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ABSTRACT

Using a new and unique data set of foreign currency settlement instructions provided by CLS Bank, we investigate activity and liquidity in the foreign exchange market. In the major currency pairs, CLS settlement volume shares are similar to those reported in the BIS triennial surveys. They are also similar to shares computed from EBS trade data reported by Mancini, Ranaldo and Wrampelmeyer (2013)(MRW), but only for currency pairs that do not belong to the "UK Commonwealth" pairs, for which EBS coverage is limited.

We estimate Amihud (2002) illiquidity ratios from CLS submissions and Olsen price records, and examine the correlations between these ratios and price impact estimates based on high frequency EBS data and reported by MRW. The correlation is 0.748, but with marginal statistical significance and only when the commonwealth pairs are excluded from the analysis. When the commonwealth pairs are included, the correlation drops to -0.130 (insignificant). We believe that, as with the volume estimates, this reflects EBS' limited coverage of the commonwealth currency pairs. The common liquidity factor in our illiquidity ratios constructed from all major pairs is highly correlated, however, with the factor based only on non-commonwealth pairs, suggesting that liquidity factors constructed from EBS data may be good proxies for factors based on broader samples.

Our data include numerical identifiers for counterparties to each trade which allows us to estimate market concentration by currency pair. We find that trading is more concentrated (across participants) in less actively traded currencies, which typically exhibit lower liquidity.

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I. Introduction and Motivation

The global foreign exchange (FX) market holds a pivotal place among financial markets. Most international trade in goods and services as well as risk management of international asset and liability positions depends on a liquid and efficiently functioning currency market. With April 2013 global turnover estimated at $5.3 trillion daily, the global FX market is acknowledged to be the world's largest financial marketplace.[1]

Despite its size and importance, common liquidity and activity measures for the FX market are difficult to track. The FX market is a geographically dispersed, broker-dealer market. There are numerous platforms and means for executing currency transaction, and yet, there is no central institution that records transaction data in real time or after the fact. The Bank for International Settlements (BIS) Triennial Surveys provide the most authoritative overview of FX market turnover – by currency, by country, by instrument, by counterparty, by method of execution and other broad aggregate categories but only as a snapshot every three years (Bank for International Settlements (2013)).

Over the last twenty years, a small literature has developed which investigates patterns of FX market activity and liquidity based on trade-level data. The data derive from diverse sources, such as proprietary data provided by dealing firms, regulatory data collected by central banks, bilateral messaging systems, limit order markets, and various

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[1] $5.345T is the value reported in the BIS Triennial Survey for April 2013. An updated survey for April 2016 has recently been released (Bank for International Settlements (2016)). Moore, Schrimpf and Sushko (2016) discuss the 2016 figures, and the changes and trends evident since 2013. As most of our data cover April 2013, however, most of our references to the BIS data are to the 2013 release. It should be noted that the 2016 survey contains a minor restatement of the 2013 data: $5.345T has been revised to $5.355T.

aggregators/consolidators. Most recent studies of high-frequency FX trading, however, use data from one of the two dominant electronic limit order markets: Reuters or EBS.

Among the studies based on EBS data, Chaboud, Chernenko and Wright (2007) use one-minute time-aggregated volume and price data to document intraday volume patterns for the EUR/USD and USD/JPY spot exchange market, and in addition, to examine price and volume responses to macroeconomic news announcements. Mancini, Ranaldo and Wrampelmeyer (2013) (MRW) utilize one-second time-aggregated data for nine currency pairs. Their sample period 2007-09 allows the authors to analyze liquidity before and after the Lehman Brothers bankruptcy, and also to identify a common factor that explains co-movement in liquidity across the 9 currency pairs as well as liquidity in other principle financial markets. Karnaukh, Ranaldo and Söderlind (2015) (KRS) use a longer sample of EBS data covering January 2007 – May 2012 to estimate and explain time varying and cross-sectional variation in FX liquidity. Like MRW, KRS find evidence of "significantly stronger commonality in periods of market stress—as indicated by high FX and stock market volatility, tight funding constraints (high TED spread), and losses of carry trade portfolios."[2] Hagströmer and Menkveld (2016) study a sample of EBS data at 100-millisecond intervals to characterize patterns of price discovery before and after the January 15, 2015 revaluation of the Swiss franc.

While these studies reflect rigorous analysis and offer many useful insights, they also harbor certain limitations. Firstly, although EBS claims to be "the recognized primary

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[2] KRS also analyze low frequency (LF) daily data over the same sample period and find that liquidity measured with LF data co-moves with HF measures. See King, Osler and Rime (2013) for a critical survey of the FX market microstructure literature and Berger, Chaboud and Hjalmarsson (2009) for a review of the literature on FX volatility.

source of global transactional spot FX market data," it is not uniformly preeminent. King, Osler and Rime (2012) note that, "EBS has long dominated interbank trading for the EUR, JPY, and CHF, while Reuters dominates the GBP, AUD, CAD, and the Scandinavian currencies." Secondly, EBS and Reuters together constitute a small fraction of the overall FX market, 15.0% of daily spot FX turnover by our estimate. Most spot FX transactions are executed via other means such as single bank proprietary trading systems, multi-bank proprietary trading systems, voice communication either directly with a dealer or intermediated by a voice broker, and so on. Thirdly, EBS bids and offers are visible and accessible only between participants who have established mutual credit arrangements. They are not uniformly available across all EBS participants.[3] While it is likely that most large banks have mutually established arrangements, smaller banks may not be as well-connected. This would limit their ability to compete as liquidity suppliers. Finally, although MRW construct their data from individual messages, the commercially available EBS datasets are time-aggregated and report only summary data on the trades within a given window.[4]

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[3] The document EBS Dealing Rules – EBS Market Appendix notes, "Each Participant must establish a relationship with its Counterparties, satisfy itself of the creditworthiness of its Counterparties and extend credit to them as it sees fit. For a Match to be made in EBS Market between two Participants, mutual credit must exist between those Participants. If credit has not been established with or given by another Participant, or when credit given by or to another Participant is exhausted, the prices submitted by each Participant will not be Dealable prices for the other," (EBS (2016)).

[4] A product description from EBS (2012) summarizes the features of "Data Mine 2.0" as follows: "One second time-slice; Best bid/offer with volume; Lowest given, highest paid; Actual volumes." A more detailed description of the EBS Data Mine Record Format (2011) provides additional information about the nature of the data. As EBS (2011, p. 2) describes it: "The Price Record lists the EBS Best prices at the end of a time-slice, and the Deal Record lists the highest paid and the lowest given deal prices during the period of a time-slice."

The motivation for our research is to utilize a new database that seeks to overcome some of these limitations and holds the possibility of offering new and/or more robust insights regarding FX market conditions and liquidity based on high frequency data for a larger sample of currency pairs. The new database comes from CLS Bank International (or simply CLS Bank, or CLS) which operates a payment-versus-payment (PVP) settlement service designed to mitigate settlement risk for the FX transactions of its settlement members and their customers (known as third parties). Our data consist of submissions to CLS that specify settlement instructions.

We estimate that CLS submissions cover about 37.2% of global spot FX turnover considered in the 2013 BIS triennial survey (after adjusting the BIS figures for prime brokerage). In contrast, EBS covers about 7.3%, while EBS and Reuters combined account for 15.0%. Thus, CLS coverage of the market is substantially more comprehensive in terms of value. Furthermore, CLS coverage is more extensive across major currency pairs than EBS. In particular, CLS activity in the (UK) commonwealth currencies is much closer to the 2013 BIS figures. It is not the case, however, that settlement data are superior in all respects. We find that due to limitations of timeliness and sequencing, the settlement

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Thus, there seems to be no representation or assurance that the one second time slice captures all trading activity within that interval. While EBS may provide an authoritative close-up of FX market conditions among FX traders who post quotes and execute trades on their platform, the EBS data appear to fall short of reporting a complete record of actual consummated trade prices and amounts – even those executed on the EBS platform. A more enhanced product ("Data Mine 5.0") offers time-slices matching EBS Live, all bids and offers (up to 10 levels of book) with volume, and other features – but not actual trade and volume data. As of September 2012, Data Mine 5.0 was only available to current EBS customers.

instructions correspond only approximately to market transactions and quotes. Liquidity measures based on the settlement data are therefore limited to estimates over broad time windows.

This paper proceeds as follows. In the next section, we briefly describe CLS Bank and its operations. Section III presents summary features of the settlement data. In Section IV we discuss the BIS survey methodology, compare the coverage of BIS and CLS samples, and perform a similar analysis for EBS data. Section V examines the properties of the settlement network. In Section VI we augment the settlement data with bids and asks (collected at a ten-second frequency), and discuss the extent to which settlements are likely to correspond to market transactions. Section VII discusses Amihud liquidity measures. A summary concludes the paper in Section VIII.

II. CLS Bank Operations

A foreign exchange settlement is the last stage of the trade process, and constitutes irrevocable transfers (in opposing directions) of the two currencies. It is initiated when the two parties to the transaction separately submit instructions that name each other as the counterparty, and specify the terms of the settlement (the amounts of the two currencies being exchanged, who is receiving which currency, and when the settlement is scheduled to occur). When the details match, the transfers proceed.

A settlement is generally distinct from what might be considered, in other contexts, a trade. An execution on an electronic platform, for example, would typically report price, quantity, and a time stamp. The settlement instructions would also include counterparty identifications, but would not identify the platform or any other attribute of the execution process (such as the time stamp). There is another important distinction. Because many

execution mechanisms, such as electronic limit order books or voice brokers, provide pre-trade anonymity, the resulting trades are presumed to be arms-length transactions at market prices. Settlements, however, are bilateral transfers, and the terms of the exchange bear no necessary relation to current market prices. An exercise of an FX option, for example, involves a transfer at the exercise price, not the current market price.

CLS Bank operates the largest FX settlement service. Developed and owned by a consortium of major banks, it began operations in 2002, and is generally considered to be, "the sole multi-currency settlement system of its kind, offering both liquidity savings and settlement risk mitigation across all the major currencies, and the only one that operates on a global basis across all the major currencies," (Financial Stability Oversight Council (2012)).[5] It was originally formed to address Herstatt risk, a reference to a 1974 incident of settlement failures in the US dollar/Deutschemark market that involved transfers between entities in different time zones.[6] Herstatt risk is pernicious not simply because of the loss of principal (which in the global FX market could be substantial), but also because of a systemic cascade effect should dealers withdraw from the market and be unwilling to quote and trade with their normal counterparties.

As noted earlier, CLS Bank operates a payment-versus-payment (PVP) settlement service which mitigates settlement risk in the FX transactions of its settlement members and their customers. While the details of the entire system are complex, the general

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[5] The initials "CLS" denote "continuous linked settlement," but the settlement procedure is now generally characterized as "payment versus payment" (PVP). See CLS Group (2013).
[6] On June 26, 1974, Herstatt Bank received Deutschemark settlement payments at its offices in Cologne Germany, but was later that day closed down and forced to cease operations by German banking regulators. It was thus unable to deliver US dollars to its counterparties once US banks opened for business.

principle is straightforward.[7] Both counterparties independently submit to CLS Bank detailed settlement instructions ("submissions"), which CLS then matches. On the agreed-upon settlement date, during the settlement cycle window, CLS Bank receives currency A from one counterparty and currency B from the other counterparty. Once both amounts have been received and CLS has verified that all details match, CLS releases the funds and pays out both counterparties.[8] Once settlement has been concluded, it is final and irrevocable. If counterparty B fails to provide adequate funding, CLS suspends the failing counterparty and takes remedial action to protect the full amount of counterparty A's principal, which avoids settlement risk.[9] The transaction between A and B is left to settle in some other manner.

Because of the complex nature of the actual CLS system – e.g. the need for a real-time gross settlements domestic payments system, the need for countries to accept the legality of a foreign entity (CLS Bank) to deem a transaction final and irrevocable, and the risk that CLS Bank accepts when dealing with counterparties – CLS is available only for a

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[7] For example, of transactions submitted to CLS, only those that are matched and not rescinded will be settled, subject to satisfying certain risk tests. More detail on how CLS works is available here: https://www.cls-group.com/About/CG/Pages/CorePrinciples.aspx

[8] The FX market generally works on a "T+2" settlement schedule (or "T+1," if both parties are in North America). That is, when a spot trade occurs on day "T", settlement instructions are submitted to CLS contemporaneously, but these instructions specify that the transfer should actually occur two days later. Forwards and far legs of swaps, of course, will have varied settlement dates, and so will depart from this convention. The date-time stamps on our data refer to the submission (of the settlement instructions).

[9] The Allsopp Report, an influential document that prefigured CLS, refers to a "guaranteed refund system," wherein "counterparties are guaranteed that any settlement payment they make will be cancelled or returned if their counterparties fail to pay what they owe," (Bank for International Settlements (1996)). This contrasts with the "guaranteed delivery system" used in regulated futures and options markets, where counterparties post collateral and a clearinghouse guarantees delivery.

restricted set of eligible currencies, eligible products, and eligible counterparties or members.

In April 2013, there were 17 CLS-eligible currencies including the major G-10 currencies plus the Korean won, South African rand, and others.[10] Collectively, these 17 currencies accounted for 93.7% of global turnover in the 2013 BIS survey although this overstates the potential reach of CLS because both currencies as well as both counterparties in a trade must be CLS-eligible to settle in CLS. Levich and Packer (2015) estimate that turnover among all pairs of the 17 CLS currencies measures 90.46% of global turnover.

In April 2013, CLS settlement was available for spot FX trades, outright forward contracts and FX swaps. Collectively, these three products accounted for 92.7% of global turnover in the 2013 BIS survey. As of April 2013, CLS did not settle cross currency swaps (representing 1.0% in the BIS Survey), however CLS added the initial and final notional principal exchanges of cross currency swaps as CLS-eligible in November 2015. FX options (representing the final 6.3% in the BIS survey) are a special case. The initial payment of an FX option premium does not settle through CLS (the premium is simply a one-way payment from the buyer to the seller). However, an option exercise is CLS eligible and appears as a spot settlement when exercised. Section IV.A provides more detail.

Direct participation in CLS is limited to settlement member financial institutions (63 in number, as of April 2013). CLS also allows for indirect access. Third parties gain access by contracting with a member acting as a Third Party Service Provider (TPSP). In effect,

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[10] The 17 currencies are listed in Table 2. Subsequently to our sample, in November 2015, CLS added the Hungarian Forint.

TPSPs act as gatekeepers to CLS, assume the risks of dealing with their third party clients, and charge these clients for their services.[11] Third party institutions can be commercial banks, central banks, non-bank financial institutions, corporations and investment funds. They may also be subsidiaries, affiliates, or other sub-units of settlement members. This is significant because it precludes identifying any given member as a distinct and independent economic agent. As of April 2013, there were over 9,000 third parties. Although members and third parties have the right to submit eligible transactions for settlement in CLS, they are under no obligation to do so. Bilateral settling (the accepted practice prior to the start of CLS) is still an available option.[12]

III. Data and summary statistics.

Our data sample consists of all submissions to CLS during April, 2013 (to correspond to the 2013 BIS survey of global FX turnover). Each record corresponds to one settlement, but reflects submissions by both sides. By convention, the first member to submit settlement instructions is designated as the "trading party," and the currency they are receiving as the "buy currency"; the later submitter is considered the counterparty, and their received currency is the "sell currency". There is no economic content to these designations, however, as the essentials of the settlement would be identical if the

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[11] "TPSPs process all payment instructions and funding on behalf of their customers." *CLS Third Party Evaluation Guide*, August 2013, p. 3.

[12] A CLS survey of their own settlement members reported that bilateral netting was used to settle 25.8% of turnover even for trades involving CLS-eligible currencies (CLS Group (2014)). Members may also elect other settlement methods such as on-us (when the counterparty holds an account at the member's financial institution), bilateral netting, or other PVP systems. Given the risk mitigation advantages associated with using CLS and the large number of member counterparties, it is unclear why counterparties select bilateral settlement. See Kos and Levich (2016) for further discussion.

designations were to be reversed. The two parties to the settlement are identified by Bank Interchange Codes (BICs) that are encoded to ensure anonymity. The data are time-stamped with one-second precision. Appendix A summarizes further details.[13]

Table 1 reports total sample counts and settlement values, categorized by CLS' classification of instrument type. Spot settlements account for over 90% of all settlements by number, but only approximately 25% by value. FX option exercises are imputed by CLS based on an algorithm that identifies outlier prices.[14]

In most of what follows we concentrate on spot settlements. Table 2 reports shares of turnover by currency. The dominant currencies are the USD, EUR, and JPY. The percentages total to two hundred because each settlement has two sides/currencies. The percentages are very close to the corresponding figures from the BIS 2013 survey reported for comparison purposes in the last column. (Section IV presents a more thorough reconciliation.)

The Table 2 percentages summarize the overall importance of a given currency, but there is substantial variation across counterparty currencies. To illuminate this variation, Table 3 reports for each currency, the relative occurrence (by value) of currencies on the

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[13] Each record reports the time when CLS accepted the submission of the trading party, the accept time of the counterparty's submission, and the time when the instructions were matched. Because the trading party is designated when the first submission is processed, it is the earliest. It is therefore closest in time to the trade or similar event that motivated the settlement. References to "time" in this paper accordingly denote the trading party accept times. Submissions are generally processed continuously, on arrival. In our sample, however, each day generally contains one interval of three or four minutes where submissions are queued and the accept times are batched. We estimate that this affects about 0.4% of the observations. Data from 2016 onwards do not contain queued intervals.

[14] FX swaps by definition involve a paired near and far leg. The near- and far-leg counts in Table 1 are very close, but not exactly equal. We believe that the difference is due to minor timing discrepancies in the database extraction of our sample.

other side of the settlement. The percentages sum to one hundred across each row. For example, the first row corresponds to the AUD: relative to the total value of all settlements that have the AUD on one side, 77.8% (by value) have the USD on the other side.

Table 3 confirms that while the USD is usually the dominant contra currency, there are some notable exceptions. Its share is relative small for the Nordic currencies (DKK, NOK, SEK), each of which is much more likely to be exchanged for EUR. In many currencies (CAD, HKD, ILS, KRW, SGD, ZAR) the entry in the USD column exceeds ninety percent. This may reflect the use of the USD as a vehicle currency: if a currency pair has no established market, each may be converted to/from USD as an intermediate step. The KRW is an extreme case in that *all* of the settlements involve the USD on the other side.

Table 4 reports for each currency the distribution of settlement values. That is, each time a given currency appears on one side of a settlement, we include the value of the settlement. (The total number of observations is therefore twice the number of settlements.) Across all currencies, the median settlement size is slightly under one million USD equivalent, but there are notable extreme values. On the low end, with the exception of the KRW, all currencies have at least one settlement valued at under one dollar. We conjecture that these reflect transfers that have been set up to verify trading or settlement processes. Even at the 25th percentile of the distribution, however, the sizes are generally substantially smaller than the traditional minimum size on the interdealer platforms. Chaboud, Hjalmarsson, Vega and Chiquoine (2009) note, for example, that the minimum size on EBS over their 2003-2007 sample is one million units of the base currency (generally EUR, GBP or USD). This suggests that the sample of participants and trades is somewhat broader than the usual electronic platforms.

At the other extreme, the largest settlements in many currencies exceed one billion USD. We surmise that these flows do not arise from trades on the usual execution platforms, but may instead reflect pre-arranged transfers related to securities flotations, foreign acquisitions, or repatriation of funds.

Settlement instructions can be submitted at any time, but submissions received over a weekend are queued until Sunday afternoon. Most activity is concentrated on weekdays, and is further concentrated within the day in local RTGS (real-time gross settlement) banking hours for at least one of the counterparties. (This is not a formal convention, however, as CLS submissions do not require RTGS systems.) Figure 1 presents histograms of settlement value by submission date, for currencies grouped according to geographic region. (Dates are based on Central European Time.) The plots exhibit no discernible day-of-week patterns, but given the short length of the sample, a pattern would have to be very strong to be detectible.

Figure 2 depicts histograms of values submitted for settlement by time of day (CET). EUR and European non-EUR submissions are concentrated 9:00-17:00 CET. CAD and MXN settlements peak roughly 15:00-17:00 CET, which corresponds to morning in the Western hemisphere, but exhibit substantial activity later. The time distributions of USD and Asia-Pacific currencies are distinctly trimodal.

We will subsequently consider other features of the CLS data that characterize liquidity and settlement patterns between members. As earlier mentioned, however, one important purpose of this analysis is to place the settlement data in the context of other measures of the FX market. We turn to this in the next section.

IV. Reconciliation and comparison of the CLS settlement data with other sources

BIS turnover estimates, EBS executions, and CLS settlements are all measures of flow in the FX market, but they differ markedly in coverage and construction. In this section, we survey these measures, and discuss agreements and discrepancies. We start with the BIS survey figures, which we believe are the most comprehensive, and then turn to CLS and EBS figures.

A. Comparison with BIS turnover.

In its capacity as a "bank to central banks," the Bank for International Settlements has organized a survey of global foreign exchange market turnover since 1989.[15] The first three surveys were limited to the foreign exchange markets and from 1998 thereon, both the foreign exchange and the derivatives markets have been surveyed. The survey design relies on participating central banks, which collect data from banks and dealers in their jurisdiction and calculate aggregate national results. These data are provided to the BIS which compiles global aggregates. The April 2013 survey included 53 central banks and other authorities who in turn collected data from about 1,300 banks and other dealers in their jurisdictions. The BIS surveys turnover in 5 categories: spot, outright forward, FX swaps, currency swaps, and FX options. In addition, the BIS requests information as to how the trade was executed (e.g. voice or electronic platforms), the type of counterparty (e.g. other reporting dealer, non-financial institution, retail, etc.), the location of the counterparty (local or cross-border), the tenor of the forward contract or swap, and whether the transaction was facilitated using prime brokerage, along with sub-categories

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[15] From the BIS mission statement at http://www.bis.org/about/mission.htm

of many descriptors. The survey is conducted in April to minimize the impact of national holidays and end-of-quarter transactions which could distort the results.

The gross totals in the BIS survey data simply aggregate the reported trades. In these gross data, a transaction between a reporting bank and a non-reporting entity is reported once. For example, if Citibank (New York) pays USD and receives EUR from a retail customer or a mutual fund, there is one trade report (from Citibank). When both sides of the exchange are reporting banks, however, there will be two reports. For example, if Citibank (New York) receives 10M EUR from, and pays 12M USD to, Wells Fargo Bank (San Francisco), both banks include the trade in their survey responses. To correct for this, the BIS subtracts from the gross turnover one-half of the value of trades between reporting banks. The correction is made in two stages. "Gross-net" turnover reflects corrections for trades between reporting banks in the same survey jurisdiction (as in the Citibank/Wells Fargo example). "Net-net" turnover additionally includes a correction for reporting banks in different survey jurisdictions. For example, if Citibank (New York) receives 10M EUR from, and pays 12M USD to, the Royal Bank of Scotland (London), the trade is included in Citibank's survey response to the Federal Reserve Bank, and also in RBS' response to the Bank of England.

In the examples above, all parties to the trades are acting on their own behalf. There is also a large and growing usage of prime brokerage agreements, wherein one institution (usually a major bank) acts as a broker, facilitating trades on behalf of another (such as an

institutional fund, hedge fund or other proprietary trading firm).[16] For example, access to EBS was originally restricted to the member banks belonging to the consortium that developed it. Nowadays, under prime brokerage arrangements, other institutions can trade on EBS through the sponsorship of a member, with the member essentially guaranteeing the trade. This has altered the structure of the FX market, transforming what was strictly an interdealer market into one with more direct customer participation.

Suppose that hedge fund *A* trades with Wells Fargo, and *A* is using Citi as the prime broker. There are several ways of characterizing the prime brokerage. One perspective (the "one-trade" view) is that *A* has essentially done a trade with Wells Fargo, and that Citi's role is incidental, becoming substantial only if *A* were to default on settlement of the trade. The "two trade" perspective imputes two exchanges: Citi's with Wells Fargo, and *A*'s with Citi. The one-trade interpretation emphasizes the ultimate counterparties to the trade. The two-trade view focuses on the exposures to counterparty risk: *A* vs. Citi and Citi vs. Wells Fargo.[17]

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[16] The 2013 BIS survey instructions specified reporting conventions for prime brokered trades: "Prime brokers are defined as institutions (usually large and highly -rated banks) facilitating trades for their clients (often institutional funds, hedge funds and other proprietary trading firms). Prime brokers enable their clients to conduct trades, subject to credit limits, with a group of predetermined third-party banks in the prime broker's name," (Bank for International Settlements (2012)).

[17] Neither perspective has an obvious and exclusive claim to validity. In fact, the question of how to characterize the role of broker/dealer intermediaries arises in other markets, and both of the above views appear in different contexts. In US securities markets, for example, an agency trade (that is, one conducted by a broker on behalf of a customer) is conventionally reported once. Nevertheless FINRA rules also allow for two reports in "riskless principal trades," as when, for example, a broker buys securities in a market and simultaneously sells them to a customer. Even when two reports are submitted, however, only one is considered a "tape" report, and included in the usual trading volume statistics (see FINRA's "Trade Reporting Frequently Asked Questions," FINRA (2015)).

While we do not definitively favor one perspective or the other, we must attempt to ensure that similar conventions apply when making comparisons across different data sources. The CLS settlement data report a prime-brokered settlement once, as occurring between the ultimate counterparties. The BIS survey instructions, on the other hand, specify that when a reporting bank is acting as a prime broker it must report both legs of the transaction as two separate deals (allocating them by instrument, currency and counterparty). In addition, both legs are included in a turnover subtotal labeled "of which prime brokered," (o/wPB).

To estimate single-counted turnover in the BIS data we subtract one-half of the o/wPB from the net-net turnover. The following example illustrates the intuition. Suppose that (hedge fund) A trades one unit with (proprietary trader) B; A uses Citi as a prime broker and B uses RBS. From the BIS survey perspective, the trade can be diagramed as $A \leftrightarrow Citi \leftrightarrow RBS \leftrightarrow B$. Citi reports both legs, as "2 units, o/w 2 are prime brokered." Similarly RBS reports "2 units o/w 2 are prime brokered," for a total gross-gross turnover of 4 units, o/w 4 are prime brokered. The double counting of the $Citi \leftrightarrow RBS$ trade is corrected, leaving net-net turnover of 3 units. Subtracting one-half the o/wPB leaves $3 - \frac{4}{2} = 1$, the correct single-counted volume.[18, 19]

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[18] This example is straightforward only because we have focused on one particular trade. In discussions, BIS personnel have told us that the adjustment cannot be relied upon for correcting the aggregate numbers, particular for trades in which only one side is prime brokered.

[19] BIS turnover figures also include transactions between related parties, defined in the 2013 survey instructions as, "trades between desks and offices, and trades with their own branches and subsidiaries and between affiliated firms," (Bank for International Settlements (2012)). Transfers in which a bank "passes the book" between desks in

The BIS turnover figures are stated on a per (business) day basis, wherein the total over April for a given reporting area is divided by the number of official business days in the same reporting area. We cannot implement this calculation for the CLS figures because we do not know the locations of our settlement parties. The CLS settlement volume is highly concentrated on twenty-two days, however, and we therefore divide the totals by 22 to arrive at per day estimates.

BIS and CLS both classify trades/settlements according to instrument type. Three of the categories in principle agree: spot, outright forwards, and FX swaps (far leg). CLS also reports the near legs of FX settlements, but the BIS survey asks reporting banks to include only far legs.

Both BIS and CLS have a category labeled "options", but the classification differs significantly between the two entities. In the BIS survey, reporting dealers are requested to provide information on turnover for over-the-counter (OTC) FX options. In practice, this implies options that are created *de novo* rather than exchange traded options that are created once and then bought and sold in a public market. More specifically, reporting dealers are asked to report the notional amount of the option implying that a call option on

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different time zones, for example, would appear to fall in this category. It is difficult to generalize about the extent to which these events constitute substantive legal and economic transfers of ownership, but few would require that the transfer be finalized by any settlement. The BIS tabulations do not break down these transfers by instrument, so we cannot impute an adjustment to spot turnover estimates, but the size of such an adjustment might well be large. The survey reports related party transactions across all instruments for April 2013 as $817,995 million (per day, USD equivalent), or roughly 15% of the $5,344,549 million total turnover.

10M EUR is reported as 10M EUR volume regardless of the strike price or tenor of the contract. At the same time, the BIS asks reporting dealers to *exclude* option exercise as part of spot FX trading activity. The rationale could be that option exercise reflects a contract that was struck earlier (possibly prior to the April 2013 survey period) and the BIS survey is intended to gauge current market conditions and activities. In the CLS submissions, option settlements arise from option exercises. These are identified by a CLS classification algorithm that flags outliers, that is, settlements occurring at implied rates that differ substantially from current market rates and presumably reflect the exercise of in-the-money options.

Table 5 reports BIS turnover for the spot, forward, and swap categories (line 1). The next lines contain the corresponding BIS "of which Prime Brokered" figures (line 2), the implied turnover net of the prime broker adjustment (line 3), the average daily CLS settlement volume (line 4), and the ratio of CLS volume to BIS volume.

In the spot category, CLS settlement volume extends to 37.2% of BIS spot turnover, slightly over one-third. Although the CLS/BIS spot coverage might initially appear low, the two sources are focusing on different market segments. The BIS turnover includes large components representing reporting banks' transactions directly with customers, including retail and institutions that do not use prime broker arrangements. In the other two categories, the CLS market share of swaps is comparable to that of spot trades, while the share of outright forwards is substantially smaller.[20]

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[20] The 2013 BIS survey estimates that other reporting dealers are the counterparties for 33.0% of the spot turnover, but only 26.7% of outright forward turnover. Thus, outright forwards may be relatively underrepresented in the settlement data.

B. Comparison with overall EBS and Reuters trade volumes

EBS and Reuters report monthly averages of daily spot volume on their websites. For EBS, the average daily volume for April 2013, $128,300 M, is indicated in Table 5 (line 6). This constitutes about 7.3% of BIS turnover net of PB (line 7). Comparison with line 5 suggests that CLS appears to cover about five times as much activity as EBS. Reuters daily average spot turnover for the month is $133,000M (line 8). This figure reflects all Reuters electronic systems (including Reuters Matching and FXall). The sum of EBS and Reuters turnover accounts for 15.0% of BIS net of PB; CLS turnover is about two-and-a-half times as large.[21]

C. Cross-currency comparisons with EBS

Mancini, Ranaldo and Wrampelmeyer (2013) (MRW) report (in the internet appendix) average daily EBS trade counts for nine major currency pairs. The subsample in their data that most closely corresponds to a BIS survey is mid-September 2008 to December 2009 ("post-Lehman"). A triennial BIS survey was conducted in 2010.

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[21] The BIS survey classifies turnover according to execution method. In these statistics, EBS and Reuters are combined into one category ("Reuters Matching/EBS", a subcategory of "electronic, indirect" turnover. The reported average daily turnover in this category is $313,118M, a value substantially greater than $261,000M total based on the markets' self-reported figures. We believe that the discrepancy is largely due to prime brokerage: the markets' own figures would report only execution volume conducted on their systems, implying a single-counting of trades. The BIS survey instructions state that for prime-brokered trades conducted on indirect electronic systems, both legs of the trade should be counted. Interestingly, the BIS numbers (inclusive of both legs) imply that the Reuters/EBS share of spot turnover is $313,118M/$2,046,158M=15.3%, which is very close to the 15.0% reported in Table 5.

Table 6 reports activity measures for the nine MRW currency pairs, derived from the 2013 and 2010 BIS surveys, CLS and MRW. The left side of the table reports average daily flows; the right side of the table reports the corresponding percentage shares across currency pairs.

The BIS turnover figures in columns (1) and (2) are stated on a "gross-gross" basis: both sides of the trade are reported and there is no adjustment for prime brokerage. The CLS settlement volumes are similarly reported. (The total of $1,101B (column 3) is slightly less than twice the $650,480M reported in Table 2 due to activity in other currency pairs.) Column (4) reports the number of CLS settlement sides (twice the number of settlements). Column (5) contains the EBS figures reported by MRW.

Of particular interest are the market shares across currencies. The CLS percentages for both number of settlements and turnover approximate the BIS 2013 survey turnover percentages. A comparison of the 2008-9 EBS and 2013 CLS percentages, though, displays differences that are consistent with prior beliefs and assumptions. Specifically, the EBS share is markedly lower in commonwealth pairs: 1.2% (EBS) vs. 9.8% (CLS) for the AUD/USD; 1.4% vs. 8.8% for the GBP/USD; and 0.6% vs. 5.3% for the USD/CAD. Presumably, the flow that goes through CLS, but not EBS, in these pairs is accounted for by other execution methods or venues (such as Reuters).[22]

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[22] The totals in the bottom row of Table 6 are consistent with estimates presented earlier. If one settlement corresponds to one trade, an appropriate comparison would be $\frac{469,466}{2} = 234,733$ CLS settlements vs. 50,217 EBS trades. The two numbers come from different time periods, however. We adjust for this as follows. Using figures reported on the EBS website, the average daily turnover over the approximate MRW sample (October 2008 through December 2009) is $143.2B. The April 2013 EBS figure of $128.3B

V. Activity by BIC

In this section we consider the structure of the FX market in terms of settlement activity between particular counterparties. Each participant in the CLS system is identified by a Bank Interchange Code (BIC). The BICs in our sample are anonymized so that while we can trace the activity of a particular participant, we do not know its true identity.

The correspondence between BICs and distinct economic or legal entities is inexact. As noted earlier, direct access to the CLS system is limited to settlement members, but many more entities use CLS as third-parties. A third-party might be separate from any settlement member, but might also be a subsidiary or affiliate of a settlement member.

Table 7 summarizes the distribution of trading activity across BICs by number of sides (Panel A) and USD value (Panel B). All statistics (except the number of observations) are reported on a per [business] day basis.

There are 7,267 distinct BICs in the sample of spot settlements. The first row of Panel A reflects all BICs that had at least one submission over the month. Most of these have low activity: the representative BIC at the 90th percentile has only 1.86 submissions per day. The remaining rows of the table reflect subsamples constructed by currency. For example, a BIC is included in the AUD row if it had at least one side denominated in AUD over the month. Also, the settlement activity (number or value of sides) in the row reflects

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constitutes roughly a -10% change, in moving from the early period to the later. Applying this adjustment to the 2008-9 EBS numbers gives an imputed April 2013 value of $50{,}217 \times 0.9 \approx 45{,}200$. The imputed ratio of EBS trades to CLS settlements is $\frac{45{,}200}{234{,}733} = 19.3\%$. From Table 5, the ratio of CLS settlement volume to EBS trade volume is $\frac{128.3}{650.48} \approx 19.7\%$.

only activity in the AUD. (Note that this differs from the subsampling for sides in other tables.)

The most active currencies by trading volume are generally characterized by larger numbers of BICs, especially the USD and EUR. In almost all currencies, the distribution of activity reflects a large number of low-activity BICs. The KRW is a notable exception in that virtually all of its activity is confined to a small number of large BICs.

Table 8 reports the distribution (across BICs) of the number of counterparties (that is, other BICs).[23] The first row of Table 8 summarizes settlement links across all currencies. The classic hub and spoke interdealer network arises when a very small number of dealers are mutually linked, but each peripheral customer is linked to one or two dealers. The EBS interdealer platform, for example, started as a consortium of 13 dealers. Viewed in these terms, the CLS network is more comprehensive. The representative BIC at the 99th percentile of the degree centrality distribution has 107 counterparties.

The rows in Table 8 below the first correspond to individual currencies. The sample in a given row essentially reflects the sub-network of BICs that had at least one submission in which the indicated currency appeared on one side. Although these currency networks are smaller than the larger settlement network, they are in one sense better connected. For example, the 95th percentile of the full network is 15 settlement parties. The corresponding percentiles for the individual currency networks are uniformly higher.

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[23] In terms of network formalities, each BIC may be viewed as a node, and we impute an edge (link) between two BICs if there is at least one settlement between them. The number of counterparties is then equivalent to the degree centrality of the node (Newman (2010)).

VI. Settlements and market prices.

Since most settlements occur in connection with trades, it might be supposed that there is a correspondence between settlement prices and market quotes. While this correspondence is broadly valid, there are also some significant differences. In the first place, the trades being settled are not necessarily arms-length transactions at market rates (as in the case of FX option exercises, discussed earlier).

The trading and settlement processes also place different priority on timeliness. In a trading system (a limit order book, for example), trades are important informational events. Users generally expect that price and quantity will be reported promptly (presently, within microseconds). In settlement, on the other hand, while accuracy of price, quantity, buyer identity and seller identity are important, promptness can be satisfied in seconds, minutes, or longer. In balancing the conflicting goals of speed and accuracy, trade reporting favors the former, while settlement favors the latter.

To investigate the relation between market and settlement activity, we supplement the CLS data with Olsen quotes for April 2013. Olsen Financial Technologies, a commercial data provider (olsendata.com), has compiled historical bid and ask data for major currency pairs. Their data derive from consolidators such as Reuters, Knight Ridder, GTIS and Tenfore. Our data are constructed over ten-second intervals, and within each interval Olsen supplies the first new bid-ask pair. In practice, these observations are close to the start of the interval: the lag relative to the start of the interval had sample median of 0.46 seconds and a 90th percentile of 2.51 seconds. While the CLS data cover twenty-two days in April 2013, the Olsen data are only available for twenty-one days.

We view these as indicative prices. They are not necessarily firm (available for immediate execution) nor are they necessarily the best bid and offer available to any participant. The Olsen data we use correspond to a subset of the CLS sample. There are ten Olsen currencies (vs. seventeen CLS currencies); and thirteen Olsen pairs (vs. seventy-five CLS pairs). The Olsen sample is concentrated in the major trading pairs, however, and so approximately eighty-seven percent of the CLS spot trades occur in an Olsen pair.

For each Olsen currency pair, Table 9 reports the sample average of the bid-ask midpoint and distributional statistics on the bid-ask spread. The smallest observed spread is indicative of the tick size (pip): 0.001 when JPY is quote currency, and 0.00001 otherwise.

For purposes of illustration, Figure 3 depicts several views of EUR/USD activity on April 17, 2013. Panel A plots the exchange rate for each of the roughly 180,000 trades that CLS has designated spot or option exercise.[24] The vast majority of the trades cluster around a narrow band in the vicinity of $1.3100, suggesting that most of the transfers reflect trades at market prices. Nevertheless, there are also many outliers, at rates ranging from about $1.2200 to $1.4400. These are indicative of settlements that don't correspond to arms-length trades at market rates.

Panel B of Figure 3 plots CLS spot trades, excluding those flagged as option exercises. The extreme outliers have been removed (although others remain). With a narrower band of exchange rates, Panel B provides better detail, revealing two more

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[24] The CLS data include settlement instructions for options written at an earlier date and exercised during April 2013. By comparison, BIS survey data include all FX options written during April 2013.

features of the data. First, the rates appear to exhibit high local variation. Visually, there is substantial blurring of rates with nearby time-stamps. Secondly, there are clear hourly effects, on-the-hour concentrations of trades at away-from-the market rates (at 9:00, 11:00, 12:00, and 13:00, for example). There is directional variation in the peaks: the rates are sometimes above and sometimes below the market.

It is useful at this point to compare the CLS rates with the Olsen prices. Panel C of Figure 3 plots the midpoint of the Olsen bid-ask series for the day (with CLS trades now shown in gray). Panel D provides detail for the late afternoon 16:00-18:00 subinterval. If the CLS prices simply reflected the quote midpoint plus some mean-zero error, we'd expect to see the quote midpoint (solid black line) to lie in the middle of the cloud of trade observations. Instead, the midpoint line tends to define, along the time axis, the leading edge of the cloud. This is most clearly visible in the full-day plot (Panel C) with the exchange rate drop that starts shortly before 16:00, and in the detail plot (Panel D) from 17:00 to 17:10.

The observed pattern seems consistent with submission delays in the CLS data. As noted above, both parties submit instructions to CLS. However, these submissions are not trade reports. They are not directly generated by the execution platform, and the execution platform is not identified to CLS. For settlement purposes, it is essential that the parties to the trade agree on buyer and seller identities, the price and the quantity, but submission time and method of execution have little relevance.

For purposes of assessing liquidity, however, accurately time-stamped records of trade volumes and prices are highly useful. We therefore seek better characterization of the CLS accept times. To this end, for each CLS trade, we look backwards to find the most

recent Olsen quote consistent with the CLS exchange rate. The process is depicted in Figure 4 for two trades denoted A and B. For trade A, the backwards search identifies one earlier compatible price, and one imputed delay, τ_A. For trade B, the most recent compatible price implies a delay of τ_B, but there is another earlier price that would lead to a longer delay of τ_B^*. This procedure can therefore generally identify at best a lower bound to the delay. More formally, denote by p_t the price of a CLS trade with a reported accept time of *t*. Searching backwards from *t*, the trade is considered matched with lag $\Delta = t - s$ when $p_t \in \left[bid_s - 5 \times \overline{spread}, ask_s + 5 \times \overline{spread}\right]$, where $\overline{spread}$ is the average bid-ask spread for the currency pair.

Table 10 summarizes the distribution of the imputed reporting lag for each currency pair and the full sample. Most of the distribution lies within thirty seconds or less, and only a negligible amount lies in the range of thirty seconds to ten minutes. Thus, if settlements can't be matched within thirty seconds, they generally can't be matched within ten minutes (or at all). Over the full sample, 95.3% of the CLS trades can be matched within thirty seconds, but the remaining 4.7% can't be matched within ten minutes. Across currency pairs, match rates are generally good, but they are noticeably poorer for the JPY pairs. In the GBP/JPY pair, 8.8% of the trades can't be matched within ten minutes. We investigated the sensitivity of the imputed delays to the match criterion. Using a more stringent match criterion, $p_t \in \left[bid_s - \overline{spread}, ask_s + \overline{spread}\right]$, 81.3% of the trades were matched within 30 seconds, but 18.6% of the trades couldn't be matched within ten minutes.

We conjectured that when the difference between the trading party's accept time and the counterparty's accept time was small, the match rate would be higher, on the

theory that close agreement was likely to be more indicative of automated (and more timely) reporting. The data did not support this conjecture.

VII. Liquidity measures

From the preceding discussion, it should be clear that the settlement data do not closely correspond to the stream of market transactions. Most importantly, the ordering of successive settlement records is unlikely to correspond to the ordering of the trades that generated them. This limitation rules out liquidity measures based on ordered sequences of trade prices, such as Roll (1984) or Hasbrouck (2009).

As an alternative, therefore, we consider the measure suggested by Amihud (2002). The Amihud illiquidity ratio is defined as $I = |r|/Volume$, where $|r|$ is the absolute value of the return over some interval and *Volume* is the quantity traded. *I* is an inverse liquidity proxy. It is analogous to Kyle's lambda, $\lambda = \Delta p/(Signed\ Order\ Flow)$, where Δp is the (signed) price change and the denominator is the cumulative signed order flow over the interval (Kyle (1985)). Order is signed positive if buyer-initiated, and negative if seller-initiated. For a single order, $r = \Delta p/p$ and $Volume = |Signed\ Order\ Flow|$, and so *I* and λ differ only by a scale factor, *p*. However, if the interval includes returns and order flows that are take on positive and negative values, the absolute values used in the computation of *I* will not aggregate correctly. Although the close correspondence between *I* and λ breaks down in this case, *I* is still commonly used as a proxy for λ.

Because *I* is computed using summary measures of volume, the within-interval ordering of transactions is irrelevant. The measure is not unaffected, however, by reporting lags that shift volume outside of the interval.

We compute our estimates of *I* as follows. We initially compute illiquidity ratios over all one-minute intervals with non-zero volume. For a given currency pair, let $I_{d,h,i}$ denote the illiquidity ratio on day *d*; $h = 0{:}00, 0{:}30, 1{:}00, \ldots, 23{:}30$ indexes the start of all 30-minute intervals within the day; and $i = 0, \ldots, 29$ indexes minutes within the interval. Then

$$I_{d,h,i} = \frac{|r_{d,h,i}|}{Volume_{d,h,i}}$$

where $r_{d,h,i}$ is the average of the log change in the bid and the log change in the ask over the minute, based on the Olsen data, and multiplied by 10,000 (to arrive at basis points).[25] $Volume_{d,h,i}$ is the cumulative value of all CLS settlements in the currency pair (that is, the average of reported buy and sell values, in million USD). As stated in these units, a value $I = 0.1$ implies that a trade with a value of one-hundred-million USD would be associated with an exchange rate change of $100 \times 0.1 = 10$ basis points. To mitigate the influence of outliers in trading volumes and returns, we report the medians of the one-minute *I* ratios.

Table 11 reports the median illiquidity ratios and confidence limits (computed under the assumption that the one-minute observations are independent). Across pairs, the median ratios are generally in the range of approximately 0.01 (for EUR/USD and USD/JPY) to 0.10 (EUR/GBP, and so forth).

Among the set of estimates, the illiquidity ratio for the GBP/JPY pair, at 0.7192, stands as a striking outlier. It might be conjectured that this is a sample artifact. At the beginning of April 2013, the Japanese government announced a more aggressive monetary

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[25] As noted above, our Olsen data are observed at a ten-second frequency and consist of the first bid and ask pair observed in a ten-second window. For purposes of constructing returns, of course, it would be preferable to have prices from the end of each ten-second window.

policy intended to curb deflation. JPY volatility increased, which would directly affect the numerator of the estimated illiquidity ratio. On the other hand, the illiquidity ratios for the two other JPY pairs (the EUR/JPY and USD/JPY) are much lower. This suggests that JPY volatility is unlikely to have been the sole cause of the elevated *I*.

The analysis of contra-currencies in Table 3, however, suggests another major consideration. While both the EUR and USD are actively traded against the JPY (18.2% and 75.2%, respectively), GBP volume is much lower (2.2%). It is the combination, therefore, of high volatility in the JPY and low volume in the GBP that causes the elevated GBP/JPY illiquidity.

Comparison with other measures

Mancini, Ranaldo and Wrampelmeyer (2013) discuss a wide range of liquidity measures based on precisely time-stamped quote and trade data from EBS. As noted above, the correspondence between settlement records and trades is not sufficiently strong to support estimates of the MRW measures, which is why we focus on time-aggregated illiquidity. There is nevertheless one MRW measure which bears a strong similarity to the illiquidity ratio: the price impact coefficient. Like the illiquidity ratio, the price impact coefficient can be viewed as a proxy for Kyle's lambda. MRW estimate it as φ_t from the specification:

$$r_{t_i} = \vartheta_t + \varphi_t\left(\upsilon_{b,t_i} - \upsilon_{s,t_i}\right) + \sum_{k=1}^{K} \gamma_{t,k}\left(\upsilon_{b,t_{i-k}} - \upsilon_{s,t_{i-k}}\right) + \epsilon_{t_i}$$

where r is the return on a given currency pair and t_i refers to the i^{th} one-second interval on day *t*. The order flow measures υ_b and υ_s refer respectively to the number of buyer- and

seller-initiated trades in the interval. The difference is therefore the net order flow.[26] MRW's median price impact estimates (from their internet appendix table IA.III) are reported in the last column of Table 11.

Figure 6 depicts a log-log scatterplot of the price impact coefficients and illiquidity ratios. Visually there appears to be a weak positive correlation between the two measures, but the dependence becomes stronger if we exclude the commonwealth currency pairs. More formally, if we include all pairs, the correlations are -0.130 (Pearson) and 0.250 (Spearman), with neither statistically significant. If we exclude the commonwealth pairs, the correlations are 0.748 (Pearson) and 0.886 (Spearman). The estimated type-I error probabilities are 0.087 (Pearson) and 0.019 (Spearman), however, and given the small sample size, we view these results as suggestive rather than definitive.

That the commonwealth price impacts estimated from EBS data are outliers is nevertheless consistent with the fact that EBS is not the dominant trading platform for these currencies. Since EBS is relatively illiquid, it is not surprising that estimated price impacts are outliers on the high side.

A key contribution of MRW, however, is the construction and interpretation of a liquidity risk factor. It is quite possible that even though EBS-based impact measures are misleading for some currency pairs, dynamic variation in the common factor can be well-estimated from those remaining. To examine this possibility further, we construct common

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[26] There are several differences between the present paper's illiquidity ratio and the price impact coefficient φ_t. The major one is, of course, that the impact coefficient specification uses a signed return and order flow, while the illiquidity ratio uses unsigned return and volume. Another point of difference is that φ_t is based on buy/sell counts; the illiquidity ratio uses USD volume. Finally, the φ_t specification includes lagged signed order flows.

factors from our illiquidity ratios using all nine MRW pairs and also, alternatively, from the six non-commonwealth pairs. To avoid variation associated with intraday patterns, we use daily means of the illiquidity ratios (twenty-one days, nine currency pairs). We use three approaches to constructing a daily common factor: the arithmetic mean of the illiquidity ratios, the first principal component constructed from the correlation matrix, and the first principal component constructed from the covariance matrix, for a total of six candidate factors.

Table 12 reports the correlations between these factors. It is emphasized that the sample is limited to the twenty-one days covered by the Olsen data , and the reported statistical significance numbers are not corrected for degrees of freedom lost in construction of the factors.[27] There are nevertheless several noteworthy features. Firstly, principal components constructed from correlation and covariance matrices are very highly correlated. This is because the means and standard deviations of the illiquidity ratios are of similar magnitudes across currency pairs. Secondly, the factors constructed as unweighted means are only modestly correlated with the principal components. This is consistent with the fact that the principal components method seeks only to maximize explained variation (subject to a normalization). The weights that define the first principal component (that is, the elements of the first eigenvector) exhibit large values of opposing signs. Thirdly, no matter which of the three construction methods is used, the factor based on all currency pairs is very highly correlated with that based solely on the non-

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[27] In addition, principal components are identified only up to multiplication by ± 1. In the present context, we set the sign so that correlation with the mean factors is positive.

commonwealth pairs. Thus, exclusion of the currency pairs in which EBS is not dominant does not appear to substantially affect the dynamics of the estimated common factor.

VIII. Conclusions

This paper provides a first look at CLS Bank FX settlement data. Like EBS and Reuters quotes and trades analyzed by others, the submitted settlement instructions constitute a continuous record of FX transactions. With respect to typical EBS/Reuters datasets, the CLS settlement data have several distinctive advantages. Firstly, they are more comprehensive in terms of currency pairs covered. Whereas Reuters concentrates on the (British) commonwealth currencies and EBS on the non-commonwealth, the CLS settlement data uniformly cover the seventeen major currencies that constitute the bulk of FX trading. Secondly, the CLS data are more comprehensive in terms of volume coverage. We estimate that EBS and Reuters together account for about 15.0% of BIS spot turnover, after adjustment for prime brokerage. The corresponding figure for CLS is 37.2%.

The comprehensiveness of the CLS settlement flows offer insights into patterns of exchange. Against most other currencies, the USD is the dominant contra currency: most settlements have the USD on one side of the trade. The Scandinavian currencies (DKK, NOK, SEK) are the exceptions, with the EUR being the dominant currency.

Platform-specific quote and trade data can still claim, however, other advantages. They generally reflect arms-length transactions at current market prices; they are generally correctly sequenced (at least within a given currency pair); and, they have accurate time stamps. Settlement instructions, however, are submitted separately by the parties to the trade, and sometimes well after a particular platform (like EBS or Reuters) might have deemed the execution to have occurred. Furthermore, the submissions do not

necessarily reflect arms-length transactions, and therefore may include pre-arranged transfers on terms that are far removed from current market prices. When we attempt to match up submissions with current market quotes, we find patterns consistent with these limitations.

The fact that time-stamps and sequencing in settlement instructions do not appear to correspond closely to market transactions means that many standard liquidity measures (quoted spread, effective spread, price impact, and so forth) are not available. The Amihud illiquidity ratio, however, can be constructed using time-aggregated price and flow data, and this is our main liquidity measure.

We find that in the cross-section, across currency pairs, the illiquidity ratio is positively correlated with the price impact estimates computed by MRW based on EBS data. This association is strong, however, only for the currency pairs in which EBS is the dominant market. EBS-based estimates of price impact in the commonwealth pairs, however, do not agree with the illiquidity ratios. Our illiquidity ratio estimates suggest that these markets are much more liquid than the price impact estimates would suggest. We document time-of-day patterns in the illiquidity ratios, and find these consistent with local business hours for most currencies.

In summary, the CLS settlement data offer a broad window on flows and liquidity in the FX market. The correspondence between settlement instructions and market transactions is not sufficiently precise to support the same liquidity estimates that can be constructed from EBS/Reuters data. At all but the highest frequencies, however, the settlement instruction data can provide useful measures of liquidity and liquidity variation based on time-aggregated returns and volume. As larger samples of settlement data

become available, longer series of the liquidity measures can be formed, and the relations between liquidity and FX pricing can be studied over longer horizons and also during specific macroeconomic and political events.

Appendix A. Data description

The CLS data in our sample reflect FX settlements initiated during the month of April 2013, scheduled for settlement at a later value date, and authenticated ("matched") by CLS against other counterparty instructions to verify all the critical details of the transaction – currency paid, currency received, counterparty identifiers, value date, and so on. Trades and instructions submitted to CLS that do not match have been rejected and are not in our sample. Our data reflect settlements initiated during April (rather than settlements that occurred during April, but arranged at some earlier time). Each record includes 14 data fields:

TradeID	A unique record identifier
TradeDate	The trade date in Central European Time (CET), supplied by the trading party.
ValueDate	The value (settlement) date for the trade
TradeAcceptTimeTP	Date and time (CET) when settlement instructions were received from the first counterparty
TradeAcceptTimeCP	Date and time (CET) when settlement instructions were received from the second counterparty
StatusMatchTime	Date and time (CET) when CLS system matched trading details
TradingBIC	Anonymized Bank Identification Code for Trading Party (TP)
CounterPartyBIC	Anonymized Bank Identification Code for Counterparty (CP)
BuyCCYISO	Currency code for the bought currency (received by the trading party)
SellCCYISO	Currency code for the sold currency (received by the counterparty)
BuyAmt	Buying amount
SellAmt	Selling amount
Rate	Implied exchange rate (Buy amount / Sell amount)
InstrumentType	Spot, Outright forward, CAS Spot, Far leg, Near leg, FX Option, Other

Some spot settlements, by prior agreement of the buyer and seller, may be batched for settlement purposes (using the CLS Aggregation Service, CAS). When this happens, we

observe the separate component settlement instructions. For FX Swaps, CLS records the value date for both the near leg (the date when the swap is initiated) and the far leg (when the swap is reversed).

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Table 1. CLS Settlements, April 2013

The sample comprises all CLS settlements initiated (that is, with a trade date) in April, 2013. USD values are estimated using average spot exchange rates over the month.

	N		Value, USD	
Spot	12,642,572	90.0%	$14,311B	25.1%
FX Option	22,971	0.2%	$478B	0.8%
Far Leg FX Swap	239,369	1.7%	$16,817B	29.5%
Near Leg FX Swap	236,396	1.7%	$16,820B	29.5%
Other	426,278	3.0%	$6,601B	11.6%
Outright Forward	477,854	3.4%	$1,969B	3.5%
All	14,045,440	100.0%	$56,996B	100.0%

Table 2. Market share by currency, spot settlements

The sample is all spot settlements initiated on CLS during April 2013. For each settlement, both sides are valued in US dollars using the average exchange rates over the month. Currency totals therefore sum to twice the total turnover. The last column is based on BIS Triennial Survey data from the April 2013 survey (less ILS, which the survey does not separately report).

		Percentage of Turnover	
Currency	Code	CLS	BIS
US dollar	USD	83.8	87.0
Euro	EUR	38.5	38.8
Japanese yen	JPY	29.6	31.5
UK pound	GBP	12.0	11.7
Australian dollar	AUD	11.0	10.1
Canadian dollar	CAD	8.3	4.8
Swiss franc	CHF	4.6	4.3
Mexican peso	MXN	2.4	2.9
New Zeeland dollar	NZD	2.2	2.0
Swedish krona	SEK	1.5	1.4
Norwegian krone	NOK	1.2	1.1
South Korean won	KRW	1.2	1.0
South African rand	ZAR	1.1	1.0
Singapore dollar	SGD	1.0	1.1
Hong Kong dollar	HKD	0.8	1.1
Danish krone	DKK	0.4	0.4
Israeli sheckel	ILS	0.2	
		200.0	200.0

Table 3. Contra currencies

A row summarizes all submissions in which the row-currency is involved in the exchange. Percentage entries in the row reflect the total USD equivalent value of the submission, broken out by the other currency in the exchange. For example, of the total dollar value of all submissions involving the AUD, 1.1% occurred in the AUD/CAD pair.

buy/sell	AUD	CAD	CHF	DKK	EUR	GBP	HKD	ILS	JPY	KRW	MXN	NOK	NZD	SEK	SGD	USD	ZAR
AUD		1.1%	0.4%		5.9%	1.6%	0.0%		9.3%		0.0%	0.0%	3.6%	0.0%	0.2%	77.8%	0.0%
CAD	1.5%		0.3%		2.9%	1.4%			1.1%		0.1%	0.0%	0.2%	0.0%		92.4%	
CHF	0.9%	0.6%		0.0%	42.6%	2.8%	0.0%		1.7%			0.1%	0.2%	0.1%		51.0%	0.0%
DKK			0.0%		82.8%	0.9%			0.5%							15.8%	
EUR	1.7%	0.6%	5.1%	0.9%		6.2%	0.0%	0.0%	14.0%		0.1%	2.1%	0.2%	2.5%	0.0%	66.5%	0.1%
GBP	1.5%	1.0%	1.1%	0.0%	20.1%		0.0%		5.3%		0.0%	0.1%	0.3%	0.2%	0.0%	70.3%	0.0%
HKD	0.2%		0.0%		1.4%	0.4%			0.1%							97.8%	
ILS					1.1%											98.9%	
JPY	3.5%	0.3%	0.3%	0.0%	18.2%	2.2%	0.0%				0.0%	0.0%	0.3%	0.0%	0.0%	75.2%	0.0%
KRW																100.0%	
MXN	0.1%	0.3%			1.0%	0.1%			0.1%							98.5%	
NOK	0.2%	0.1%	0.3%		64.5%	1.0%			0.3%					13.2%		20.3%	
NZD	17.9%	0.9%	0.5%		2.8%	1.4%			4.0%						0.0%	72.6%	
SEK	0.1%	0.1%	0.2%		64.1%	1.4%			0.4%			10.7%				22.9%	
SGD	2.3%				1.1%	0.2%			0.9%				0.0%			95.5%	
USD	10.2%	9.2%	2.8%	0.1%	30.6%	10.0%	1.0%	0.2%	26.5%	1.4%	2.8%	0.3%	1.9%	0.4%	1.2%		1.3%
ZAR	0.0%		0.1%		1.8%	0.2%			1.1%							96.8%	

Table 4. Distribution of settlement values

The sample is all CLS spot submissions for April, 2013. Both sides of each submission are used. (For example, a submission in the EUR/USD pair would appear in both the EUR row and the USD row.) Values are reported as USD equivalents.

	N	Min	P1	P5	P10	P25	P50	P75	P90	P95	P99	Max
All	25,285,144	$0.01	$1,302.10	$10,099	$29,875	$196,816	$791,892	$1,282,030	$1.531M	$2.604M	$7.442M	$3,107.754M
AUD	1,533,394	$0.01	$1,037.98	$10,380	$31,139	$207,596	$726,586	$1,037,979	$1.300M	$2.076M	$6.511M	$2,173.529M
CAD	698,981	$0.01	$1,000.78	$9,815	$20,143	$196,299	$907,276	$1,002,893	$1.305M	$2.016M	$10.700M	$1,962.992M
CHF	655,241	$0.01	$997.67	$6,185	$15,277	$130,993	$697,815	$1,012,481	$1.313M	$2.180M	$6.526M	$1,552.734M
DKK	21,148	$0.35	$996.84	$9,917	$19,897	$99,708	$780,142	$1,302,639	$6.512M	$13.024M	$32.566M	$521.111M
EUR	4,706,180	$0.13	$1,302.10	$13,021	$26,042	$195,315	$783,863	$1,302,099	$1.302M	$2.604M	$6.510M	$2,196.033M
GBP	1,455,177	$0.02	$1,531.07	$4,593	$15,311	$142,287	$765,534	$1,531,067	$1.531M	$3.062M	$7.655M	$3,062.134M
HKD	50,439	$0.03	$128.82	$3,791	$19,515	$191,938	$999,920	$1,311,515	$5.000M	$9.998M	$26.998M	$499.168M
ILS	14,029	$0.01	$1,570.87	$29,707	$110,499	$673,781	$1,000,578	$1,006,932	$3.985M	$5.014M	$24.994M	$274.040M
JPY	4,693,202	$0.01	$1,098.75	$10,137	$30,480	$165,654	$524,482	$1,010,235	$1.318M	$2.028M	$5.137M	$2,035.094M
KRW	98,400	$572.49	$495030.56	$503,940	$986,765	$994,872	$1,002,088	$1,521,841	$2.996M	$4.969M	$9.998M	$199.919M
MXN	281,121	$0.12	$7,271.81	$81,910	$101,036	$501,599	$995,990	$1,006,122	$1.991M	$2.793M	$9.921M	$302.469M
NOK	165,439	$0.05	$984.55	$15,624	$52,375	$172,503	$657,582	$1,296,190	$1.328M	$2.619M	$7.858M	$639.554M
NZD	465,459	$0.42	$848.14	$4,241	$8,481	$84,814	$419,249	$848,144	$1.035M	$1.696M	$4.241M	$968.776M
SEK	198,667	$0.16	$1,541.28	$17,473	$65,897	$172,928	$665,224	$1,296,973	$1.376M	$2.629M	$7.821M	$1,155.961M
SGD	112,543	$0.52	$999.25	$10,021	$64,718	$250,884	$998,850	$1,002,312	$2.006M	$4.000M	$10.014M	$300.923M
USD	9,955,218	$0.01	$1,306.37	$11,449	$45,886	$239,990	$1,000,000	$1,096,492	$1.540M	$2.618M	$7.850M	$3,107.754M
ZAR	180,506	$0.10	$219.73	$7,690	$12,634	$109,863	$975,298	$1,007,191	$1.515M	$2.027M	$5.893M	$219.726M

Table 5. Alternative activity measures, April, 2013

BIS turnover figures are from the 2013 BIS Survey (Bank for International Settlements (2013)); CLS settlement volume is estimated from data supplied by the CLS Bank; EBS and Reuters values are reported on their websites. All flows are normalized "per day".

Line	Source	Total	Spot	Outright forwards	FX Swaps Far
1	BIS turnover	$4,953,781 M	$2,046,158 M	$679,994 M	$2,227,629 M
2	BIS o/w PB	$818,354 M	$598,252 M	$115,917 M	$104,185 M
3	BIS net of PB	$4,544,604 M	$1,747,032 M	$622,036 M	$2,175,536 M
4	CLS	$1,504,382 M	$650,480 M	$89,514 M	$764,389 M
5	$\frac{CLS}{BIS\ net\ of\ PB}$	33.1%	37.2%	14.4%	35.1%
6	EBS turnover		$128,300 M		
7	$\frac{EBS}{BIS\ net\ of\ PB}$		7.3%		
8	Reuters spot turnover		$133,000 M		
9	EBS + Reuters		$261,300 M		
10	$\frac{EBS + Reuters}{BIS\ net\ of\ PB}$		15.0%		

Table 6. Alternative activity measures for MRW currency pairs, April, 2013

Table reports comparative activity measures and relative shares. Columns (1)-(3) report turnover (Billion $US per day), in the indicated currency pair. Following the BIS convention, these figures reflect both sides of the trade. Columns (1)-(5) report levels, per day; columns (6)-(10) report percentage shares. Sources: cols. (1), (2), BIS (2013); cols. (3), (4), the present paper; col. (5), internet appendix to Mancini, Ranaldo and Wrampelmeyer (2013), Tale IA-II, post-Lehman subsample.

	Levels					Percentage shares				
	Turnover (Billion USD)			Settlements	Trades	Turnover (Billion USD)			Settlements	Trades
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Source, Sample	BIS, 2013	BIS, 2010	CLS, 2013	CLS, 2013	EBS, 2008-9	BIS, 2013	BIS, 2010	CLS, 2013	CLS, 2013	EBS 2008-9
Pair										
EUR/USD	1,289	1,098	333	131,953	21,590	33.9%	37.7%	30.3%	28.1%	43.0%
USD/JPY	978	567	290	143,388	12,355	25.7%	19.5%	26.3%	30.5%	24.6%
AUD/USD	364	248	112	46,235	617	9.6%	8.5%	10.1%	9.8%	1.2%
GBP/USD	472	360	109	41,376	697	12.4%	12.4%	9.9%	8.8%	1.4%
USD/CAD	200	182	100	25,095	310	5.3%	6.3%	9.1%	5.3%	0.6%
EUR/JPY	147	111	70	42,493	5,871	3.9%	3.8%	6.4%	9.1%	11.7%
EUR/GBP	102	109	31	12,969	544	2.7%	3.7%	2.8%	2.8%	1.1%
USD/CHF	184	166	30	15,964	4,938	4.8%	5.7%	2.8%	3.4%	9.8%
EUR/CHF	71	71	25	9,993	3,295	1.9%	2.4%	2.3%	2.1%	6.6%
Total	3,807	2,912	1,101	469,466	50,217	100%	100%	100%	100%	100%

Table 7. Distribution of trading activity by BICs

The trading activity for each BIC (account) in the sample is measured by the total number of its sides (Panel A) and the total USD value of its sides (Panel B). The row labeled "All" contains all BICS, and each BIC is measured by its total activity. A row with a currency identifier contains just those BICs that had at least one side in that currency, and each BIC is measured by its activity in that currency. All table entries except "N" are reported on a daily basis.

Panel A. Number of sides per day

	N	Min	P1	P5	P10	P25	P50	P75	P90	P95	P99	Max
All	7,267	0.05	0.05	0.05	0.05	0.09	0.23	0.68	1.86	19.45	920.32	168,967
AUD	1,135	0.05	0.05	0.05	0.05	0.05	0.09	0.91	12	77	1,237	9,785
CAD	907	0.05	0.05	0.05	0.05	0.05	0.14	0.73	8	67	622	4,234
CHF	1,297	0.05	0.05	0.05	0.05	0.05	0.09	0.36	5	21	505	4,118
DKK	657	0.05	0.05	0.05	0.05	0.05	0.09	0.23	1	4	42	106
EUR	3,568	0.05	0.05	0.05	0.05	0.05	0.09	0.32	3	24	639	32,216
GBP	2,608	0.05	0.05	0.05	0.05	0.05	0.09	0.32	2	8	286	9,276
HKD	1,670	0.05	0.05	0.05	0.05	0.05	0.14	0.32	1	3	29	198
ILS	253	0.05	0.05	0.05	0.05	0.05	0.09	0.32	6	19	45	59
JPY	1,805	0.05	0.05	0.05	0.05	0.05	0.14	0.45	13	69	1,670	35,493
KRW	35	0.55	0.55	0.86	12.55	51.86	91.27	158.09	280	462	530	530
MXN	656	0.05	0.05	0.05	0.05	0.05	0.09	0.32	4	37	696	2,084
NOK	802	0.05	0.05	0.05	0.05	0.05	0.09	0.36	3	14	267	970
NZD	513	0.05	0.05	0.05	0.05	0.09	0.23	1.23	26	117	1,492	3,265
SEK	920	0.05	0.05	0.05	0.05	0.05	0.09	0.39	2	12	275	1,116
SGD	636	0.05	0.05	0.05	0.05	0.05	0.14	0.64	8	29	255	713
USD	5,085	0.05	0.05	0.05	0.05	0.05	0.18	0.41	2	22	704	64,283
ZAR	517	0.05	0.05	0.05	0.05	0.05	0.14	0.77	8	45	511	1,065

Panel B. USD value

	N	Min	P1	P5	P10	P25	P50	P75	P90	P95	P99	Max
All	7,267	$2	$120	$889	$2,721	$15,900	$97,995	$1M	$6M	$57M	$1,621M	$171,297M
AUD	1,135	$2	$97	$398	$1,063	$9,614	$103,503	$1,804,763	$24M	$125M	$1,319M	$9,328M
CAD	907	$1	$22	$319	$1,098	$8,141	$72,725	$1,421,653	$37M	$186M	$1,499M	$4,822M
CHF	1,297	$1	$46	$419	$1,455	$9,479	$62,263	$693,663	$8M	$30M	$507M	$3,876M
DKK	657	$0	$7	$318	$1,017	$5,022	$35,043	$259,136	$3M	$12M	$94M	$417M
EUR	3,568	$0	$106	$701	$1,949	$10,237	$55,559	$418,753	$10M	$51M	$1,005M	$34,126M
GBP	2,608	$1	$49	$456	$1,461	$9,677	$57,295	$427,813	$5M	$22M	$419M	$9,189M
HKD	1,670	$0	$78	$578	$1,522	$6,690	$29,277	$142,204	$1M	$9M	$104M	$266M
ILS	253	$6	$25	$427	$1,130	$3,868	$30,811	$376,705	$11M	$45M	$92M	$108M
JPY	1,805	$0	$61	$697	$2,884	$16,651	$125,502	$1,030,312	$22M	$111M	$1,704M	$31,045M
KRW	35	$145,241	$145,241	$864,334	$18,371,745	$101,514,741	$179,172,249	$332,997,096	$453M	$695M	$697M	$697M
MXN	656	$4	$74	$879	$2,296	$11,107	$52,671	$532,480	$8M	$56M	$788M	$2,377M
NOK	802	$0	$63	$274	$868	$4,783	$34,931	$384,580	$5M	$21M	$332M	$886M
NZD	513	$3	$77	$416	$838	$5,116	$115,656	$2,347,817	$27M	$100M	$742M	$2,194M
SEK	920	$0	$45	$390	$1,148	$5,869	$41,298	$580,734	$5M	$21M	$364M	$1,125M
SGD	636	$2	$93	$501	$1,527	$7,343	$46,658	$665,090	$13M	$38M	$233M	$846M
USD	5,085	$0	$58	$678	$2,084	$11,528	$64,970	$473,811	$7M	$67M	$1,426M	$70,213M
ZAR	517	$14	$50	$50	$424	$14,094	$93,955	$651,572	$9M	$51M	$348M	$820M

Table 8.
Number of settlement entities and counterparties.

For settlement purposes, counterparties are identified by BICs. The table reports, for the full sample and by currency, the number of distinct BICs, and the number of counterparty BICs. In the "all currencies" row, for a given BIC, another BIC is considered a counterparty if there is at least one settlement between them (involving any currency). The separate tabulations for the individual currencies are constructed as follows. A BIC is considered a member of the Australian dollar (AUD) set if it participated in at least one AUD settlement, and the number of counterparties refers to the number of counterparty BICs in AUD trades.

		Number of counterparty BICs										
Currency	Number of BICs	Min	P1	P5	P10	P25	P50	P75	P90	P95	P99	Max
All Currencies	7,267	1	1	1	1	1	3	5	9	15	107	2,629
AUD	1,730	1	1	1	1	1	2	4	15	42	144	536
CAD	1,198	1	1	1	1	1	2	4	16	42	166	377
CHF	2,093	1	1	1	1	1	2	3	9	23	136	550
DKK	1,062	1	1	1	1	1	1	3	7	15	95	243
EUR	4,766	1	1	1	1	1	2	4	8	18	124	1,535
GBP	3,819	1	1	1	1	1	2	4	8	15	97	1,076
HKD	2,214	1	1	1	1	1	2	4	8	13	134	653
ILS	364	1	1	1	1	1	1	3	13	35	80	130
JPY	2,485	1	1	1	1	1	2	4	12	32	151	750
KRW	35	1	1	1	12	22	25	29	31	32	32	32
MXN	961	1	1	1	1	1	2	4	9	28	126	248
NOK	1,123	1	1	1	1	1	1	3	11	24	125	300
NZD	697	1	1	1	1	1	2	7	29	52	167	286
SEK	1,531	1	1	1	1	1	1	3	9	19	119	409
SGD	886	1	1	1	1	1	2	5	18	48	138	289
USD	6,341	1	1	1	1	1	2	5	10	17	123	2,236
ZAR	779	1	1	1	1	1	2	5	19	42	144	231

Table 9. Summary statistics on Olsen pairs, April 2013

	Mean	Min	P10	P25	P50	P75	P90
	bam	spread	spread	spread	spread	spread	spread
AUD/USD	1.0382	0.00001	0.00006	0.00013	0.00017	0.00022	0.00030
EUR/CHF	1.2199	0.00001	0.00009	0.00015	0.00022	0.00030	0.00036
EUR/GBP	0.8506	0.00001	0.00006	0.00011	0.00016	0.00021	0.00028
EUR/JPY	127.2645	0.00100	0.00600	0.01700	0.02200	0.02600	0.03300
EUR/NOK	7.5449	0.00001	0.00139	0.00222	0.00316	0.00500	0.00798
EUR/SEK	8.4475	0.00001	0.00137	0.00220	0.00327	0.00541	0.00800
EUR/USD	1.3018	0.00001	0.00003	0.00010	0.00014	0.00019	0.00025
GBP/JPY	149.6099	0.00100	0.01200	0.02100	0.03300	0.04300	0.07000
GBP/USD	1.5305	0.00001	0.00008	0.00015	0.00021	0.00026	0.00031
NZD/USD	0.8474	0.00001	0.00011	0.00019	0.00024	0.00028	0.00040
USD/CAD	1.0187	0.00001	0.00006	0.00013	0.00020	0.00026	0.00040
USD/CHF	0.9371	0.00001	0.00008	0.00013	0.00018	0.00025	0.00040
USD/JPY	97.7469	0.00100	0.00300	0.00800	0.01300	0.02000	0.03000

Table 10. Imputed reporting delays

For a CLS trade with an accept time of t and a price of p_t, the imputed reporting delay is $\Delta = t - s$, where, searching backwards from t, s is the time of the first match encountered. The criterion for a match is $p_t \in \left[bid_s - 5 \times \overline{spread}, ask_s + 5 \times \overline{spread}\right]$, where bid_s and ask_s are the Olsen quotes at time s, and $\overline{spread}$ is the average bid-ask spread for the currency pair. Table reports frequencies in the indicated categories. Unmatched trades are included in "$> 10m$".

			Distribution of imputed reporting delay, Δ						
	N	*All*	$[0,1s]$	$(1s, 5s]$	$(5s, 10s]$	$(10s, 30s]$	$(30s, 1m]$	$(1m, 10m]$	$> 10m$
All	10,963,087	100.0%	12.9%	38.0%	42.8%	1.6%	0.0%	0.0%	4.7%
AUD/USD	1,016,446	100.0	12.8	38.5	42.0	3.0	0.0	0.0	3.7
EUR/CHF	219,690	100.0	13.9	39.5	44.6	0.9	0.0	0.0	1.0
EUR/GBP	285,182	100.0	13.2	38.7	43.5	1.6	0.0	0.0	3.1
EUR/JPY	934,005	100.0	12.8	36.7	41.7	1.6	0.0	0.0	7.1
EUR/NOK	88,074	100.0	14.8	39.0	43.2	2.8	0.1	0.0	0.1
EUR/SEK	110,097	100.0	15.1	38.9	42.6	2.7	0.2	0.1	0.4
EUR/USD	2,901,009	100.0	13.1	38.3	42.8	1.6	0.0	0.0	4.3
GBP/JPY	163,755	100.0	12.5	36.3	41.5	0.9	0.0	0.0	8.8
GBP/USD	909,705	100.0	12.9	38.5	43.6	0.8	0.0	0.0	4.2
NZD/USD	280,897	100.0	13.0	38.8	43.1	2.4	0.1	0.0	2.7
USD/CAD	551,472	100.0	12.9	39.1	43.0	2.4	0.0	0.0	2.5
USD/CHF	350,945	100.0	13.4	39.1	43.5	1.1	0.0	0.0	2.8
USD/JPY	3,151,810	100.0	12.5	37.3	42.9	1.2	0.0	0.0	6.1

Table 11. Amihud Illiquidity Measures, April 2013

Estimated medians for illiquidity ratios. For a given pair, the illiquidity ratio is $I_{d,h,i} = |r_{d,h,i}|/Volume_{d,h,i}$. The time subscripts on all variables are days $d = April\ 1, \ldots, April\ 30$; half-hour intervals $h = 0{:}00, \ldots, 23{:}30$; and minute within the interval $i = 0, \ldots, 29$. $r_{d,h,i} = 10{,}000 \times [\Delta \ln(bid) + \Delta \ln(ask)]/2$, where $\Delta \ln(bid)$ and $\Delta \ln(ask)$ are the changes in the log of the (Olsen) bid and ask over the minute. $Volume_{d,h,i}$ is the cumulative value (in Million USD) of all settlements in the pair over the minute. $I_{d,h,i}$ is computed for each minute with at least one settlement. The estimated lower and upper limits are computed for a 95% confidence interval. The last column reports price impact coefficient estimates from Mancini, Ranaldo and Wrampelmeyer (2013), internet appendix, Table IA.III. Asterisks denote British Commonwealth currency pairs.

	Amihud illiquidity ratios			Price impact coefficients (MRW)
	Estimated Median	Lower confidence limit	Upper confidence limit	Estimated Median
AUD/USD*	0.0291	0.0287	0.0297	0.870
EUR/CHF	0.0566	0.0547	0.0580	0.098
EUR/GBP	0.0998	0.0972	0.1023	0.405
EUR/JPY	0.0962	0.0945	0.0980	0.219
EUR/NOK	0.1075	0.1041	0.1114	
EUR/SEK	0.0951	0.0922	0.0984	
EUR/USD	0.0102	0.0100	0.0104	0.060
GBP/JPY*	0.7192	0.6990	0.7378	
GBP/USD*	0.0268	0.0262	0.0273	0.334
NZD/USD	0.1536	0.1495	0.1574	
USD/CAD*	0.0354	0.0345	0.0363	0.766
USD/CHF	0.1059	0.1044	0.1072	0.159
USD/JPY	0.0170	0.0167	0.0173	0.103

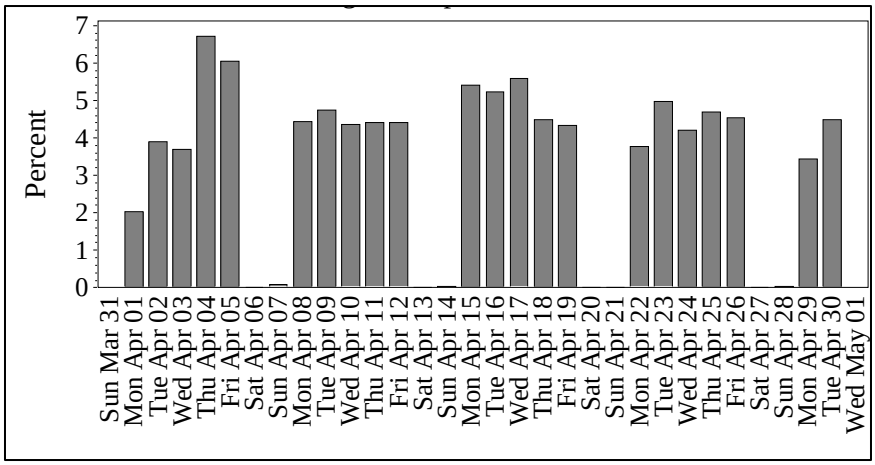
Table 12. Correlations between common factors

Common liquidity factors are constructed in alternative ways and based on different variable sets. The data underlying all calculations consists of daily means of illiquidity ratios for all nine currency pairs examined in Mancini, Ranaldo and Wrampelmeyer (2013), for twenty-one days in April 2013. The construction either uses all pairs ("All") or just the six non-Commonwealth pairs ("Non-Com"). The methods of construction are simple arithmetic mean, the first principal component (using the correlation matrix), and the first principal component (using the covariance matrix).

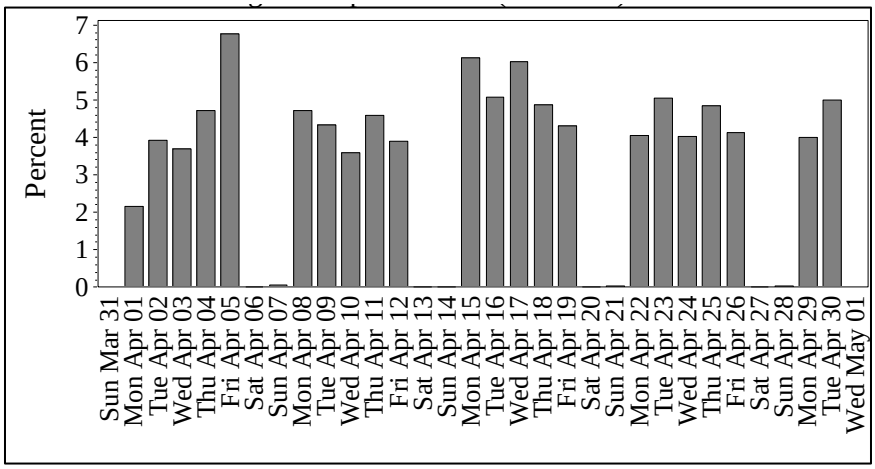
		Mean		First Principal Component (Correlations)		First Principal Component (Covariances)	
		All	Non-Com	All	Non-Com	All	Non-Com
Mean	All	1.00000	0.97727 <.0001	0.25249 0.2695	0.31683 0.1617	0.30311 0.1817	0.30846 0.1737
	Non-Com	0.97727 <.0001	1.00000	0.32910 0.1452	0.38771 0.0825	0.37485 0.0941	0.37893 0.0903
First Principal Component (Correlations)	All	0.25249 0.2695	0.32910 0.1452	1.00000	0.96048 <.0001	0.93098 <.0001	0.92569 <.0001
	Non-Com	0.31683 0.1617	0.38771 0.0825	0.96048 <.0001	1.00000	0.94864 <.0001	0.94834 <.0001
First Principal Component (Covariances)	All	0.30311 0.1817	0.37485 0.0941	0.93098 <.0001	0.94864 <.0001	1.00000	0.99981 <.0001
	Non-Com	0.30846 0.1737	0.37893 0.0903	0.92569 <.0001	0.94834 <.0001	0.99981 <.0001	1.00000

Figure 1. Distribution of trades by date

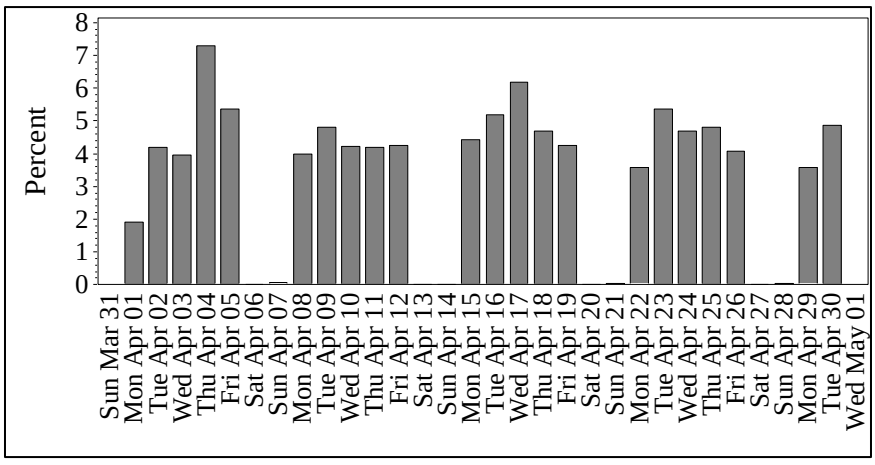
Panel A. USD



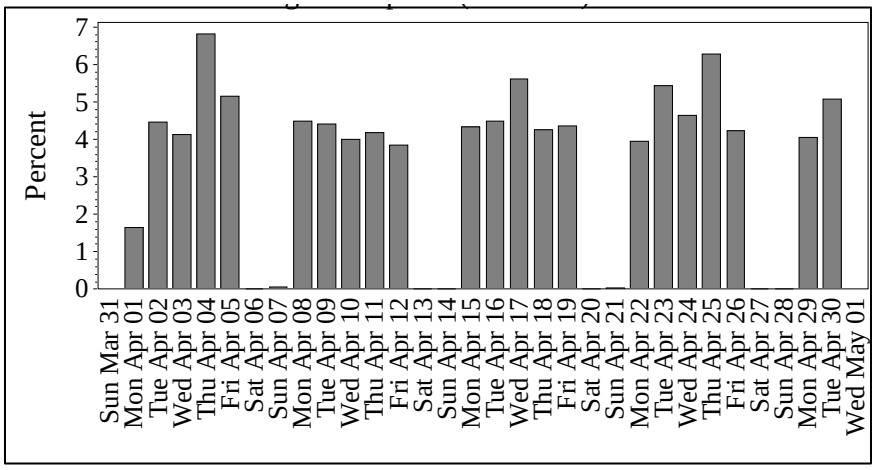
Panel B. American, non-US (CAD, MXN)



Panel C. EUR



Panel D. European, non-Euro (GBP, CHF, SEK, NOK, ZAR, DKK, ILS)



Panel E. Asia-Pacific (JPY, AUD, KRW, SGD, HKD, NZD)

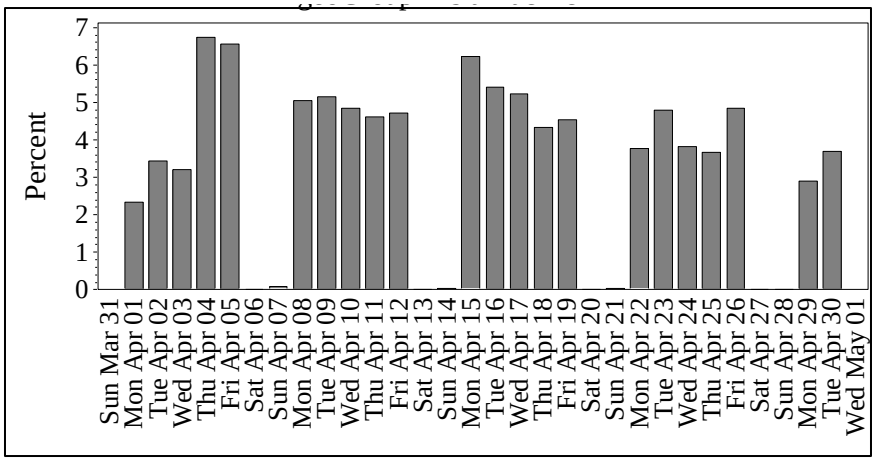
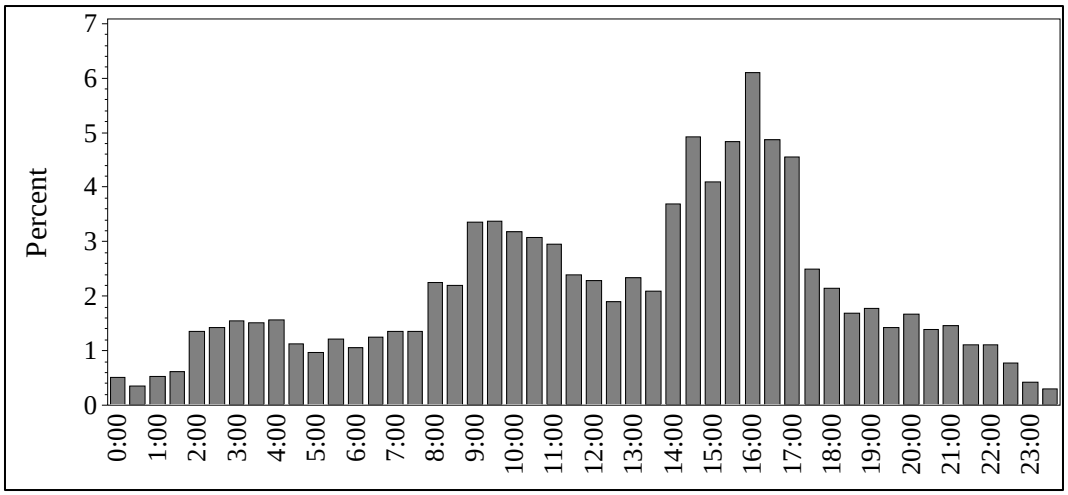
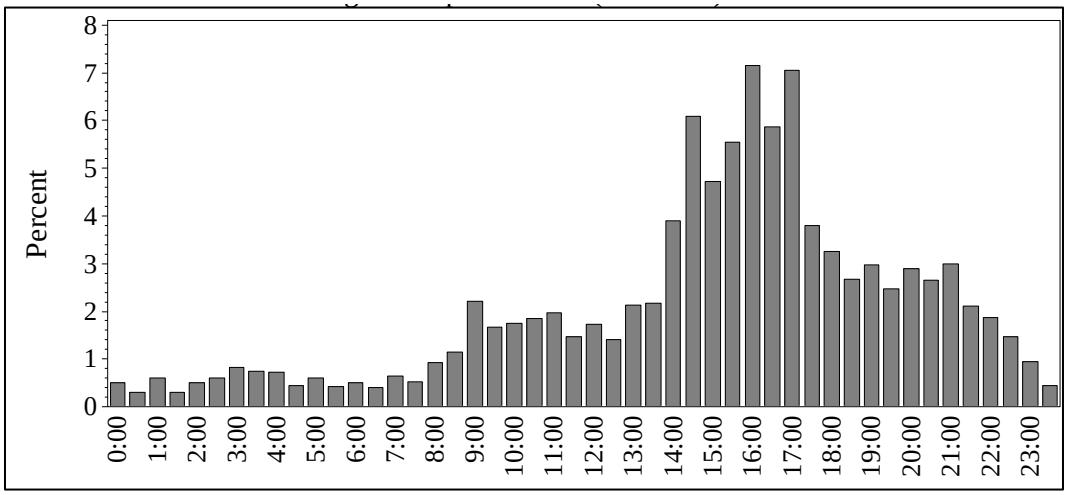


Figure 2. Distribution of trades by time of day

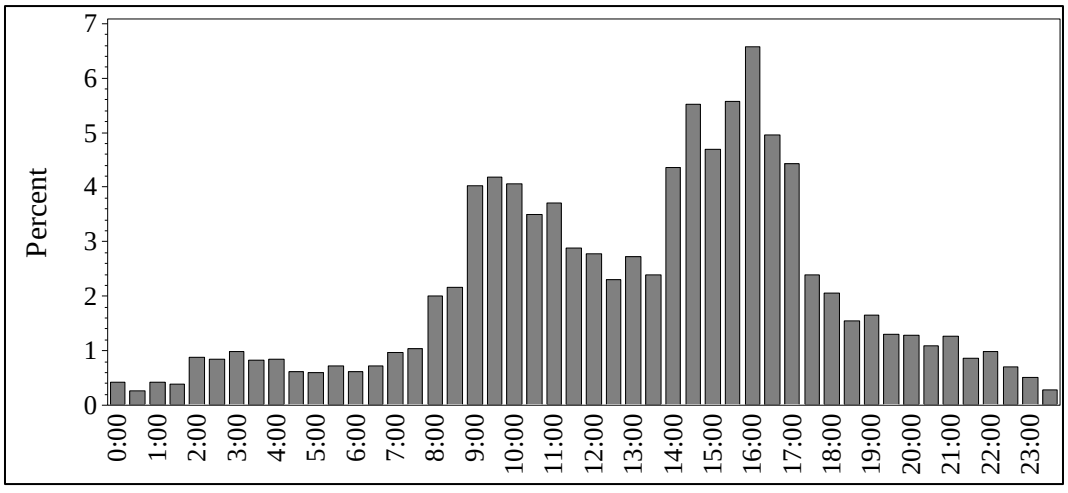
Panel A. USD



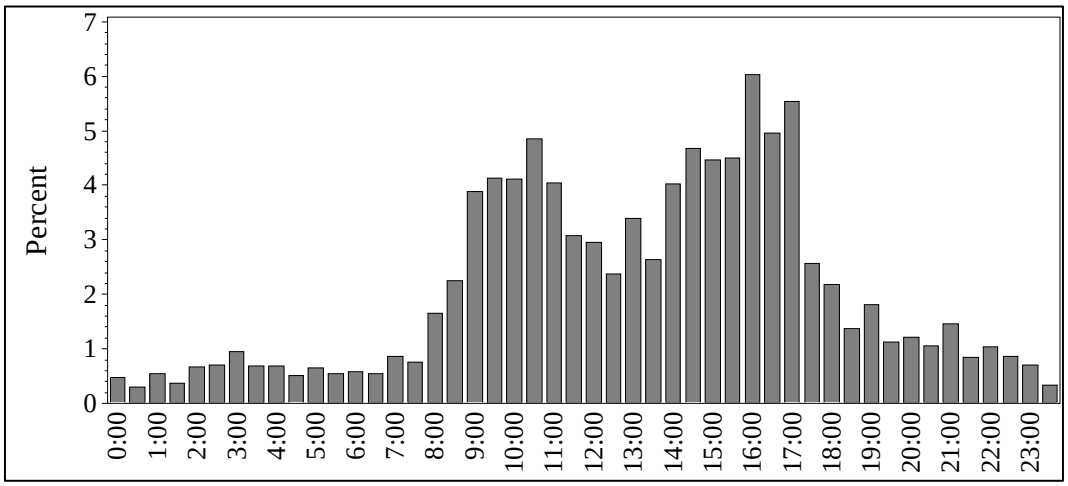
Panel B. American, non-US (CAD, MXN)



Panel C. EUR



Panel D. European, non-Euro (GBP, CHF, SEK, NOK, ZAR, DKK, ILS)



Panel E. Asia-Pacific (JPY, AUD, KRW, SGD, HKD, NZD)

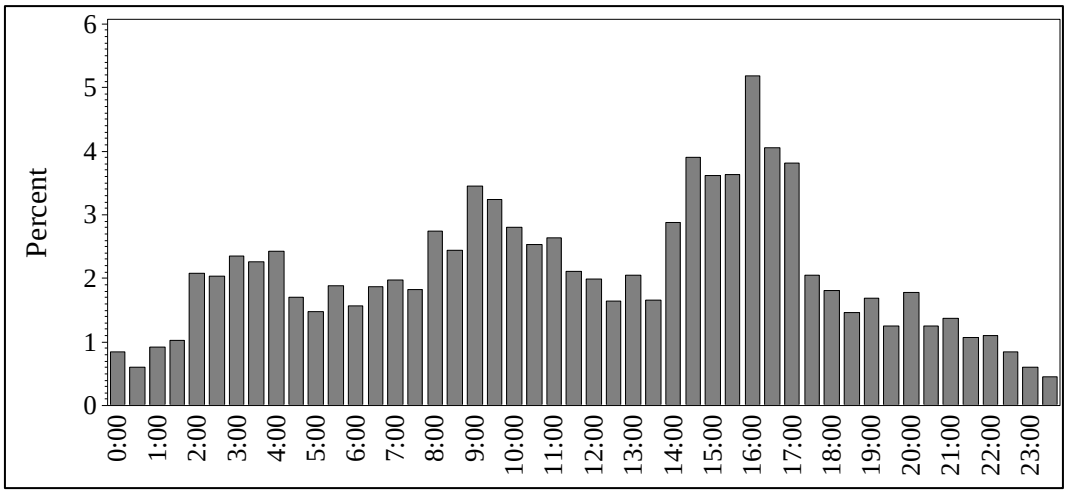
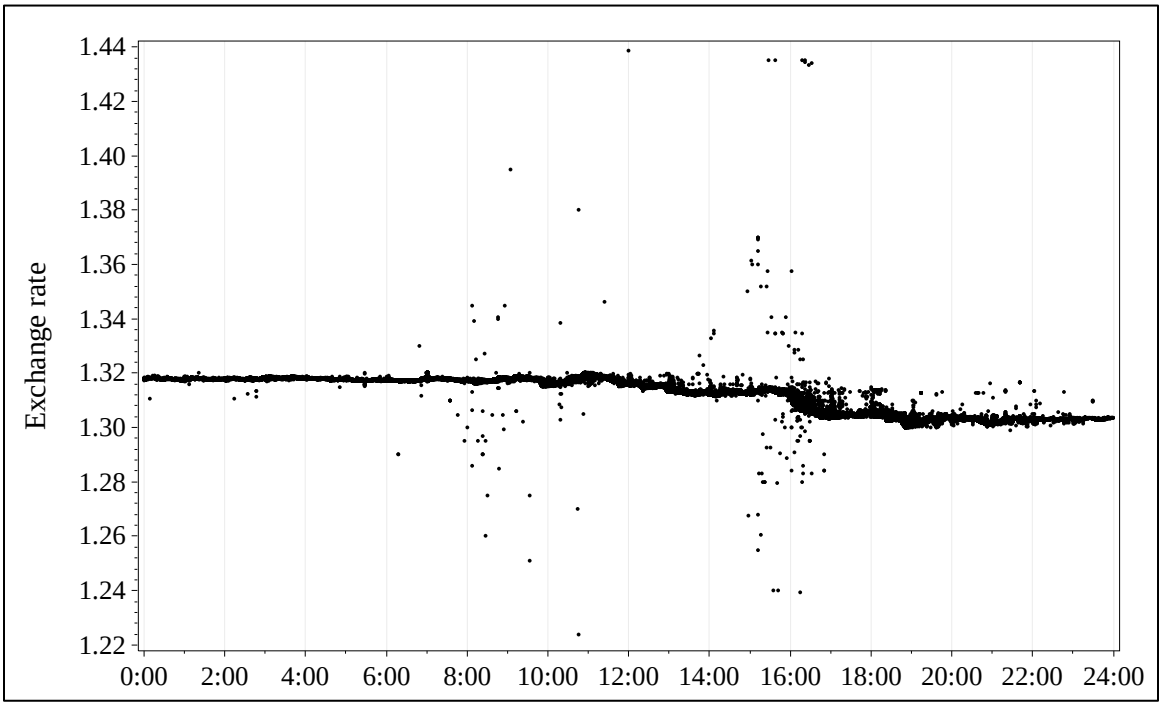
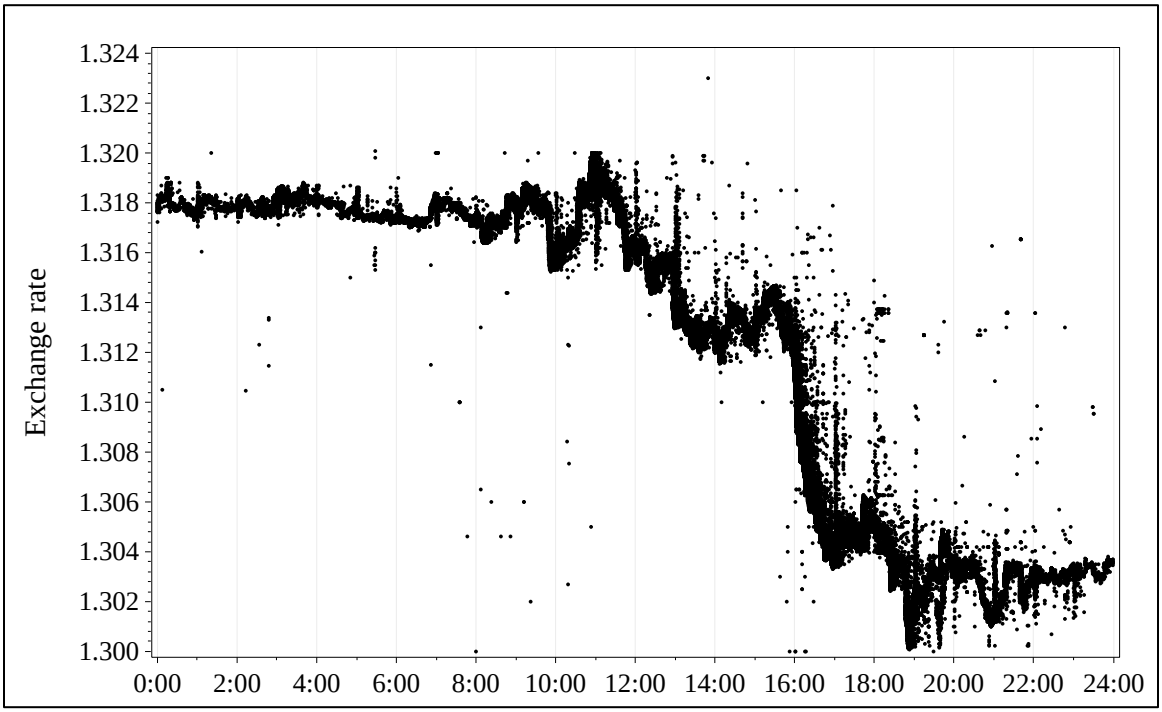


Figure 3. EUR/USD, April 17, 2013

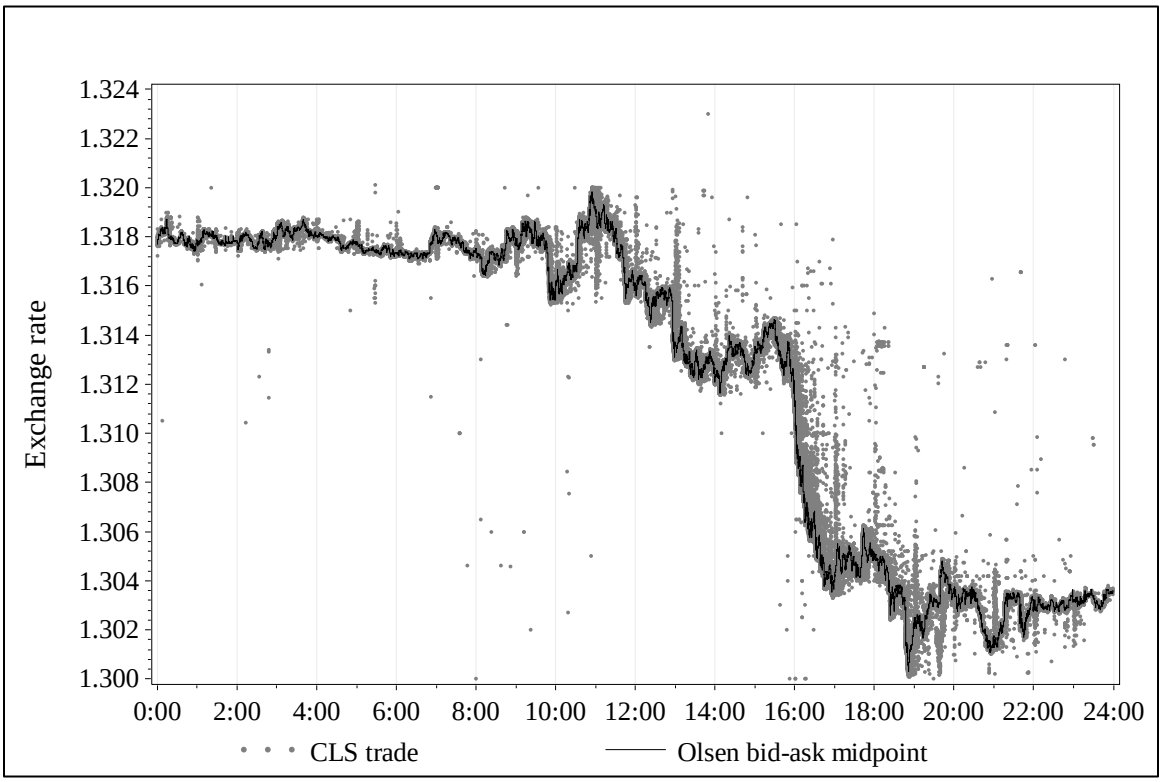
Panel A. CLS transactions (spot trades and trades flagged as option exercises)



Panel B CLS transactions (spot trades)



Panel C. CLS spot trades, Olsen bid-ask midpoint



Panel D. CLS spot trades, Olsen bid-ask midpoint, detail 16:00-18:00

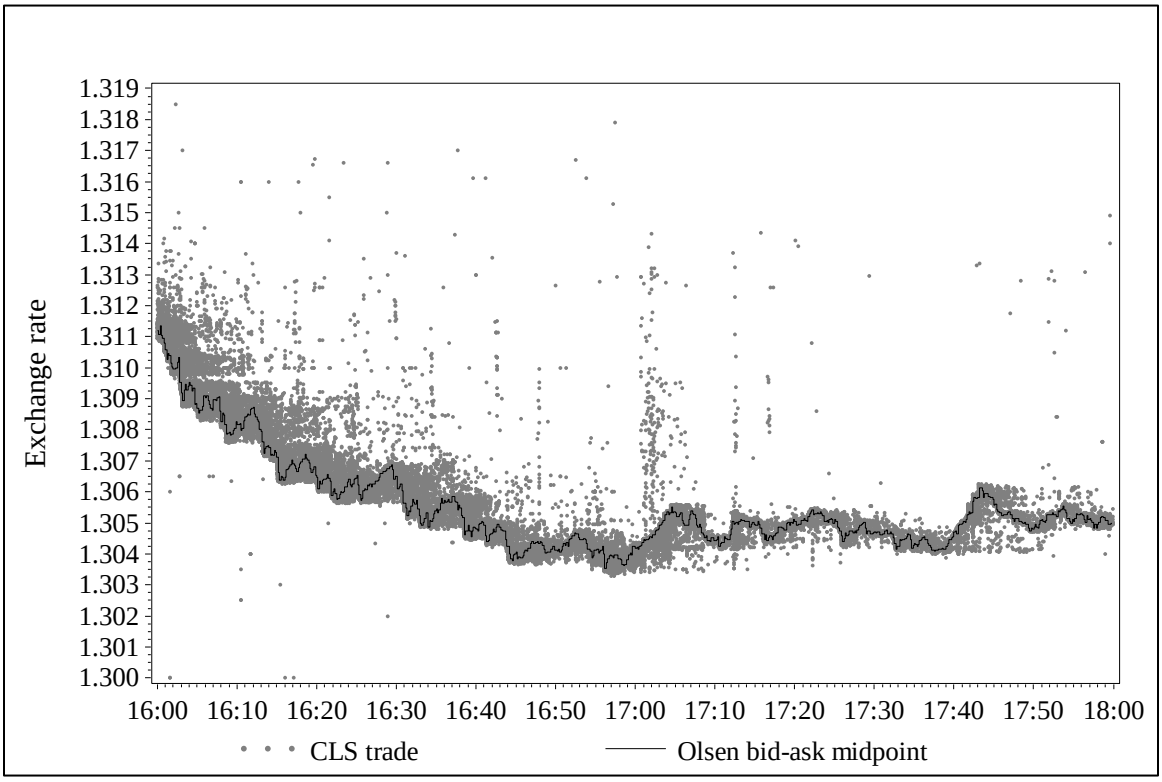


Figure 4. Imputation of reporting delays

Points A and B mark reported prices and times of trades. The bid-ask midpoint is indicated as a step function. The imputation involves looking backwards in time to determine the most recent price at which the trade could have occurred. For trade A, this implies a reporting lag of τ_A. For trade B, the imputed reporting lag is τ_B, but there is another (longer) reporting lag, τ_B^*, that is also consistent with the reported price.

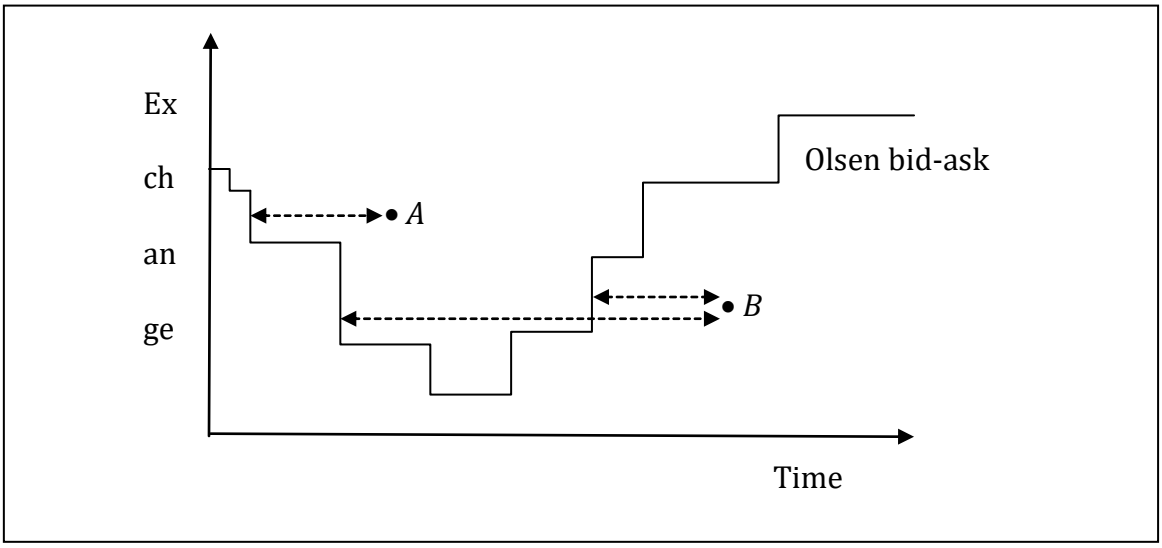
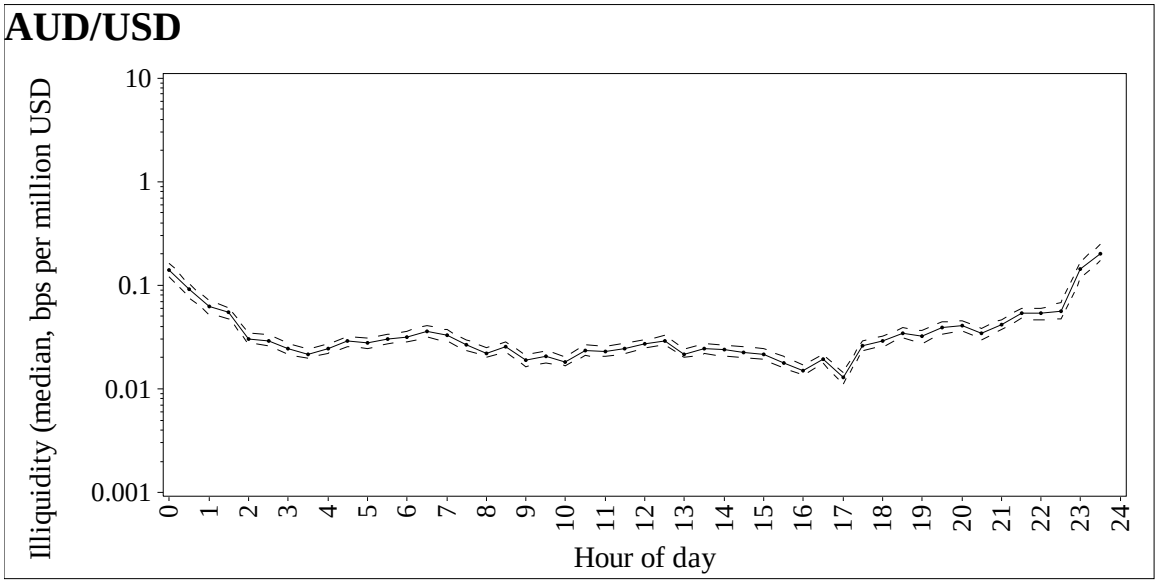
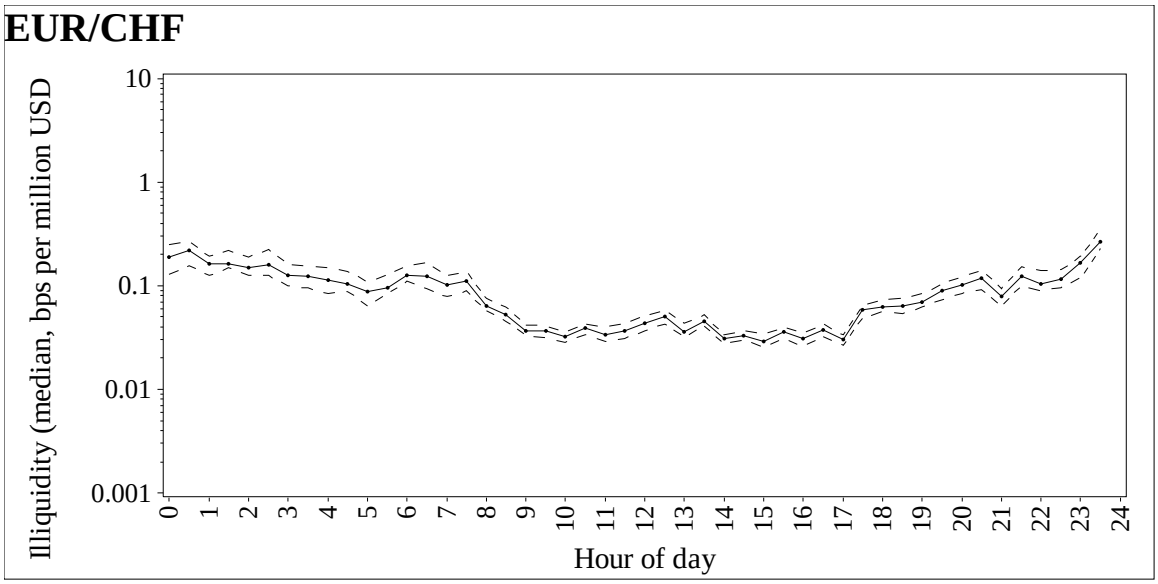
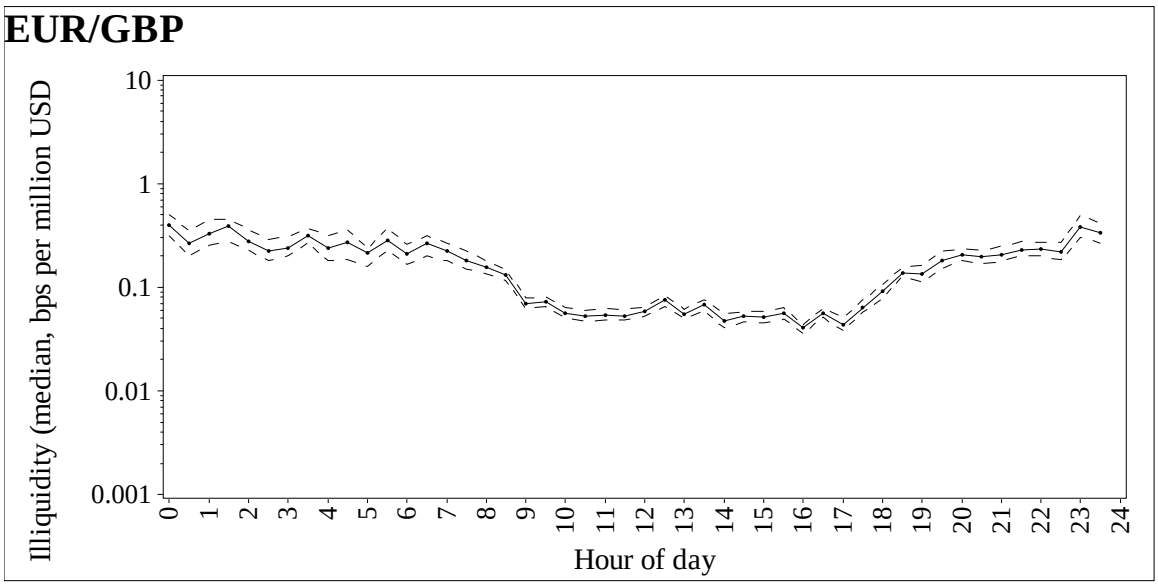


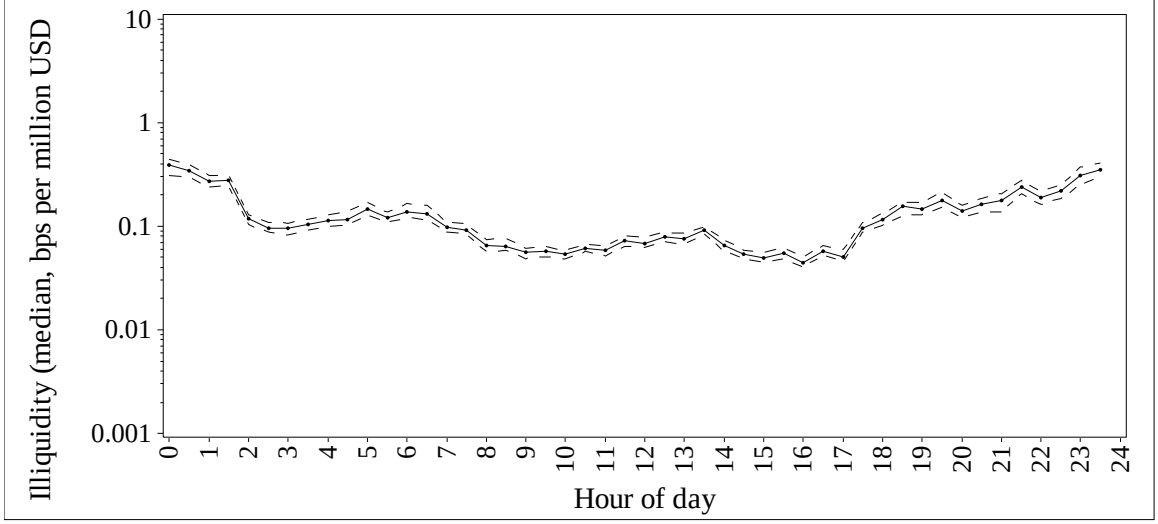
Figure 5.
Time of day patterns in illiquidity



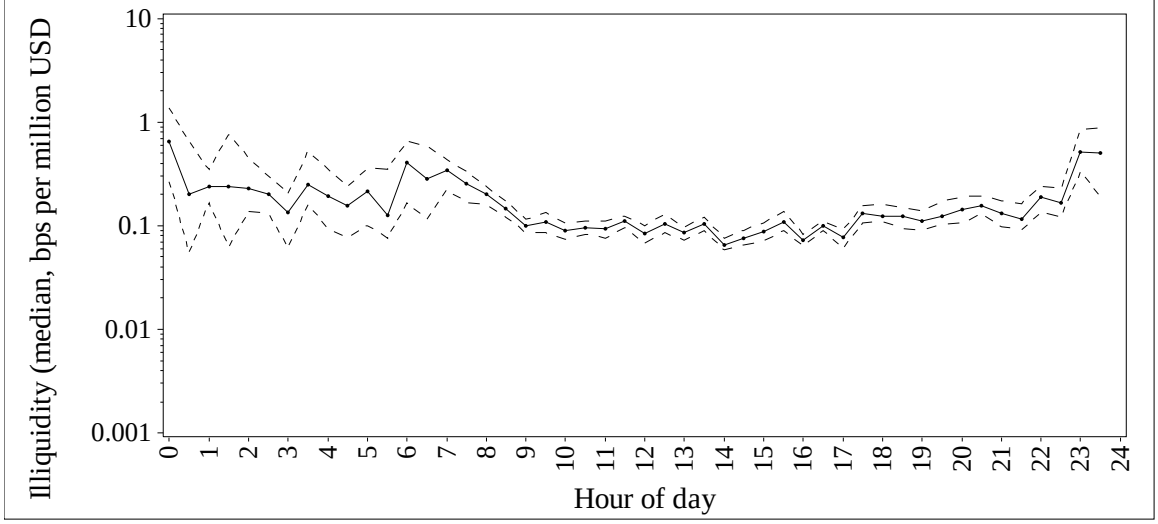




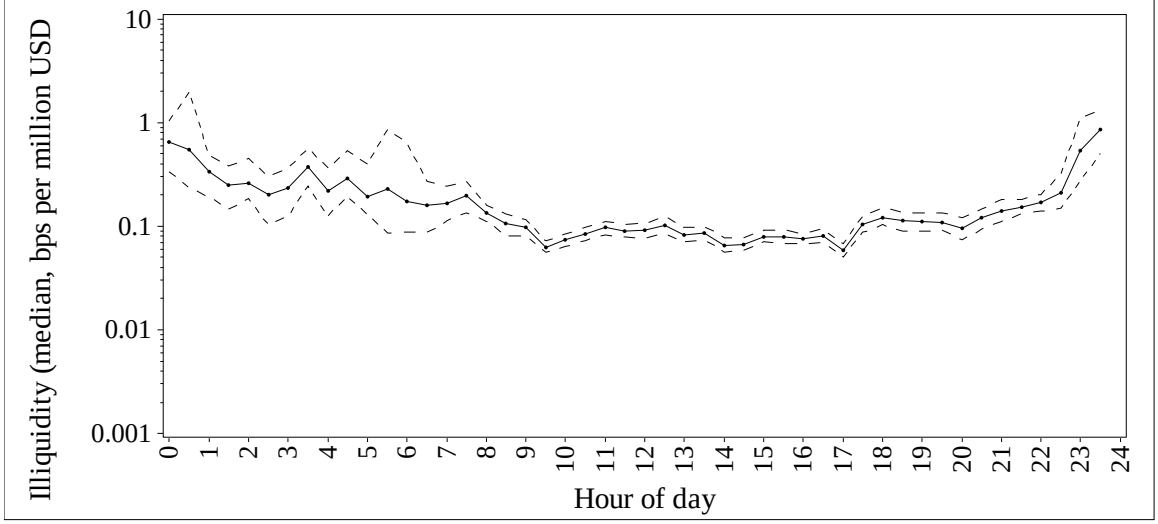
EUR/JPY



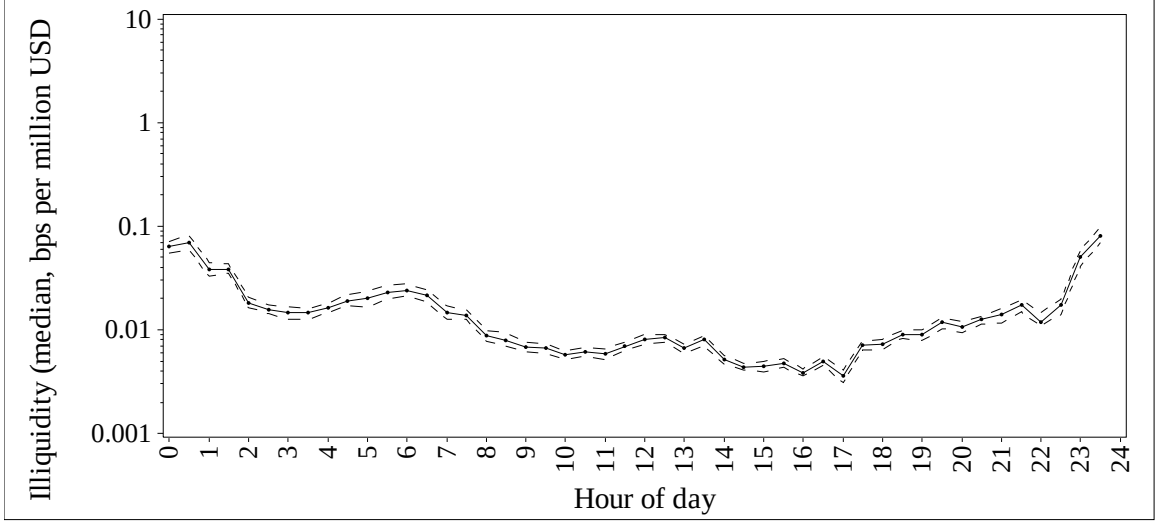
EUR/NOK



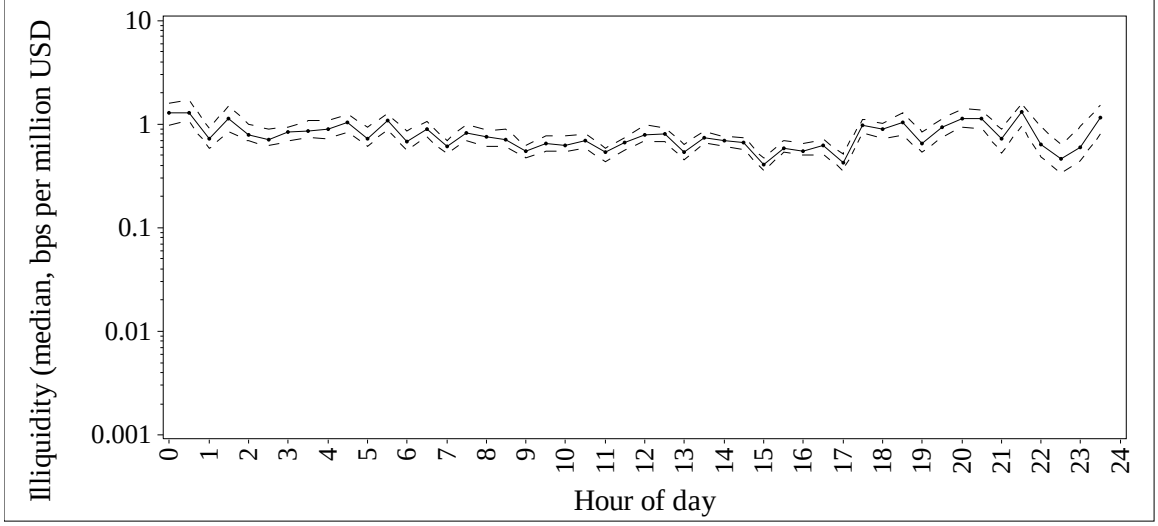
EUR/SEK



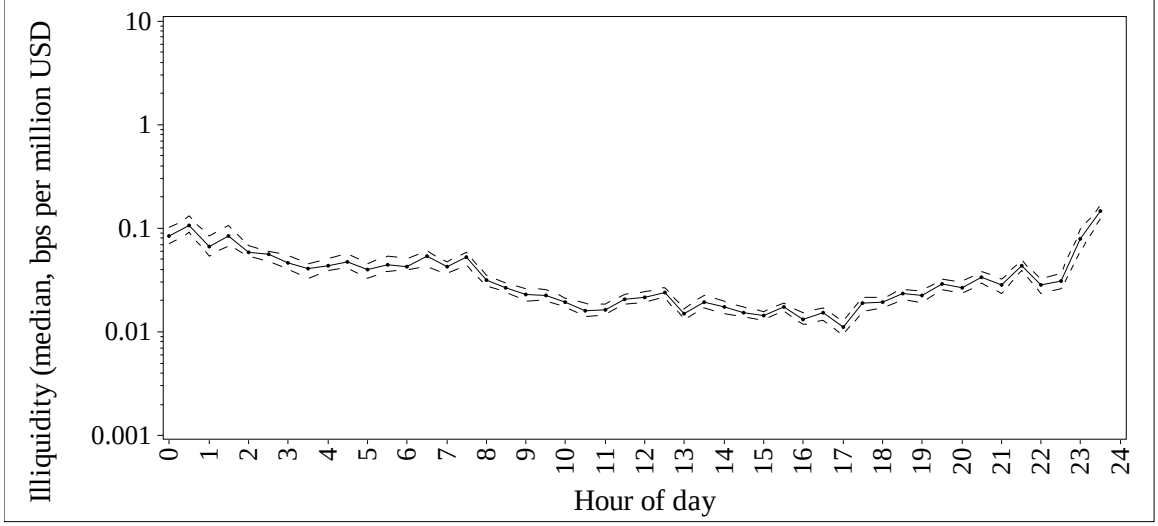
EUR/USD



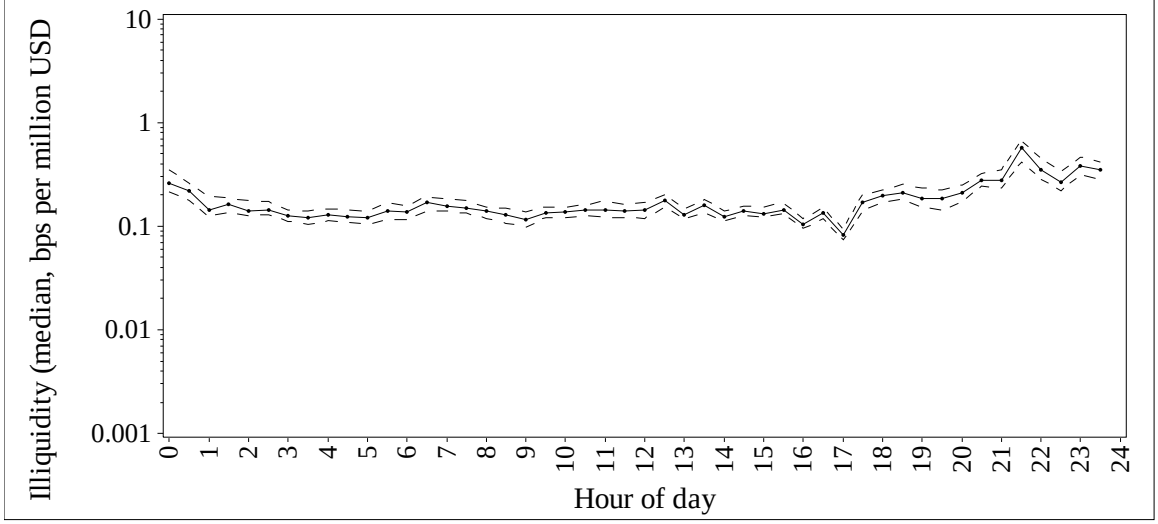
GBP/JPY



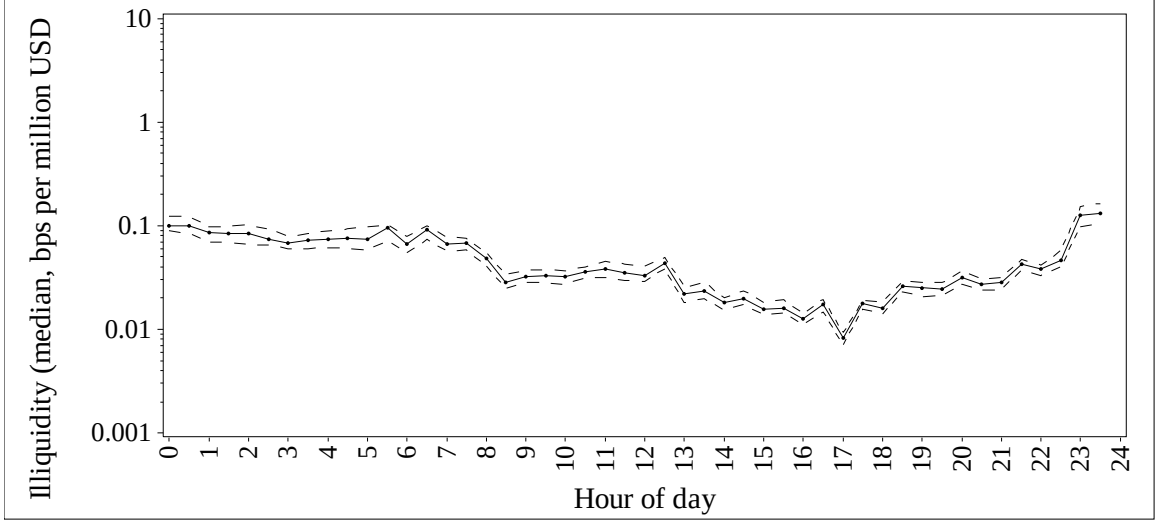
GBP/USD



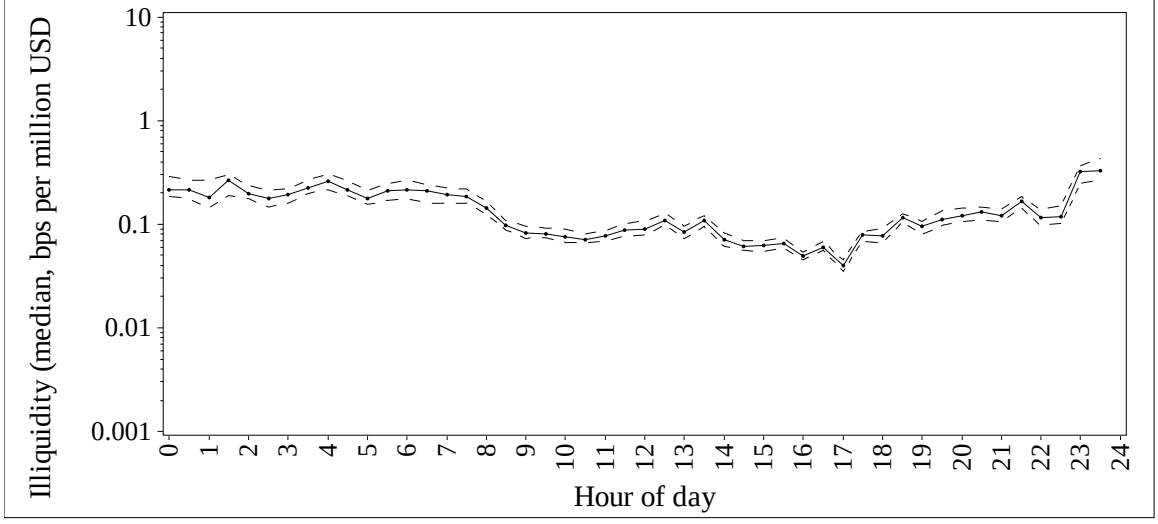
NZD/USD



USD/CAD



USD/CHF



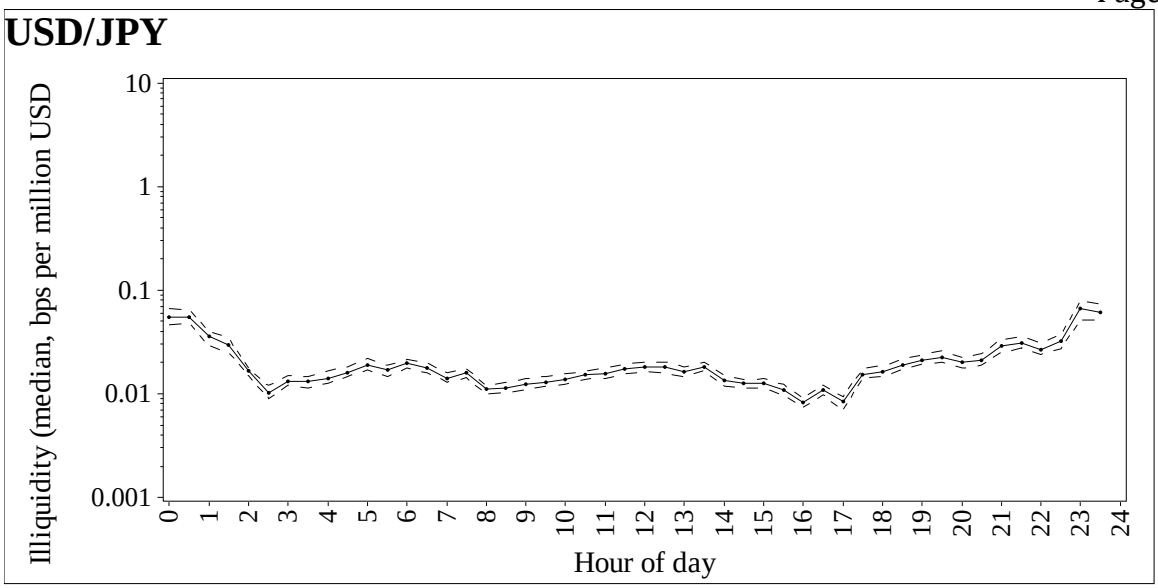

USD/JPY
Illiquidity (median, bps per million USD
10
1
0.1
0.01
0.001
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of day

Figure 6. Alternative liquidity measures across currency pairs

Log-log scatterplot of estimated price impact coefficients (on the vertical axis) vs. illiquidity ratios (on the horizontal axis). The price impact coefficients are the medians reported in Mancini, Ranaldo and Wrampelmeyer (2013), internet appendix IA.III.