530.01	19.09	1.37	14.83	23.04
	STR (Brazil)				**Pooled Statistics**			
	mean	sd	min	max	mean	sd	min	max
P (USD bn)	26.26	12.30	3.03	92.78	649.92	968.71	0.22	4931.80
L (USD bn)	8.14	3.89	0.78	31.23	139.06	234.95	0.13	1087.55
Q	3.28	0.76	1.30	8.77	6.44	3.67	1.35	26.90
G	0.38	0.11	0.11	0.80	0.4	0.13	0	0.94
T	0.52	0.04	0.35	0.71	0.53	0.10	0.16	0.92
Tdiff	0.40	0.06	0.10	0.66	0.39	0.12	0.00	0.86
Members	172.69	32.07	138.00	273.00	859.89	1765.92	12	6184
IBOR(%)	11.68	4.91	1.90	26.35	3.39	4.75	-1.98	26.35
Reserves (USD bn)	15.13	6.56	4.71	41.00	374.83	591.46	-20.46	2699.97
$N = 26065$								

typically motivated by the fact that LVPS participants have an inherent incentive to delay their payments so as to economize on their liquidity by recycling incoming payments. They may also be motivated by operational risk considerations in that the earlier payments are released and settled during the day, the less likely they are to be affected and potentially delayed by an operational incident later on in the day. These incentives can take different forms ranging from throughput rules, which require banks to make a certain amount of payments by various points of time during the day, to late settlement fees.

- *Central bank credit regime*: The conditions under which central banks provide intraday liquidity to payment system participants vary across jurisdictions. The two ways for doing so is either on a collateralized or an uncollateralized basis. In the first case, system participants need to pledge collateral with the central bank to cover the full amount of intraday liquidity that they may obtain. In the latter case, there are arrangements in place that allow system participants to obtain intraday liquidity from the central bank either on an uncollateralized basis or at a substantially lower collateral cost. This may include collateral pooling or more generally the ability to use collateral at low (or zero) marginal cost. For example, system participants may use unencumbered collateral pledged with the central bank for term funding in order to obtain intraday credit. The opportunity cost of pledging collateral will also depend on whether "double duty" is permitted or not.[17] If it is permitted and banks can borrow funds by pledging collateral that they have to hold, in any case, for regulatory purposes, then the marginal cost of obtaining intraday liquidity, is zero.

An additional important determinant of intraday liquidity usage is the presence of Liquidity Saving Mechanisms (LSMs) and their specific design features. LSMs are queuing mechanisms that store, prioritize and offset payments. To offset payments, LSMs typically settle participants' outgoing payments if and when these are fully or partially offset (or matched) by incoming ones. This implies that participants' liquidity is fully or partially replenished after each payment is made, which ensures that participants do not have to use large amounts of their own liquidity, or borrow them from the central bank, in order to make their daily payments. This, in turn, should incentivize participants to submit their payments earlier on as the LSM removes the need for participants to wait for incoming payments before submitting their own. In addition, LSMs may facilitate netting of any partially or fully offsetting payments, further reducing the liquidity burden of these payments.[18]

LSMs typically run multiple matching cycles during the day but they can differ significantly across payment systems in terms of their matching frequencies, the algorithms and criteria being used to facilitate matching, whether or not these criteria can be bypassed by system participants, etc. Furthermore, the extent to which LSMs are used by participants to settle payments may also vary substantially across systems. Overall, the institutional characteristics and specific LSM design features that we include in our analysis are:

- *FIFO bypass*: This characterizes the priority rules by which payments are processed in an LSM queue. Typically, payments submitted first in the queue will also be processed first on a first-in-first-out (FIFO) basis. However, some LSM matching algorithms may apply exceptions to this priority rule in order to maximize liquidity efficiency. If, for example, the first payment in the queue of one LVPS member is similar in size to the third payment in the queue of one of its counterparties, then an LSM that can bypass the FIFO protocol would be able to match these two payments despite the fact that for the counterparty this is the third payment in the queue.

- *Multilateral offsetting*: The simplest way to offset payments in an LSM queue, between system participants, is do so on a bilateral basis. That is, payments in the queue from participant A to participant B can only be offset against payments submitted by participant B and intended to credit participant A. Some LSMs however, may also offset payments on a multilateral basis which means that as long as the gross outstanding payment value between a subset of participants is larger than the net outstanding value, then these payments can be offset. Multilateral offsetting improves liquidity efficiency as it enables netting for a wider set of payment queue configurations.

[17] "Double duty" is a bank practice of using regulatory liquid asset buffers (typically measured as at the end of the day) to support intraday payment system activity. In the run-up to the financial crisis of 2008-09, double duty was permitted in several jurisdictions around the world. For more details, see Ball et al. (2011).

[18] When netting is possible and payments are only partially offset, the LSM ensures that payments are only released when there is sufficient liquidity to cover the net outstanding obligation.

- *Priority setting*: Payments submitted to an LSM may have to wait in the queue to be settled. LVPS participants however may wish to expedite specific time-sensitive payments whose delay would otherwise be costly. For this reason, some LSMs make it possible to alter the priority of payments already submitted in the queue.[19]

- *Liquidity reservations*: In some LVPSs with an LSM, participants can also reserve liquidity to make payments outside the LSM. Typically this is liquidity earmarked for the most urgent payments.

Panel A of Table 3 lists these institutional characteristics and LSM features for which we construct dummy variables to use in our empirical analysis. Panel B of the same table shows how these characteristics vary across jurisdictions. All systems included in our sample, except Fedwire, feature LSM queuing - central queues that allow for a varying set of system features listed above, whereas CHAPS introduced one during our sample period, in April 2013. However, there is more variation in institutional characteristics and LSM features across systems, which allows us to empirically compare and contrast their effects on intraday liquidity usage.

5 Empirical analysis

Our empirical analysis proceeds in two steps. First, we examine the determinants of payment timing and coordination as measured by the T and $Tdiff$ variables defined in equations (5) and (6) respectively. These two variables are intended to capture the most important decisions that payment system participants can make: when to submit their payments and whether to coordinate with other participants in doing so. Thus, we are interested in examining whether these decisions are correlated with market-wide variables such as the opportunity cost of reserves and the aggregate amount of available liquidity but also with the institutional characteristics of each jurisdiction as summarized in Table 3. For this reason, we first estimate a number of models where timing and dispersion are treated as dependent variables with the market-wide ones and the institutional characteristics as independent.

In the second step, we examine the determinants of liquidity efficiency (defined in equation 3) and inequality of liquidity provision across participants (defined in equation 4). In principle, both of these variables are entirely determined by the payment patterns of system participants and for this reason, our timing and dispersion metrics are now included as explanatory variables in these specifications.

A couple of caveats are however in order. First, our timing and dispersion variables are imperfect proxies of participants' payment patterns. For instance, if payments were highly coordinated at a few points of time that are relatively far apart (e.g. early and late on the business day), our dispersion metric would fail to capture that and instead would take on a relatively higher value. Similarly, it could be the case that for liquidity efficiency, specific timing percentiles matter as much (if not more) as average settlement

[19] System participants also have the option to immediately settle their payments outside the LSM queue. However this is a common feature across all systems and as such we cannot use it to draw cross-system comparisons.

Table 3: Institutional characteristics and LSM design features. This table describes the various institutional characteristics and LSM design features that we study, shows the relevant dummy variables that we construct and also the values that these variables take for each jurisdiction in our sample. The date range for each system is shown in Table X. In the UK an LSM was introduced on April 22, 2013. In Switzerland, the ability to reserve liquidity was introduced on June 18, 2016.

Panel A: Dummy variable definitions

Dummy variable	Definition
Institutional characteristics	
Incentives	Equals 1 if there are in place incentives or requirements for settling payments early
Credit	Equals 1 if the central bank can provide intraday credit on an uncollateralized basis or at a lower collateral cost (e.g. via collateral pooling)
LSM design features	
LSM	Equals 1 if there is an LSM in place
FIFO_bp	Equals 1 if the LSM allows for the FIFO protocol to be bypassed
Offsetting	Equals 1 if the LSM enables multilateral offsetting
Priority	Equals 1 if it is possible to change the priority of payments in the LSM queue
Reservations	Equals 1 if it is possible to reserve liquidity for payments outside the LSM

Panel B: Dummy variable values by jurisdiction

System name	Jurisdiction	*Incentives*	*Credit*	*LSM*	*FIFO_bp*	*Offsetting*	*Priority*	*Reservations*
CHAPS	United Kingdom	1	0	0/1	0/1	0/1	0/1	0/1
CUD	Colombia	1	0	1	1	1	1	0
Fedwire	United States	0	1	0	0	0	0	0
Kronos	Denmark	1	0	1	1	1	1	0
LVTS	Canada	1	1	1	0	1	0	0
SIC	Switzerland	1	0	1	0	0	1	0/1
SPEI	Mexico	0	0	1	0	1	0	0
STR	Brazil	0	0	0/1	0/1	0/1	0/1	0
TARGET2	Eurosystem	0	0	1	1	1	1	1

time. Second, as mentioned earlier, we only observe settlement times rather than submission times. The former are contaminated by the random settlement processing times and as such capture less accurately participants' behavior. For these two reasons, our liquidity efficiency and inequality specifications also include as controls the same set of market-wide and jurisdiction-specific variables used in the first set of regressions. The goal is to allow these variables to capture any effects that our payment timing and coordination proxies might fail to properly account for.

5.1 Payment timing and coordination

RTGS system participants generally have the flexibility to choose the timing of their outgoing payments with the exception of: (i) any payments that are deemed urgent either by themselves or by institutions for which they may act as correspondents and (ii) payments submitted to ancillary systems such as securities settlement systems and clearing houses. Given that incoming payments may be used to fund outgoing ones, this flexibility can give rise to strategic behaviors as it implies that system participants may time their payments in a way that minimizes their own liquidity commitment (e.g. Bech and Garratt (2003)).

Therefore, in this section we examine the determinants of average settlement times (as captured by T) and the degree of payment dispersion across participants (as captured by $Tdiff$). For this purpose, we estimate the following panel specifications across systems and over time:

$$T_{it} = a_1 + d_1 X'_{it} + u_{it} \tag{7}$$

$$Tdiff_{it} = a_2 + b_2 T_{it} + d_2 X'_{it} + e_{it} \tag{8}$$

where i denotes systems and t denotes days. The vector X' includes regressors that are motivated by the theoretical literature on payment timing as well as economic intuition. For instance, explanatory variables include the aggregate value of payments made (P), the total number of system participants (*Members*), innovations in the overnight interbank rate ($\Delta IBOR$), the total amount of reserves (*Reserves*) and dummies for the various institutional characteristics and LSM design features as described in Table 3. These regressors are natural candidates for our timing specifications. A higher value of outgoing payments could mean that they have to be spread more evenly during the day, affecting both their average settlement time as well as their dispersion. Similarly, the number of system participants may affect their individual incentives to settle earlier and their ability to coordinate their payments. Given that payments in RTGS payment systems are liquidity-intensive and that participants have the ability to recycle incoming payments, the timing and dispersion of payments should also in theory depend on the amount of available liquidity (*Reserves*) and its opportunity cost (*IBOR*). The same is true of institutional features such as the central bank credit regime and the various LSM characteristics: the presence of a mechanism that is designed to help participants economize on liquidity could reduce participants' incentives to delay or concentrate payments. We estimate both models (5) and (6) using random effects and inference is done by clustering at the system level.[20]

The results of these specifications are shown in Tables 4 and 5. With respect to average settlement time (Table 4), wider system membership is associated with payments being made later on in the day in most specifications. This could be because incentives to delay payments might increase in the number of direct participants.[21]Alternatively, it could be because the marginal cost of liquidity and the associated incentives for delay are higher for smaller participants who tend to be present in systems with wider participation. However, the effect of wider membership disappears in the full specification (column 12).

On the other hand, increases in the opportunity cost of reserves (as captured by changes in *IBOR*) are associated with later settlement times (columns 4, 6, 12). If the opportunity cost of reserves increases, then system participants would have an incentive to delay their outgoing payments in anticipation of incoming ones.

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[20]We use random effects because our models feature time-invariant characteristics. Owing to the large time and small cross-sectional dimensions of our sample, in practice the random effects estimators are mostly determined by the within (time) variation of our sample and are therefore unlikely to be biased because of group unobserved, time-invariant characteristics.

[21]Given the public good nature of intraday liquidity, the incentives of LVPS participants are similar to those faced by players in a volunteering game. In such setups, the probability that any given player volunteers, decreases with the number of players. See Diekmann (1985).

The negative relationship between available liquidity (as captured by aggregate reserves balances) and payment settlement times (columns 5, 6, 12) is also consistent with this idea since aggregate reserves balances are a key instrument that central banks use to target short term interest rates. However, the fact that reserves balances are significant after controlling for $\Delta IBOR$ suggests that there is an incremental effect, not necessarily associated with the opportunity cost of liquidity. The negative relationship between reserves balances and payment timing confirms similar findings from Fedwire reported in Bech et al. (2012) and Bech and Garratt (2012). This finding is important because several central banks engaged in quantitative easing programs, during our sample period, after having reduced interest rates to historically low levels. These programs increased significantly the reserves balances in their respective systems and our results suggest that this likely had a positive effect on payment systems as it induced earlier payment submissions.[22]

The presence of incentives to settle payments early is weakly associated with earlier settlement times and only the full specification (column 12), whereas the possibility to obtain intraday credit from the central bank, at a lower collateral cost, is associated with a later average settlement time (columns 8, 10, 12). If collateral has opportunity cost, this is contrary to what one might expect as the costlier the central bank liquidity, the more likely LVPS participants would be to delay their payments in anticipation of incoming ones.

We also find a negative, albeit statistically insignificant, association between the presence of an LSM and payment timing (columns 9, 10). This appears to be driven by the opposite association with timing of specific LSM characteristics. For instance, average settlement time is strongly negatively correlated with FIFO bypass and multilateral offsetting (columns 11, 12). Since these are the features that increase the potential for liquidity savings in the LSM queue, they could reduce participants' incentives to delay submitting their outgoing payments in anticipation of incoming ones. On the other hand, priority setting in an LSM is associated with later average settlement times (columns 11, 12). This could be because the ability to prioritize specific payments in the LSM queue allows for the more urgent payments to be settled faster so that there is less of an incentive to expedite the submission of all payments in the queue.[23] Alternatively, it could be that prioritizing payments within the LSM queue results in poorer offsetting matches or liquidity being blocked for high-value high-priority payments which, on average, delays settlement.[24]

Table 5 shows the results on payment dispersion. Dispersion tends to decrease with average settlement times although the effect is not statistically significant. This might arise because payments that are made later have to settle within a narrower time frame before the end of the business day. Dispersion is also negatively associated with LVPS membership (columns 11, 14). It is not immediately clear what drives this effect but it could be purely

[22]Earlier payment submission and settlement in the day is desirable not the least because it lowers the impact of a potential operational outage in the LVPS that might occur during the day and which might prevent participants from sending or receiving payments. If a larger volume of payments has been processed before such an outage occurs, its impact will be smaller.

[23]This explanation is consistent with the findings of Nellen et al. (2018) who study the relationship between submission and settlement times in the Swiss payment system.

[24]A reduction in matching efficiency might result if urgent payments are larger than non-urgent ones and if only a few system participants have to make them on any given day so that there is less of a chance that they are netted in the LSM queue. Unfortunately, we cannot test this specific hypothesis as we cannot distinguish between urgent and non-urgent payments in our data.

mechanical: as the number of participants increases, the number of payments that coincide may also increase, which would tend to decrease dispersion.

Dispersion increases with the level of reserves balances (columns 5, 6, 14) and with changes in their opportunity cost ($\Delta IBOR$; columns 4, 6, 11, 14). The first effect is consistent with the idea that an abundance of liquidity reduces participants' incentives to coordinate their payments whereas the second effect is consistent with liquidity hoarding at times of stress. That is, when market conditions deteriorate (i.e., liquidity becomes more expensive) then system participants may withhold or delay outgoing payments with the result being that payment coordination weakens and dispersion increases. The positive relation between $\Delta IBOR$ and payment timing discussed earlier, seems to corroborate this.

Dispersion is also higher when it is possible to obtain credit from the central bank at a lower collateral cost (columns 8, 10, 11, 13, 14), suggesting that a lower collateral cost potentially reduces participants' incentives to coordinate their payment submissions to economize on liquidity. Additionally, incentives for early payment are associated with lower dispersion in the full specification (column 14). Although our results showed no substantial correlation between such incentives and average settlement timing, it could be the case that these incentives induce more uniform payment patterns especially if delaying payments consistently carries a penalty. One could hypothesize that in the presence of such rules, system participants might have an incentive to avoid being an outlier in terms of their payment patterns which would result in lower average dispersion.

Finally, several LSM features are also related to payment dispersion (columns 12-14). *FIFO bypass* is associated with higher payment dispersion. This effect is unlikely to be mechanical because, if anything, FIFO bypass increases the opportunities for settlement which should decrease dispersion. As such, we suspect that system participants might be endogenously modifying their behavior in the presence of this functionality. In particular, FIFO bypass could be reducing participants' incentives to coordinate their payment submissions because even if payments are submitted in the LSM queue, at different points in time, this functionality will reschedule them so as to maximize any offsetting opportunities.

The same effect, in reverse, could explain the negative correlation between *priority setting* and dispersion: if priority setting overrules the offsetting algorithm and, as a result, decreases offsetting efficiency, this might increase participants' incentives to coordinate their payments so as to economize on liquidity.[25]

Multilateral offsetting is also associated with reduced dispersion. This could be either a mechanical effect or a behavioral one (or both). Multilateral offsetting, by definition, enables a wider set of payments submitted by multiple participants to settle simultaneously which would reduce our dispersion measure. Alternatively, given that this functionality is more effective when more participants' payments are in the queue at any given point in time, it could ex-ante incentivize participants to coordinate their payment submission. Since we do not observe payment submission times, unfortunately we cannot disentangle the effect of multilateral offsetting on the dispersion of submission times versus that of settlement times and thus see which of the two explanations drives our result.[26]

[25]This could be the case whether LVPS participants actually use the LSM bypass functionality or not. The fact that the functionality is available could create ex-ante incentives for participants to coordinate more.

[26]See Nellen et al. (2018) for a study of the Swiss SIC payment system utilizing data on both submission and settlement times.

Overall, our results suggest that an LSM (or particular LSM design features) can potentially attenuate the degree of strategic complementarity that is found in pure RTGS environments. If, for example, a FIFO bypass functionality reduces LVPS participants' incentives to better coordinate their payments, this could explain the higher dispersion in settlement times. Interestingly however, our findings suggest that particular LSM features (e.g. multilateral offsetting) could also be *increasing* the degree of strategic complementarity between LVPS members by increasing the benefits of coordination in payment submissions.

5.2 Intraday liquidity efficiency

In this section we study the determinants of intraday liquidity efficiency. Given that RTGS systems with larger flows of payments can naturally be expected to be more liquidity intensive, we examine how liquidity efficiency, defined in equation (3), is influenced by payment system behavior (i.e. payment timing and dispersion), the opportunity cost and quantity of available liquidity as well as a number of specific LSM features.

As discussed earlier, our measure of liquidity efficiency would in principle only depend on the value, the timing and degree of coordination of payments in an LVPS. Payment system activity, in turn, would depend on (and might also influence) the price and quantity of available liquidity. However, our two variables of LVPS activity (average settlement time and dispersion), while informative, likely do not capture all aspects of LVPS activity and, as such, additional variables are included as regressors in our specification for Q to account for any ultimate effects on efficiency from market variables that our timing and dispersion variables fail capture.

With this in mind, we estimate the following panel specification:

$$Q_{it} = a_3 + b_3 T_{it} + c_3 \mathit{Tdiff}_{it} + d_3 X'_{it} + v_{it} \tag{9}$$

where i denotes systems, t denotes days and X' contains the same regressors as in model specifications (7) and (8). In addition, Tdiff is included as a regressor because payment coordination allows RTGS system participants to recycle payments and thus economize on liquidity usage.

Table 6 presents the results of this specification. Indeed, a higher degree of payment dispersion is empirically associated with lower levels of liquidity efficiency (columns 2, 12, 13) confirming the idea that in liquidity-intensive RTGS systems, payment recycling is a way for system participants to economize on liquidity. Otherwise, the timing of payments does not seem to be significantly associated with liquidity efficiency whereas the number of system members seems to only be indirectly associated with efficiency through other variables, as its effect disappears once additional controls are included.

Changes in the opportunity cost of reserves (as captured by $\Delta IBOR$) are positively associated with efficiency only after we control for timing effects (average settlement time and dispersion). We saw earlier that increases in *IBOR* are strongly positively correlated with dispersion which negatively predicts efficiency. Thus, it is not surprising that the effect of IBOR becomes more positive in the presence of these controls. It is not clear however how the opportunity cost of reserves would affect liquidity efficiency other than via payment coordination. On the other hand, while reserves balances are negatively correlated with efficiency in some specifications, their effect disappears once additional controls are included (columns 11-13) suggesting that reserves balances might be related with efficiency only indirectly by influencing (negatively) payment coordination.

The presence of incentives for early settlement is associated with higher liquidity efficiency (columns 12-14) which is likely partially driven by the negative correlation between those incentives and dispersion discussed earlier. On the other hand, the ability to obtain uncollateralized (or partially collateralized) credit, seems to correlate with efficiency only via dispersion as the inclusion of our *Tdiff* variable eliminates its significance (columns 11-13).

Finally, the presence of an LSM is uncorrelated with liquidity efficiency in our sample (columns 8, 9). This is somewhat surprising as LSMs' intended purpose is precisely, to help economize on liquidity. Looking at specific LSM design features, FIFO bypass is uncorrelated with efficiency despite its strong positive correlation with our dispersion measure. On the other hand, multilateral offsetting is positively correlated with efficiency (columns 10, 11) with this effect being likely driven by the negative effect of multilateral offsetting on dispersion since the inclusion of $Tdiff$ as a control eliminates the significance of the former. The negative relation between priority setting and liquidity efficiency, after controlling for dispersion, could be because changing the priority of payments within the LSM queue is driven by payment urgency rather than liquidity saving considerations, resulting in poorer payment offsets. In other words, to the extent that the LSM matching algorithm releases payments in a way that minimizes liquidity usage, altering payment priority may result in less liquidity-efficient matches. Finally, the ability to reserve liquidity for urgent payments could result in some liquidity being released in the payment system early in the day and subsequently being recycled to fund additional payments. This effect arises after controlling for payment dispersion and other variables, since payment reservations are themselves also positively associated with dispersion.

Overall, these empirical regularities imply that the various LSM features may not all have the desired effect of improving liquidity efficiency with some features potentially even being detrimental to it.

5.3 Inequality in intraday liquidity usage

In the final part of our empirical analysis we look at the determinants of inequality in the usage (and provision) of intraday liquidity. We estimate a number of panel specifications where the dependent variable is the Gini coefficient of the relative usage of intraday liquidity, defined in equation (4). This variable captures the extent to which some participants tap into their own available liquidity more (or less) relative to their daily payment obligations. To the extent that some participants use more of their own liquidity in relation to the value of their payments, these participants contribute to system-wide liquidity that can be subsequently recycled by other participants in order to meet *their* payment obligations.

Our empirical specification is thus:

$$G_{it} = a_4 + b_4 T_{it} + c_4 \mathit{Tdiff}_{it} + d_4 X'_{it} + u_{it} \tag{10}$$

where i denotes systems, t denotes days and X' contains the same regressors as in the previous models. T and *Tdiff* are again included as a regressors to gauge if payment timing and the degree of payment coordination are associated with overall equality (or lack thereof) in liquidity provision.

Table 7 presents the results of these specifications. The first thing to notice is that the Gini coefficient is unrelated to our timing and dispersion variables. This suggests that the Gini index is not associated with the overall timing and degree of coordination in payments. However, it is negatively correlated with $\Delta IBOR$ (columns 4, 9, 11, 13). This result suggests that when the opportunity cost of reserves increases, there is less reliance on fewer participants for liquidity and instead more participants commit their own liquidity. This is consistent with the earlier results that $\Delta IBOR$ is positively correlated with average settlement times and dispersion. If a higher opportunity cost of liquidity results in payment delays and hoarding, then one would indeed expect more participants to be forced to commit their own liquidity in order to meet their payment obligations.

The aggregate amount of reserves and the presence of incentives for early settlement are both associated with a lower Gini coefficient across models. This is likely because a higher amount of reserves reduces participants' incentives to rely on recycled liquidity provided by other participants. Additionally, the presence of incentives for early settlement limits the degree to which certain participants can recycle liquidity provided by only a few other participants, since every participant has an incentive (or obligation) to make some early payments and thereby inject liquidity in the payment system. Finally, the presence of an LSM is positively correlated with the Gini index with the effect being driven almost entirely by the LSM priority setting functionality (columns 10-13). This is a rather unexpected finding since LSMs are intended to level the playing field of liquidity provision by ensuring that all submitted payments are offset by incoming ones and that no participants bear the brunt of consistently supplying liquidity to the system.

6 Summary and conclusions

This is the first paper to systematically study intraday liquidity usage, by financial institutions, across several jurisdictions and over a long period of time. Using a unique cross-country data set, we measure intraday liquidity usage on a daily frequency and at system level and assess its drivers. We find that intraday liquidity usage is highly economically significant accounting, on average, for 15% of daily aggregate payment values or about 2.3% of local GDP.

Consistent with the theoretical literature, we also find that intraday liquidity usage depends on the way participants interact with one another in an LVPS. For instance, a higher degree of payment coordination is associated with higher liquidity efficiency, i.e. a higher value of payments made for every unit of intraday liquidity used. Participant interaction in turn, depends on both policy-related variables such as the overall supply of central bank reserves balances as well as system-specific institutional characteristics.

Regarding the former, we find, for example, that higher aggregate reserves balances (largely as a result of quantitative easing programs in several of the jurisdictions in our sample) are associated with reduced incentives among participants to coordinate their payments and thus economize on intraday liquidity usage. On the flip side, higher reserves balances appear to induce earlier payment submissions and also reduce the reliance on just a few system participants to provide liquidity to the rest. Both of these effects are desirable as they help reduce the impact of a potential outage in the payment system. In general, the amounts of excess liquidity that have been injected by central banks in many jurisdictions appear to have reduced the benefit of liquidity saving and the need to manage liquidity. This will likely change in the future when central banks start reducing the size of their balance sheets.

The most novel contribution of our paper however is to study the impact of institutional and system-specific characteristics on intraday liquidity usage. Given that these characteristics are generally time-invariant, such an analysis requires cross-country data on large-value payments, which our paper is the first to assemble. Our analysis yields several new results. The first is that incentives for early payment submissions seem to have more of an effect on payment coordination than actual payment submission times. Given that these incentives often take the form of penalties, it appears that they induce LVPS participants to coordinate their submission times likely in an attempt to "not stand out from the pack". Interestingly however, this increased coordination renders the payment system more liquidity-efficient as it facilitates payment recycling.

A second novel result is that LVPS participants appear to endogenize some of the LSM features which in some cases improves liquidity efficiency but in other cases it is detrimental to it. For example, multilateral offsetting is associated with increased payment coordination. One explanation of that could be that participants coordinate their payments more in order to take full advantage of this functionality. Increased participant coordination then further enhances liquidity efficiency. On the other hand, the presence of a FIFO bypass functionality, whereby the offsetting algorithm can bypass the time priority of submitted payments, is associated with reduced payment coordination. This could be because participants are less incentivized to coordinate their payments in the presence of this functionality. As a result however, liquidity efficiency is reduced.

Overall, a key insight from our paper is that, in endogenizing the various payment system design features and institutional arrangements, LVPS participants can influence the aggregate amount of intraday liquidity they use to fund their payments. We believe that understanding these endogenous dynamics is important when designing payment systems and therefore additional research in this area is warranted.

Table 4: Payment timing panel regressions. The dependent variable, T, is the value-weighted average settlement time of payments made in each system on any given day. It is defined in equation (5). P (in USD bn) is the daily total value of payment made in each system. $\Delta IBOR$ (in %) is the first difference in either the unsecured overnight interbank rate or the central bank policy rate. *Reserves* (in USD bn) is the total size of reserve balances held with the central bank by payment system participants. The *Incentives*, *Credit* and LSM characteristic dummies are defined in Table 3. The models are estimated using random effects. Robust p-values are reported in the parentheses. *, ** and *** denote significance at 10%, 5% and 1% levels respectively.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	T	T	T	T	T	T	T	T	T	T	T	T
P	-0.0000		-0.0000			0.0000						
	(0.366)		(0.859)			(0.724)						
Members		0.0001***	0.0001***			0.0001***						-0.0000
		(0.000)	(0.000)			(0.000)						(0.499)
$\Delta IBOR$				0.0121***		0.0123***						0.0118**
				(0.009)		(0.009)						(0.019)
Reserves					-0.0001***	-0.0001***						-0.0001***
					(0.001)	(0.005)						(0.000)
Incentives							0.0192			0.0315		-0.0561*
							(0.731)			(0.472)		(0.083)
Credit								0.0636*		0.0683*		0.1933***
								(0.090)		(0.087)		(0.000)
LSM									-0.0059	-0.0059		
									(0.159)	(0.160)		
FIFO_bp											-0.1441**	-0.0759**
											(0.033)	(0.030)
Offsetting											-0.0269	-0.1451***
											(0.617)	(0.000)
Priority											0.1817***	0.1887***
											(0.000)	(0.000)
Reservations											-0.0408*	0.0157
											(0.058)	(0.620)
_cons	0.5425***	0.4299***	0.4318***	0.5282***	0.5520***	0.4955***	0.5159***	0.5146***	0.5332***	0.4970***	0.5170***	0.5760***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
R2	0.0436	0.0977	0.0980	0.0005	0.0527	0.1004	0.0014	0.0796	0.0171	0.0902	0.3394	0.6457
N	26039	26039	26039	25205	26033	25200	26039	26039	26039	26039	26039	25200

Table 5: Payment dispersion panel regressions. The dependent variable, *Tdiff*, is defined in equation (6). T, is the value-weighted average settlement time of payments made in each system on any given day. It is defined in equation (5). P (in USD bn) is the daily total value of payment made in each system. $\Delta IBOR$ (in %) is the first difference in either the unsecured overnight interbank rate or the central bank policy rate. *Reserves* (in USD bn) is the total size of reserve balances held with the central bank by payment system participants. The *Incentives*, *Credit* and LSM characteristic dummies are defined in Table 3. The models are estimated using random effects. Robust p-values are reported in the parentheses. *, ** and *** denote significance at 10%, 5% and 1% levels respectively.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	Tdiff	Tdiff	Tdiff	Tdiff	Tdiff	Tdiff	Tdiff	Tdiff	Tdiff	Tdiff	Tdiff	Tdiff	Tdiff	Tdiff
T	-0.3773					-0.2110					-0.5610***			-0.3549
	(0.442)					(0.685)					(0.009)			(0.274)
P		0.0000				-0.0000					0.0001***			-0.0000*
		(0.585)				(0.412)					(0.001)			(0.054)
Members			-0.0001***			-0.0000					-0.0000**			-0.0001***
			(0.000)			(0.813)					(0.016)			(0.000)
$\Delta IBOR$				0.0332***		0.0356***					0.0369***			0.0372***
				(0.000)		(0.000)					(0.001)			(0.000)
Reserves					0.0001***	0.0001***					0.0000			0.0000**
					(0.000)	(0.005)					(0.539)			(0.040)
Incentives							-0.1004			-0.0799	0.0272		-0.0246	-0.2518***
							(0.186)			(0.264)	(0.684)		(0.523)	(0.000)
Credit								0.1265**		0.1014**	0.1089***		0.1108***	0.4237***
								(0.011)		(0.034)	(0.000)		(0.000)	(0.000)
LSM									-0.0233	-0.0233	-0.0482			
									(0.360)	(0.360)	(0.235)			
FIFO_bp												0.2581***	0.2725***	0.4713***
												(0.001)	(0.000)	(0.000)
Offsetting												-0.0608	-0.1019***	-0.3855***
												(0.326)	(0.001)	(0.000)
Priority												-0.2631***	-0.2364***	-0.1472**
												(0.000)	(0.000)	(0.024)
Reservations												0.1051***	0.1051***	0.0604
												(0.000)	(0.000)	(0.133)
_cons	0.5813**	0.3719***	0.4786***	0.3824***	0.3490***	0.4834**	0.4487***	0.3537***	0.3997***	0.4305***	0.6406***	0.4347***	0.4327***	0.8505***
	(0.023)	(0.000)	(0.000)	(0.000)	(0.000)	(0.043)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
R2	0.0602	0.2647	0.1307	0.0016	0.2079	0.1661	0.1308	0.1423	0.0769	0.2462	0.5215	0.4384	0.5491	0.6429
N	26035	26035	26035	25201	26029	25196	26035	26035	26035	26035	25196	26035	26035	25196

Table 6: Liquidity efficiency panel regressions. The dependent variable, Q, is defined - in equation (3) - as the ratio of the aggregate value of payments made to the aggregate amount of intraday liquidity used. The independent variables T and *Tdiff* are defined in equations (5) and (6) respectively. $\Delta IBOR$ (in %) is the first difference in either the unsecured overnight interbank rate or the central bank policy rate. *Reserves* (in USD bn) is the total size of reserve balances held with the central bank by payment system participants. The *Incentives*, *Credit* and LSM characteristic dummies are defined in Table 3. The models are estimated using random effects. Robust p-values are reported in the parentheses. *, ** and *** denote significance at 10%, 5% and 1% levels respectively.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q
T	4.8259												2.4497
	(0.125)												(0.591)
Tdiff		-3.5611*										-12.5865***	-12.1812***
		(0.061)										(0.002)	(0.007)
Members			0.0013***						-0.0004		0.0013	0.0003	0.0004
			(0.000)						(0.721)		(0.100)	(0.678)	(0.629)
$\Delta IBOR$				-0.0383					-0.0287		0.0480	0.4552***	0.4133*
				(0.191)					(0.196)		(0.612)	(0.004)	(0.059)
Reserves					-0.0016**				-0.0017**		0.0003	0.0010	0.0012
					(0.010)				(0.029)		(0.825)	(0.397)	(0.293)
Incentives						0.1142			-1.3430		5.3491**	3.3869*	3.5877**
						(0.956)			(0.689)		(0.042)	(0.072)	(0.043)
Credit							0.5983		2.6634		-5.7255**	-2.2255	-2.8119
							(0.764)		(0.391)		(0.034)	(0.266)	(0.191)
LSM								-0.6718	-0.5579				
								(0.631)	(0.666)				
FIFO_bp										-1.6296	-5.7207	-0.4172	-0.4015
										(0.631)	(0.149)	(0.922)	(0.925)
Offsetting										3.0812*	6.5399*	3.3422	3.8002
										(0.095)	(0.099)	(0.393)	(0.328)
Priority										-0.9878	-4.6873	-7.3624*	-7.7391*
										(0.581)	(0.269)	(0.080)	(0.066)
Reservations										-2.8161***	4.5631**	5.1767***	5.1186***
										(0.000)	(0.040)	(0.005)	(0.005)
_cons	3.4915*	7.4022***	4.9260***	6.0355***	6.6009***	5.9659***	5.9090***	6.5580***	7.7179**	5.7597***	2.3485	9.4304**	7.7919
	(0.064)	(0.000)	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.018)	(0.002)	(0.560)	(0.035)	(0.154)
R-sq	0.0036	0.0113	0.0321	0.0000	0.0114	0.0012	0.0155	0.0111	0.1352	0.0637	0.3610	0.4351	0.4363
N	26039	26035	26065	25231	26059	26065	26065	26065	25226	26065	25226	25196	25196

Table 7: Inequality in liquidity usage panel regressions. The dependent variable, G, is the Gini coefficient in relative intraday liquidity usage, defined in equation (4). The independent variables T and *Tdiff* are defined in equations (5) and (6) respectively. $\Delta IBOR$ (in %) is the first difference in either the unsecured overnight interbank rate or the central bank policy rate. *Reserves* (in USD bn) is the total size of reserve balances held with the central bank by payment system participants. The *Incentives*, *Credit* and LSM characteristic dummies are defined in Table 3. The models are estimated using random effects. Robust p-values are reported in the parentheses. *, ** and *** denote significance at 10%, 5% and 1% levels respectively.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
	G	G	G	G	G	G	G	G	G	G	G	G	G
T	0.0113												0.1361
	(0.961)												(0.445)
Tdiff		-0.1033										-0.1735	-0.1510
		(0.487)										(0.483)	(0.518)
Members			0.0002***						0.0001		0.0000	0.0000	0.0000
			(0.000)						(0.193)		(0.474)	(0.966)	(0.888)
$\Delta IBOR$				-0.0178***					-0.0178***		-0.0192***	-0.0135	-0.0159**
				(0.002)					(0.001)		(0.000)	(0.105)	(0.036)
Reserves					-0.0001**				-0.0001**		-0.0001***	-0.0001***	-0.0001**
					(0.015)				(0.048)		(0.000)	(0.005)	(0.021)
Incentives						-0.1145***			-0.0101		-0.2110***	-0.2380**	-0.2269***
						(0.009)			(0.930)		(0.004)	(0.011)	(0.009)
Credit							-0.0054		-0.1589		0.0679	0.1162	0.0837
							(0.938)		(0.267)		(0.365)	(0.301)	(0.326)
LSM								0.0532**	0.0546***				
								(0.025)	(0.004)				
FIFO_bp										-0.0896	-0.1042	-0.0311	-0.0301
										(0.401)	(0.103)	(0.813)	(0.828)
Offsetting										0.0415	-0.0041	-0.0481	-0.0227
										(0.567)	(0.946)	(0.610)	(0.747)
Priority										0.1098**	0.2207***	0.1840**	0.1630*
										(0.017)	(0.000)	(0.010)	(0.064)
Reservations										-0.0209	-0.0859	-0.0776	-0.0808
										(0.527)	(0.217)	(0.264)	(0.257)
_cons	0.4047***	0.4501***	0.2805***	0.4109***	0.4358***	0.4870***	0.4118***	0.3697***	0.3605***	0.3660***	0.4978***	0.5952***	0.5042***
	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
R^2	0.0432	0.0241	0.0831	0.0004	0.0170	0.1851	0.0000	0.0331	0.2226	0.0570	0.4369	0.4482	0.4512
N	26021	26017	26047	25215	26041	26047	26047	26047	25210	26047	25210	25180	25180

References

Baglioni, A., Monticini, A., 2008. The intraday price of money: evidence from the e-mid interbank market. Journal of Money, Credit and Banking 40, 1533–1540.

Baglioni, A., Monticini, A., 2010. The intraday interest rate under a liquidity crisis: the case of august 2007. Economic Letters 107, 198–200.

Ball, A., Denbee, E., Manning, M., Wetherilt, A., 2011. Intraday liquidity: risk and regulation. Bank of England Financial Stability Paper .

Bech, M., Garratt, R., 2003. The intraday liquidity management game. Journal of Economic Theory 109, 198–219.

Bech, M., Garratt, R., 2012. Illiquidity in the interbank payment system following wide-scale disruptions. Journal of Money, Credit and Banking 44, 903–929.

Bech, M., Hobjin, B., 2007. Technology diffusion within central banking: The case of real-time gross settlement. International Journal of Central Banking 3, 147–181.

Bech, M., Martin, A., McAndrews, J., 2012. How the high level of reserves benefits the payment system. Liberty Street Economics URL: https://libertystreeteconomics.newyorkfed.org/2012/02/how-the-high-level-of-reserves-benefits-the-payment-system.html#.U2eVY1ewWuo.

Becher, C., Galbiati, M., Tudela, M., 2008. The timing and funding of cHAPS sterling payments. FRBNY Economic Policy Review , 113–133.

Benos, E., Garratt, R., Zimmerman, P., 2014. The role of counterparty risk in CHAPS following the collapse of Lehman Brothers. International Journal of Central Banking 10, 143–171.

BIS, 1997. Real-time gross settlement systems. Committee on Payment and Market Infrastructures. CPMI Paper No 22 .

BIS, 2005. New developments in large-value payment systems. Committee on Payment and Market Infrastructures. CPMI Paper No 67 .

BIS, 2008. Principles for sound liquidity risk management and supervision. Basel Committee on Banking Supervision. BCBS Guidelines .

Chapman, J., Martin, A., 2013. Rediscounting under aggregate risk with moral hazard. Journal of Money Credit and Banking 45, 651–674.

Denbee, E., Garratt, R., Zimmerman, P., 2015. Identification of over and under provision of liquidity in real-time payment systems. Journal of Financial Market Infrastructures 4, 1–19.

Diekmann, A., 1985. Volunteer's dilemma. Journal of Conflict Resolution 29, 605–610.

Freeman, S., 1999. Rediscounting under aggregate risk. Journal of Monetary Economics 43, 197–216.

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

Jurgilas, M., Martin, A., 2013. Liquidity-saving mechanisms in collateral-based RTGS payment systems. Annals of Finance 9, 29–60.

Jurgilas, M., Zikes, F., 2014. Implicit intraday interest rate in the UK unsecured overnight money market. Journal of Financial Intermediation 23, 232–254.

Kahn, C., Roberds, W., 1998. Payment system settlement and bank incentives. The Review of Financial Studies 11, 845–870.

Kahn, C., Roberds, W., 2009. Payments settlement: Tiering in private and public systems. Journal of Money Credit and Banking 41, 855–884.

Kraenzlin, S., Nellen, T., 2010. Daytime is money. Journal of Money Credit and Banking 42, 1689–1702.

Martin, A., McAndrews, J., 2008. Liquidity-saving mechanisms. Journal of Monetary Economics 55, 554–567.

Martin, A., McAndrews, J., 2010. Should there be intraday money markets? Contemporary Economic Policy 28, 110–122.

McAndrews, J., Potter, S., 2002. Liquidity effects of the events of September 11, 2001. FRBNY Economic Policy Review , 59–79.

McAndrews, J., Rajan, S., 2000. The timing and funding of Fedwire funds transfers. FRBNY Economic Policy Review , 17–32.

Mills, D.C., Nesmith, T.D., 2008. Risk and concentration in payment and securities settlement systems. Journal of Monetary Economics 55, 542–553.

Nellen, T., 2019. Intraday liquidity facilitiesm late settlement fee and coordination. Journal of Banking and Finance 106, 124–131.

Nellen, T., Schumacher, S., Strasser, F., 2018. Settlement liquidity in SIC. forthcoming, Swiss National Bank working paper. .

Valukas, A., 2010. Lehman Brothers Holdings Inc. Chapter 11 proceedings; Examiner's report. Jenner & Block, March .

Appendix: Ancillary System Information

System:	CHAPS
Jurisdiction:	UK
Ancillary Systems:	Faster Payments System (FPS), BACS, ICS, LINK, VISA, CREST (for UK securities transactions), Continuous Linked Settlement (CLS)
Remarks:	All ancillary systems settle in central bank money in RTGS accounts at the Bank of England. Retail schemes settle on a deferred net basis at different times during the RTGS operating day. FPS settles net obligations 3 times per business day, all other retail schemes settle once per business day. FPS, BACS and ICS are pre-funded schemes - any net balances in the ancillary system are backed in separate collateral accounts). LINK and VISA are unfunded. Transactions in CREST are settled using the Delivery Versus Payment (DvP) model via high-frequency cycles throughout the day. After each cycle the Bank is advised of the debits and credits to be made to the CREST settlement banks' accounts in the RTGS system. Each CREST settlement participant holds segregated CREST accounts, separate from the main reserves account. CLS is a direct participant in CHAPS and has a settlement window between 07:00 – 11.00 UK time. The RTGS system opens at 06:00 and closes at 18:00 each business day UK time.
References:	https://www.bankofengland.co.uk/payment-and-settlement FPS: https://www.fasterpayments.org.uk/ BACS: https://www.bacs.co.uk/Pages/Home.aspx ICS: https://www.chequeandcredit.co.uk/cheque-users/businesses/cheque-imaging/about-cheque-imaging LINK: https://www.link.co.uk/ CREST: https://www.euroclear.com/services/en/settlement/settlement-euroclear-uk-ireland.html

System CUD
Jurisdiction Colombia
Acillary Systems Retail payments: Electronic clearing system for checks and other payment instruments (CEDEC); Automated clearing houses for electronic payments (ACH): ACH-Cenit and ACH-Colombia; Networks that process transactions with debit and credit cards, among others, made at ATMs and commercial establishments: Credibanco, Assenda Red, Mastercard, ATH, Servibanca, Redeban and Visionamos.

Securities settlement systems: Central Securities Depository (DCV) used solely for government debt securities; Centralized Securities Depository of Colombia (Deceval), for all types of securities, both government and private; Central Counterparty Risk of Colombia S.A. (CRCC), which handles term operations, standardized derivatives, both financial and energy commodities, and non-standardized derivatives, such as interest rate forwards (OIS); Colombian Stock Exchange (BVC), which is for equities.

FX transactions Foreign Exchange Clearing House of Colombia (CCDC), where exchange operations are settled in cash.

Remarks Most ancillary systems in Colombia, as direct participants of the CUD, settle via accounts in the Banco de la República. Networks that process debit and credit card transactions like ATH, Servibanca, Redeban and Visionamos are the exception because do not have an account in the central bank system; as a result, they only clear operations, which are then settled by a commercial bank through the deposit account opened in its name with Banco de la República. During the sample, the normal hours of operations at the CUD were from 7:00 to 20:00. In Cedec there are two check clearing session occurs: the first one at 20:30 (t) for the provisional registration of the net multilateral clearing and the second one at 11:30 (t+1) the devolutions of day t and the definitive multilateral clearing and settlement are recorded. Automated clearing houses settle in five deferred net cycles: ACH-Colombia (around 9:30, 11:30, 14:30, 16:30 and 17:30) and ACH-Cenit (around 9:30, 12:00, 14:00, 16:00 and 18:00). The CDCC starts operations from 7:30 and sends the payment of multilateral rights at 16:00. Direct Participants must make the payment of their multilateral obligations no later than 15:00 p.m. The settlement of net obligations of the credit and debit transaction processing networks are recorded in the CUD as follows: Credibanco (12:00, 13:00, 14:00, 15:00, 16:00 and 17:00), Assenda (10:00, 11:00, 12:00, 13:00 and 14:00), Mastercard (9:00, 10:00, 11:00 and 12:00), Redeban (10:00, 11:00, 12:00, 13:00 and 14:00), ATH (19:00), and Servibanca (10:00, 11:00, 12:00, 13:00 and 14:00)

References `https://repositorio.banrep.gov.co/bitstream/item/d8a00531-123e-4e5d-b6ca-e6be812a4b93/reporte-sistemas-de-pago-2020-eng.pdf?sequence=1`
CRCC: `https://www.camaraderiesgo.com/wp-content/uploads/2020/11/PFMI-Self-Assessment-English-June-2020.pdf`
Deceval: `https://www.deceval.com.co/portal/page/portal/Home/Marco_Legal/Reglamentos/RG-SJ-PJ-001%20REGLAMENTO%20DE%20OPERACIONES%20DECEVAL_2.pdf`
ACH-Colombia: `https://www.achcolombia.com.co/compania`

System	Fedwire
Jurisdiction	USA
Acillary Systems	In the US there are three large-value payment systems (Fedwire Funds, CHIPS, and NSS) and two security settlement services (Fedwire Securities and DTCC). There are also five clearing houses (OCC, CME, ICC, FICC, NSCC), several retail payment systems, including the two ACH operators (FedACH and EPN), multiple credit and debit card networks, many check collection services, some instant payment services, and various P2P service providers and money transmitters. The retail systems that the Reserve Banks operate include FedACH, Check services, and the forthcoming FedNow.
Remarks	Fedwire Funds is an RTGS system whereas CHIPS allows payments to be netted. CHIPS has 50 members and, currently, clears and settles $1.8 trillion in domestic and international payments per day. NSS is a multilateral settlement service and processes lower volumes and values compared to Fedwire and CHIPS. Retail payment systems tend to be lower-value, higher-volume systems. Some retail systems are deferred net settlement (e.g. EPN), while others are RTGS (TCH's RTP and forthcoming FedNow).

References	`https://www.frbservices.org/resources/financial-services`
	`https://www.theclearinghouse.org/payment-systems`
	`https://www.federalreserve.gov/paymentsystems/fr-payments-study.htm`

System	Kronos
Jurisdiction	Denmark
Acillary Systems	Retail payments (ACHs): Sum Clearing, Intraday Clearing and Express Clearing Securities transactions (SSSs): VP Securities Continuous Linked Settlement (CLS)
Remarks	All ancillary systems settle in central bank money on the accounts of Danmarks Nationalbank. Participants in Kronos have designated accounts for each of the ancillary systems to which they transfer liquidity for net settlement to take place. In the sample period, Kronos was open for interbank payments on all Danish banking days between 7:00 am and 3:30 pm, but allowed transfers to the designated accounts outside regular opening hours (In the Sumclearing, exchange of amounts between banks takes place once a day – at 1:30 am., whereas settlement in the Intraday clearing occurs four times a day – at 1:30 am, 9:00 am, 12:00 pm and 2:00 pm. The Express Clearing settles immediately on a gross basis in commercial bank money, pre-funded by central bank money in which final settlement of net obligations happens six times a day – at 0:50 am, 5:20 am, 8:20 am, 11:20 am, 1:20 pm and 2:30 pm. The CLS settlement window is between 07:00 am and 12:00 pm.)
References	https://www.nationalbanken.dk/en/bankingandpayments/interbank_payments/Pages/KRONOS.aspx https://www.nationalbanken.dk/en/publications/Documents/2016/12/Description%20of%20Kronos.pdf https://www.nationalbanken.dk/en/publications/Documents/2014/09/Express%20Transfers%20in%20Denmark_Mon3-2014.pdf

System	LVTS
Jurisdiction	Canada
Acillary Systems	Automated Clearing and Settlement System (ACSS): A retail batch payment system CDSX: The Canadian clearing, and depository service for debt and equity securities Canadian Derivatives Clearing Corporation (CDCC): Central clearing counterparty for exchange-traded derivative products Note Exchange System (NES): System for the settlement of bank notes Continuous Linked Settlement (CLS)
Remarks	In Canada, all ancillary systems settle via accounts at the Bank of Canada. These systems are not themselves direct participants of the LVTS. To settle obligations in ancillary systems, participants send a payment to the Bank of Canada with further instructions to credit the account of the ancillary system. Payments from these systems are sent via the Bank of Canada to the participants. The cycle of settlement of ancillary systems is the following. CLS has hourly pay-in cycles between 2:00 and 6:00. For same-day, CLS settlement is at 14:00. The ACSS settlement occurs at noon. CDSX settlement is at 17:00. CDCC Settlement is at 7:45. The NES settlement is at 16:00.

References	`https://www.bankofcanada.ca/core-functions/financial-system/canadas-major-payments-systems/#acss`
	`https://www.payments.ca/about-us/our-systems-and-rules/retail-system/rules-and-standards`
	`https://www.cds.ca/resource/en/78`
	`https://www.bankofcanada.ca/wp-content/uploads/2012/02/fsr-0603-mcvanel.pdf`
	`https://www.cdcc.ca/index_en`

System	SIC
Jurisdiction	Switzerland
Acillary Systems	Retail payments: Swisskey, Viseca Card Services; Securities transactions (SSSs): SIX Repo, SIX SIS, SIX Terravis; Central counterparty clearing (CCPs): Eurex; FX transactions: CLS
Remarks	Besides CLS, ancillary systems have the authorization to initiate transactions on behalf of participants in central bank money directly on their SIC accounts. Ancillary systems initiate transactions meant to either settle on an obligation-by-obligation basis or settle aggregated bilateral amounts gross. For instance, SIX SIS (the Swiss CSD) and SIX Repo run DVP model 1 exchange-of-value settlement systems (i.e. both legs of individual transactions settle gross). In contrast, CLS intermediates the settlement of FX transactions on a net basis via its own SIC and other LVPS accounts. CLS net obligations are settled among CLS and participants on their respective SIC accounts during the CLS settlement window. From May 2017 onwards, CLS transactions have been settled on the main accounts of participants. At the same time, liquidity reservations for specific payments were introduced in SIC. Before, CLS transactions were settled on dedicated subaccounts of participants.
References	`https://www.snb.ch/en/mmr/reference/sicsystem_disclosure_2021/source/sicsystem_disclosure_2021.en.pdf` Nellen, Thomas, Silvio Schumacher and Flurina Strasser (forthcoming). Settlement liquidity in SIC. SNB Working Paper.

System	SPEI
Jurisdiction	Mexico
Acillary Systems	Liquidity provision and management of current accounts: SIAC - Account Holders Service System; Securities transactions: DALÍ - Securities Deposit, Administration and Settlement System ; CCV - Central Securities Counterparty; Derivatives transactions: Asigna - Asigna Trust for Settlement and Clearing. FX transactions: CLS – Continuous Linked Settlement; Retail transactions: SICAM - Clearing House Settlement System (or CCEN); Card transactions: PROSA and E-Global are both clearinghouses for interbank card payments (VISA and MasterCard). Mobile transactions: OPM – Mobile Payments Operator Society of Mexico
Remarks	SPEI, SIAC, DALÍ and Asigna are financial market infrastructures used for the settlement of different types of transactions. Transactions in SPEI, SIAC and DALÍ settle in central bank money, with direct participants also being able to transfer reserves intraday, from and to their accounts, across these FMIs. More details are as follows: DALÍ is responsible for settlement of debt and equity securities issued in Mexico and settles direct trading operations, tri-party repo transactions, and securities lending operations conducted by its depositors in the financial markets.CCV is responsible for clearing securities transactions negotiated on the Mexican Stock Exchange (BMV). Final obligations are settled directly through DALÍ. Asigna acts as a central counterparty for derivative contracts traded on the Mexican Derivatives Exchange (MexDer), as well as derivative contracts received from trading platforms. Operations are settled in Asigna. CLS settled directly through SPEI. PROSA and E-Global are not direct participants in SPEI and final obligations are performed via settlement banks in SPEI. AMERICAN EXPRESS BANK (MEXICO) S.A. is direct participant in SPEI. OPM is not a direct participant and settled indirectly through SPEI via payment instructions. SICAM (CCEN) provide clearing services for interbank operations for checks, deferred electronic funds transfers (TEF or direct credit) and direct debit. Final obligations are settled in SIAC.
References	`https://www.banxico.org.mx/payment-systems/policy-and-functions-of-the-b.html` Banco de México's Policies and Functions Regarding FMIs: `https://www.banxico.org.mx/payment-systems/d/%7B611C4F2A-0CE2-03E3-081D-CB7A03A246C9%7D.pdf` DALÍ, securities: `https://www.banxico.org.mx/payment-systems/dali-securities-banco-mexico.html` SPEI®, transfers: `https://www.banxico.org.mx/services/spei_-transfers-banco-mexico.html` SIAC, account holders: `https://www.banxico.org.mx/payment-systems/siac-account-holders-banco-me.html` SICAM, clearing: `https://www.banxico.org.mx/payment-systems/sicam-clearing-banco-mexico.html` Document clearing service, settlement, `https://www.banxico.org.mx/payment-systems/document-clearing-service-set.html` TEF, transfers: `https://www.banxico.org.mx/payment-systems/tef-transfers-banco-mexico.html` Direct debit service: `https://www.banxico.org.mx/payment-systems/direct-debit-service-payments.html`

System	STR
Jurisdiction	Brazil
Ancillary Systems	Retail payment systems: Sitraf, Siloc, Compe; Fast payment system: SPI; Securities Settlement Systems (SSSs): B3 Balcão (OTC), SELIC; Central counterparties (CCPs): B3 Clearinghouse, B3 Foreign Exchange Clearinghouse
Remarks	The Instant Payment System (SPI) is an RTGS system operated by the Banco Central do Brasil (BCB or Central Bank of Brazil) and was launched in November 2020. It operates 24/7 and it is the only centralized infrastructure for instant payment settlement between different payment service providers in Brazil. To settle instant payments (PIX), direct participants must transfer balances from their STR to their SPI account as no overdrafts are allowed. Fund Transfer System (Sitraf) is a private RTGS payment system operated by the Interbank Payment Clearing House (CIP) for payments up to BRL 1 million (since 2011). Institutions holding accounts in STR have to transfer funds to their Sitraf account to perform electronic funds transfers. The system is open daily from 6:35 to 17:20. The System of Deferred Settlement of Interbank Credit Order Transfers (Siloc) is a multilateral settlement system used to settle low-value (up to BRL 250K) transfers of Credit transfer Documents (DOC) and electronic bills. In 2015, this system commenced the clearing and settlement of payment transactions of the main payment schemes based on credit and debit cards. Selic's platform (SELIC, operated by BCB) is the central depository for most securities issued by the National Treasury. It operates modules for the National Treasury's primary auctions and the secondary market over-the-counter trades. Through a direct connection with the STR, the SELIC provides immediate, simultaneous, and final transfer of securities and funds. All operations are settled with their real-time gross values, and the funds to be transferred are kept in accounts held at the BCB — the bank accounts. Checks Clearinghouse (Compe, operated by Banco do Brasil) provides clearing and settlement of checks up to BRL 250 thousand in daily multilateral netting cycles. B3 Balcão – OTC (operated by B3) provides clearing and settlement of transactions involving corporate, state and, municipal bonds and derivatives. B3 Clearinghouse (operated by B3) provides clearing and settlement of derivatives (futures, options, and swaps) and transactions involving equities and corporate bonds.B3 Foreign Exchange Clearinghouse (operated by B3) provides clearing and settlement of interbank foreign exchange transactions.
References	`https://www.bcb.gov.br/en/financialstability/paymentsystem`

System	TARGET2
Jurisdiction	Eurozone
Acillary Systems	EURO1: A privately owned and the only direct competitor of TARGET2 as a large-value payment systems settling in euro. EURO1 operates on a net settlement basis and achieves final settlement in central bank money (in TARGET2) at the end of the day. STEP2: A Pan-European Automated Clearing House processing retail payments in euro (e.g. SEPA payments). It settles payments in multiple cycles on a bilateral gross basis with multilateral calculated net positions settled in TARGET2. CLS: Facilitates settlement services for FX transactions. Pay-ins and pay-outs for euro business are settled in TARGET2 between 8:00 and 12:00 CET. TARGET2 Securities (T2S): T2S enables the settlement of securities in central bank money. It integrates the securities accounts of CSDs and the dedicated cash accounts (DCAs) held at central banks. Liquidity can be transferred between TARGET2 and T2S in a flexible way. The cash leg of securities transactions in T2S are settled on the DCAs that legally belong to TARGET2. At the end of the day, the credit balances of the DCAs are transferred back to RTGS accounts in TARGET2. The launch of T2S in different waves triggered a shift of the CSD traffic from TARGET2 to T2S, changing the interaction flows between these systems.
Remarks	TARGET2 consists of different (national) components operating on a single shared platform. At the end of 2020 there were a total of 83 ancillary systems, including 31 retail payment systems, 22 securities settlement systems and 19 clearing houses (including four central counterparties). TARGET2 also provides liquidity intraday to T2S, the platform operated by the Eurosystem for settlement of securities related transactions in central bank money. A plethora of ancillary systems settle transactions directly in TARGET2 and can use standardised access and clearing procedures. Different functionalities are offered by the Ancillary System Interface (ASI). Of the 83 ancillary systems, 64 made use of the ASI.

References	`https://www.ecb.europa.eu/paym/target/target2/profuse/participation/html/index.en.html`
	`https://www.ecb.europa.eu/pub/targetar/html/ecb.targetar2020.en.html`
	`https://www.bundesbank.de/en/tasks/payment-systems/target2/services/target2-services-626896#tar-8`
	`https://www.ecb.europa.eu/paym/target/target2/profuse/participation/html/index.en.html.`