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FX spot and swap market liquidity spillovers*

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Abstract

We study the joint evolution of foreign exchange (FX) spot and swap market liquidity. Trading in FX swaps exceeds that of spot, yet this market segment has been largely ignored in prior research on liquidity in FX markets. We find strong co-movement in spot and swap market liquidity conditions and a strong link between FX funding and market liquidity, as gleaned from the pricing of both instruments. This link has strengthened over time with changes in dealer behaviour. Some of the largest dealers periodically pull back from pricing FX swaps and wider spreads attract smaller dealers. At the same time, liquidity in FX swaps remains impaired, which leads to adverse illiquidity spillovers to the spot market. Our findings suggest that funding liquidity has become a more important driver of spot market liquidity than it used to be.

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1 Introduction

With average daily trading volume of over \$6 trillion, the foreign exchange (FX) market is the world's deepest financial market. Unlike, say, equity markets, FX trading is fragmented across many venues and is primarily executed over-the-counter (OTC). Hence, FX liquidity conditions are notoriously difficult to assess. Another unique feature of FX market is the predominance of trading in FX derivatives over spot transactions. Daily trading volume in FX swaps, the most liquid FX derivative instrument, has been exceeding that of spot for years and by 2019 accounted for almost half of all trading in global FX markets (BIS, 2019).[1] At the same time, as we show in the paper, the pricing of spot and FX swaps is intimately linked. Greater volume of FX swap trading thus implies that liquidity conditions in spot may very well be affected by liquidity in FX swaps. However, existing studies of FX market liquidity have overlooked this market feature by focusing exclusively on spot trading in isolation. This paper attempts to fill this gap.

We assess liquidity conditions in the FX market taking into account the interrelation between liquidity provision in FX spot and FX swaps. FX swaps have a spot leg and a forward leg, which is why price formation in FX swaps depends on price formation in the spot market, and vice-versa. Since FX swaps are term loans of one currency collateralised with another currency, the interest rate implicit in FX swaps (i.e. forward discount) reflects aspects of funding liquidity conditions in the two currency pairs. Hence, in addition to assessing market liquidity on its own, we are able to examine the interaction between FX market liquidity and FX funding liquidity. In order to circumvent endogeneity problems arising from the market liquidity funding liquidity feedback loop, our identification strategy relies on exogenous quarter-end funding liquidity shocks in FX swap markets to study their effects on spot market liquidity.

Our analysis focuses on the two most liquid currency crosses, JPY/USD and EUR/USD. Our main empirical analysis is conducted at the intra-day frequency leveraging information on prices with information on number of active dealers and their quoting behaviour.

Our main results are as follows. First, we find that bid-ask spreads in spot and FX swaps are very highly correlated, indicating that market liquidity in spot and swap markets is intimately linked. Second, we find a robust relationship between FX funding and FX market liquidity. A deterioration in FX funding liquidity, measured by the forward discount or by deviations from covered interest parity (CIP, a related measure), is associated with a

[1]In April 2019, average daily trading volume of FX swaps was approximately \$3.2 trillion compared to \$2 trillion for spot; in April 2016, analogous volume for FX swaps was \$2.4 trillion compared to \$1.7 trillion for spot, according to the BIS Triennial Central Bank Survey of FX and OTC Derivatives Markets.

widening of bid-ask spreads not only in FX swaps but also in the spot market.

Third, this link between FX market and FX funding liquidity conditions has strengthened significantly since about mid-2014. In particular, while some deterioration in FX swap market liquidity was always present around quarter-ends, these effects have become several times larger since 2014. Significant illiquidity spillovers from FX swaps to spot market also emerged in the latest period.

Fourth, we document several empirical links between dealer activity and liquidity conditions. We find that the positive marginal impact of dealer competition on market liquidity has decreased over time, particularly in FX swaps but also in spot. We also find that USD funding liquidity droughts in FX swap markets at quarter-ends, as measured by widening forward discounts and CIP deviations, have become approximately three times greater between July 2014 and May 2017 than they were during the 2011-12 European debt crisis. We find that it is the desks belonging to institutions classified as global systemically important banks (G-SIBs) that significantly cut back on their quoting activity in FX swaps during quarter- and year-ends, causing market and funding liquidity to deteriorate, with the latter resulting in violations of CIP.[2]

Even though small dealers step-up their quoting activity in FX swaps when G-SIB dealers pull-back, smaller dealers charge wider bid-ask spreads and a steeper forward discount compared to large dealers, hence liquidity in FX swaps remains impaired. We identify two reasons for this. One is that small dealers are low-volume players, thus require wider bid-ask spreads and forward spreads for their market-making activity to be profitable. The second reason is that small dealer quoting activity does not contribute to price discovery to the same extent as that by large dealers. Specifically, greater quoting intensity by small dealers does not suppress the dispersion of forward rate quotes in the same way that quoting intensity by large dealers does, indicating greater volatility of quotes around the "true" forward rate.

Finally, we identify a channel of illiquidity spillovers from FX swap to spot markets through dealer behaviour. We find empirical evidence that wider spreads charged by small dealers in FX swaps, when they take over much of the quoting activity from large dealers, translate into wider bid-ask spreads in the spot market, despite the fact that large dealers remain the predominant liquidity providers in spot. This implies that window dressing by large FX dealers in FX swaps has been disruptive not only to the swap market liquidity, but also to liquidity in the spot market, where similar window dressing is not observed.

[2]G-SIB banks are subject to the G-SIB capital surcharge and have an incentive to manage down their balance sheets to avoid crossing into the next G-SIB bucket; see, for example, J.P. Morgan "Making sense of Libor's mysterious rise", North American Fixed Income Strategy, 14 December, 2017.

As in most empirical research, our findings are conditional on the representativeness of the data source(s). We source tick-level data from Thomson Reuters (Refinitiv as of 2018) tick history database, which collects time-stamped electronic quotes covering large segment of the FX market. The data mainly captures dealer-to-client market segment, because the wholesale inter-dealer FX swap market is predominantly a brokered market, so mainly voice executed. While mid-prices are set in the inter-dealer market, our primary focus is on bid and ask quotes faced by liquidity takers, which are ultimately set in the dealer-to-client market segment. Still, given the considerable fragmentation of FX trading, for example, larger liquidity providers can be linked to more than 20 electronic communication networks (Markets Committee, 2018), we cannot entirely exclude the possibility of some bias in coverage.

This paper proceeds as follows. Section 2 reviews related literature and our contribution. Section 3 describes the data and our measures of liquidity and dealer activity. Section 4 contains a broad overview of liquidity measures at daily frequency. Section 5 presents the core intra-day analysis of FX liquidity dynamics. Section 6 concludes.

2 Related literature

This paper relates to several strands of international finance literature. We add to the study of liquidity dynamics in currency markets. Mancini, Ranaldo, and Wrampelmeyer (2013) provide a systematic assessments of FX spot liquidity, highlighting the substantial variation of liquidity across currency pairs. Their findings also suggest that FX liquidity risk is priced into currency excess returns. Banti, Phylaktis, and Sarno (2012) combine data on returns and order flows across currencies to construct a measure of systematic FX liquidity risk. Karnaukh, Ranaldo, and Söderlind (2015) provide further evidence for commonality in FX liquidity, using daily data covering a large cross-section of currency pairs for more than twenty years. Hasbrouck and Levich (2017) examine liquidity dynamics across a large number of currencies using one-month of settlement data, complemented with high-frequency data on quotes. We add to these studies by taking into account liquidity conditions in the FX swap market as well as spot.[3]

This aforementioned extension allows us to explicitly account for the joint behavior of FX market liquidity and FX funding liquidity.[4] While Banti and Phylaktis (2015) do assess this

[3]BIS (2017) covered issues related to the liquidity of currency markets in the Americas, including FX derivatives.

[4]The theoretical framework for the interaction of these liquidity measures is grounded in Brunnermeier and Pedersen (2009). Whereas market liquidity broadly refers to the costs of trade execution and the ability to trade large volumes without generating an out-sized price impact, funding liquidity refers to the ease with

interaction of funding liquidity with FX market liquidity, they do not explicitly consider the relative funding costs of one currency against another. Instead, they look at funding liquidity conditions in two major repo markets (US and UK) as indicators of global funding conditions. Similarly, Karnaukh, Ranaldo, and Söderlind (2015) show that FX liquidity declines with higher VIX and TED spread (both US market-based measures). Unlike these studies, we construct all the funding liquidity measures from activity in FX markets themselves. We measure FX funding liquidity by the forward discount (computed from quotes of FX swap points), which gives an implicit interest rate of funding one currency with another. Specifically, the forward discount computed from the pricing of FX swaps represents the cost of borrowing (lending) US dollar while lending (borrowing) a local currency in the spot market. Hence, we look at funding liquidity in the proximate market, and in currencies matching the spot market crosses under consideration.

We also add to previous studies that examine the relationship between FX market liquidity and dealer competition. Huang and Masulis (1999), in particular, also used Thomson Reuters Tick History (TRTH) data to study the effects of dealer competition on liquidity, but these authors only looked at the spot market. Hau, Hoffmann, Langfield, and Timmer (2019) find that price discrimination in FX derivatives is eliminated when clients trade through multi-dealer request-for-quote platforms. In addition, we add to studies relating FX price discovery and dealer informational advantages to dealer size (Rosenberg and Traub, 2009; Bjonnes, Osler, and Rime, 2009; Phylaktis and Chen, 2010; Menkhoff, Sarno, Schmeling, and Schrimpf, 2016). We contribute to the literature by assessing the impact of large and small dealers on liquidity conditions in both spot and FX swaps.

Finally, we contribute to academic literature on CIP violations in a non-crisis time, beginning with Du, Tepper, and Verdelhan (2018), who show that neither credit risk nor transactions costs can explain the anomaly in the period of relative post-crisis calm. Some studies have focused on the demand-side for FX hedges (Bräuning and Ivashina, 2017; Iida, Kimura, and Sudo, 2018; Borio, Iqbal, McCauley, McGuire, and Sushko, 2016; Abbassi and Brauning, 2018), others on liquidity and risk premia asymmetries in the respective money markets, (Rime, Schrimpf, and Syrstad, 2017; Wong and Zhang, 2017). In turn, Avdjiev, Du, Koch, and Shin (2019) relate CIP deviations to the shadow price of bank leverage that fluctuates with US dollar exchange rate. We contribute to this literature by documenting dynamics arising from the supply side of FX swaps. Specifically, the pull-back from liquidity provision in FX swaps by the dealing desks of G-SIB banks constitutes another contributing factor to

which such trades and the associated market positions can be funded. Importantly, funding instruments are themselves traded, and their pricing can affect market liquidity conditions, which can then feed back to funding costs.

CIP deviations, particularly at quarter- and year-ends. Hence, we emphasize a somewhat different channel than Cenedese, Della Corte, and Wang (2018), who find a link between the leverage ratio of major bank dealers with wider CIP deviations in the following quarter.

3 Data and Variable Definitions

We obtain tick-level data for JPY/USD and EUR/USD spot exchange rate, 1-month swap points, and 1-month OIS rates from Thomson Reuters (Refinitiv as of 2018) Tick History data, distributed via Reuters Datascope. Our sample period runs from 1st February 2010 to 31st May 2017. The dataset contains information on dealers' best bid and ask quote submissions, timed at the milli-second frequency. It documents the name and location of the dealer bank that submitted the quote. We also obtain information on 1-month overnight indexed swap rates for both countries. Table 1 shows the sample of tick history data for a two-second window for spot JPY/USD.[5]

[Table 1, about here]

We conduct our main analysis at the hourly frequency in order to circumvent problems arising from microstructure noise. For bid and ask price quotes for spot rate, 1-month FX swap points, and OIS rates, we use the last available price quote in each hour. In addition, we count the total number of quote submissions in each hour and total number of unique banks actively posting quotes in each hour.

Next, while activity on FX markets is not restricted to specific trading hours, we clean the data in the spirit of earlier studies (e.g. Andersen, Bollerslev, Diebold, and Vega, 2003) and exclude certain trading hours and holidays with abnormal low trading volume. On weekends and in the occasion of a holiday, we delete data entries between 21:00 (GMT) of the previous day until 21:00 (GMT) of the holiday itself. For example, we drop information on weekends from Friday 21:00 until Sunday 21:00. We drop data on fixed holidays such as Christmas

[5] While containing important information on quoting activity by FX dealer banks, our dataset is also subject to a number of limitations. First, it is primarily based on quotes supplied to Thomson Reuters (now Refinitiv). Second, the data only has information on quotes and not traded prices or volumes, which precludes us from computing a number of popular measures of market liquidity based on the volume-return relationship. Third, the dataset does not contain information on the depth of the order-book or order size. Lastly, trading venues such as Electronic Broking Services (EBS) have larger trading volumes for EUR/USD and JPY/USD. As these are the two most frequently traded exchange rates, however, we believe it is pivotal to shed light on the link between liquidity dynamics and dealer activity in spot and swap market of these two currency pairs. Breedon and Vitale (2010) show that dynamics between EBS and Reuters are highly correlated and both markets are closely linked with each other.

(24th - 26th December), New Year's (31st December - 2nd January) and July 4th.[6] In addition, we exclude flexible holidays, such as Good Friday, Easter Monday, Memorial Day, Labour Day, and Thanksgiving and the day after. For the entire sample period, we obtain 44,088 hourly observations for JPY/USD and EUR/USD each.

3.1 Price measures of market liquidity

After these steps of data cleaning, we construct the measures of market liquidity, employing spot dealers' spot bid and spot ask prices and FX swap dealers' quote bid and ask swap points. We define the 1-month forward rate implied by swap points: $F = S + SP * 10^{-2}$ for USD/JPY and $F = S + SP * 10^{-4}$ for USD/EUR, where S denotes the spot rate and SP are 1-month swap points. Following Banti and Phylaktis (2015) we measure market liquidity at the hourly frequency in the foreign exchange spot and swap market by the bid-ask spread

$$Spread_h^S = \frac{S_h^{ask} - S_h^{bid}}{S_h^{mid}} \tag{1}$$

$$Spread_h^F = \frac{F_h^{ask} - F_h^{bid}}{F_h^{mid}} \tag{2}$$

where the mid-price is calculated as the arithmetic average between ask and bid price in each respective market segment. The bid and ask forward exchange rates, F_h^{bid} and F_h^{ask}, are implied by the swap points quoted by dealers in FX swaps.

3.2 Price measures of funding liquidity

Swap point quotes from FX swap dealers contain another important piece of information: the cost of term funding of one currency against another. For example, if the reported swap points are negative, this indicates that USD is trading at a forward discount compared to the quoted currency. Hence, the pricing of FX swaps reflects the costs of obtaining say USD today at the spot rate S in exchange for say JPY, and reversing this transaction in one month at the pre-agreed forward exchange rate F.[7]

Thus, our main measure of FX funding liquidity is based on the forward spread, which we calculate as:

[6] In 2015, the official holiday is 3rd July, since July 4th falls on a Saturday.

[7] See, for example, Rime, Schrimpf, and Syrstad (2017), who document increasing importance of FX swaps as funding instruments used by banks.

$$Fdiscount_h = \frac{F_h^{mid} - S_h^{mid}}{S_h^{mid}} \tag{3}$$

where F^{mid} and S^{mid} refer to the mid-price of 1-month forward and spot rates, respectively.

As an alternative measure of funding liquidity, we adjust the forward spread (forward discount) by the level of benchmark interest rates, OIS rates, in the two currencies of the same maturity. This is because, over a longer horizon, the level of the forward-spot differential should change to reflect the relative interest rate differentials in the two currencies, as stipulated by the CIP. Hence, an alternative measure of FX funding liquidity is based on annualising the implied 1-month interest in the raw forward discount, then adjusting it by the OIS rates in the two currencies. Effectively this comes down to computing deviations from CIP:[8]

$$CIPdev_h = (1 + \frac{r_h^{mid}}{100}) - (1 + \frac{r_h^{mid*}}{100}) \times \left(\frac{F_h^{mid}}{S_h^{mid}}\right)^{(360/30)} \tag{4}$$

where r_h^{mid} and r_h^{mid*} refer to the mid-price OIS rates of both currencies.

By now, it should be fairly obvious that the pricing of FX swaps is reflective of both market and funding liquidity.[9] First, the quotes for swap ask (bid) points are the quotes for the differential between ask (bid) spot and ask (bid) forward rate, hence they reflect market liquidity conditions in FX swaps. Second, the forward discount implicit in the swap points provides a measure of term funding of one currency against another, hence it reflects FX funding liquidity conditions.

3.3 Quantity measures of FX liquidity

We compute additional quantity-based measures that account for FX dealer structure and quoting activity. First, following Huang and Masulis (1999), we measure dealer competition

[8]That said, adjustment of the forward discount by the OIS rates should not be considered as a measure of CIP arbitrage profits (see, for example, Rime, Schrimpf, and Syrstad, 2017), but is simply used to account for the relative cost of funding liquidity via FX swaps in the two currencies taking into account the level of benchmark interest rates.

[9]See Baba, Packer, and Nagano (2008) for an exposition of cash flows in an FX swaps.

by tracking the total number of quote submissions per hour. We do this not only for spot, but also for forward point quotes in FX swaps, with the number of quotes per hour denoted by Q_h^S and Q_h^F, respectively. In addition, we construct a measure of dealer competition at the extensive margin by counting the total number of active unique dealer banks within each hour. We denote this measure as N_h^S and N_h^F for spot and forward points, respectively. We treat all dealers from the same bank, independently of their geographical location, as one dealer bank. Lastly, we combine these two variables and measure quoting intensity as the ratio of submitted quotes and active banks $(\frac{Q_h^S}{N_h^S})$ and $(\frac{Q_h^F}{N_h^F})$. We interpret this measure as indicator of dealer competition at the intensive margin. An overview of our measures is provided in Table 2.

[Table 2, about here]

4 Liquidity Provision Over the Long-Run

4.1 Liquidity at daily frequency and quarter-end anomalies

Figures 1a and 1b show the dynamics of the price-based liquidity measures for JPY/USD and EUR/USD, respectively. Market liquidity in the spot and swap markets move very closely (correlation of 0.97 for JPY/USD and 0.98 for EUR/USD) over most of the sample period. For both currency pairs, bid-ask spreads widened during the European debt crisis at the end of 2011 and beginning of 2012. They subsequently narrowed, but began widening gradually for both currencies from mid-2014 until the end of the sample. Since higher bid-ask spreads are associated with more illiquid market conditions, this suggests that market liquidity has declined towards the end of our sample.

[Figure 1, about here]

We observe a similar pattern for funding liquidity. As indicated by the black lines, there was a temporary increase in the (absolute) forward discount in the period around the height of the European debt crisis. After improving in the 2012-13 period, funding liquidity began deteriorating on a re-occurring basis at quarter-ends from the third quarter in 2014 onwards.

Table 3 shows summary statistics for price-based FX liquidity measures on the months falling on quarter-ends (QE) compared to non-quarter-end (NQE) months. The sample is split according to the apparent regime change in FX liquidity conditions with the emergence of the quarter-end turn in forward discount in September 2014 for JPY/USD and March 2015 for EUR/USD. Accordingly, we pick the second sub-sample cut-off two month prior to the QE month for each currency pair. For each liquidity measure, Panel A shows the average level, difference with NQE monthly average, and p-values of a one-sided t-test. Panel B shows the average volatility of each liquidity measure on QE months, difference with NQE monthly average, and p-values of the variance ratio test.

[Table 3, about here]

The table shows that FX funding liquidity, as measured by either $Fdiscount$, or forward discount adjusted by the level of benchmark interest rates, $CIPdev$, deteriorates significantly at quarter-end months over the entire period (both wider spreads and higher spread volatility), but the magnitudes of the fall in liquidity at quarter-ends are several times larger in the second period. In addition, spot market liquidity in JPY/USD has also began exhibiting significant deteriorations at quarter-ends in the second period, as indicated by wider level and volatility of bid-ask spreads in spot. Market liquidity in EUR/USD appears less affected, although the volatility of bid-ask spreads particularly in the swap market, but also to a lesser extent in spot, has risen.

These quarter-end anomalies are a recent phenomenon that has emerged since about September 2014 for JPY/USD (March 2015 for EUR/USD). Their origins are exogenous to the FX market as such, attributed to the window dressing by global banks, as some banks shrink their balance sheets so as to manage their regulatory costs associated with the new post-crisis capital and liquidity requirements. Such balance sheet window-dressing appears to have first-and-foremost affected short-term money markets and on balance sheet funding instruments, such as repurchase agreements (CGFS, 2017 and Aldasoro, Ehlers, and Eren, 2018). However, strong effects have also been documented for off-balance sheet instruments, such as FX swaps (see Du, Tepper, and Verdelhan, 2018).

4.2 G-SIBs compared to other large and small FX dealers

Since we know which dealer is actively posting quotes, we can distinguish according to dealer characteristics. Phylaktis and Chen (2010) relied on the ranking of the Annual *Euromoney Survey* (EMS) to classify dealers by their FX business size. We follow the same methodology and classify as large FX dealers those that appear in the *Euromoney* league tables, with the rest classified as small dealers. On top of this, we layer another classification of whether the dealer's parent bank has been designated as a G-SIBs according to the Financial Stability Board's (FSB) designation (BIS, 2011, 2013).

As an example, Table 4 shows the comparison between the thirty G-SIB bank dealers and the top FX dealers according to the 2016 Euromoney survey. While almost all 30 G-SIBs are ranked as top FX dealers in the Euromoney Survey (Table 4, left column),[10] 27 additional banks have large enough FX business to be ranked in the Euromoney FX Survey but are not in the list of G-SIBs.

[Table 4, about here]

Distinguishing between G-SIBs and other banks is important because of the way FX swaps are treated in regulatory accounting and banks' capital requirements. All banks are subject to leverage ratio requirements. Calculation of exposure under the leverage ratio for the purposes determining required capital is based on banks' so-called "on-balance sheet" instruments, such as loans, securities, or repurchase agreements. Hence, window dressing around reporting of the Basel III leverage ratio has been associated with liquidity droughts in repo markets (CGFS, 2017; Kotidis and Van Horen, 2018; BCBS, 2018), because entering a repo contract directly contributes to the on-balance sheet exposure under the leverage ratio. In contrast, FX swaps fall in the category of the so-called "off-balance sheet" instruments. As such, their contribution to exposure under the leverage ratio primarily works through what is known as an "add-on factor"' for potential future exposure (PFE). For FX and gold derivatives of maturities less than or equal to one year, the PFE factor is 1%. This means that only 1% of the banks' FX swaps position counts towards the calculation of exposure under the leverage ratio, BCBS (2014). By contrast, the entire notional amount of FX swaps book contributes to the G-SIB score via the so-called complexity component, BCBS (2013). Hence, the direct incentive to window-dress FX swaps exposure is limited to banks classified as G-SIBs. These institutions have an incentive to manage broader exposures that contribute to different components of the G-SIB score in order to avoid crossing in the next G-SIB bucket.[11]

[10] The only exception is Mizuho FG, which is classified as G-SIB but not listed in the Euromoney Survey. Note that non-bank market-makers such as Citadel Securities, XTX Markets, Tower Research Capital, or Virtu Financial do not appear in our database by name. This is because their activity is prime-brokered by major FX dealers banks. Therefore the quotes of such non-bank market-makers appear under their prime-broker's name and not their own. Dealers that are not part of our database are marked in grey in Table 4.

[11] Appendix Figure A1 illustrates this using end-2016 G-SIB scores for the banks in our sample for JPY/USD. Note, off-balance sheet derivatives, including FX swaps, are only one part of the total score (contributing to about 1/3 of one out of five (20%) components of the G-SIB score, BCBS (2013)).

[Figure 3, about here]

Figures 2a and 2b show, using Venn diagrams, the relative size of activity in FX swaps and spot in the 2010-2014 versus the 2014-2017 periods for three types of dealers: G-SIBs, EMS (non G-SIB), i.e. large FX dealers but not G-SIBs, and Other, i.e. those banks not listed in the *Euromoney* tables.[12] For conciseness, we will refer to these categories as Tier-1, Tier-2, and Tier-3 dealers, respectively. The figures show that Tier-1 dealers (G-SIBs) decrease the share of quotes in FX swaps from 55% in the 2010-2014 period to 50% in the 2014-2017 period, while Tier-2 (non G-SIB large dealers) and Tier-3 (small dealers) increased the share of their quoting activity devoted to FX swaps over the same period (from 66% to 69% and from 31% to 44%, respectively). Hence, the demarcation of the shift in FX swaps business run along the G-SIB vs non G-SIB split, rather than being a common feature due to all banks having to adhere to the Basel III leverage ratio. Figure 2c further shows that the shift away by G-SIB dealers from quoting prices for both FX swaps and spot to only quoting spot was particularly pronounced around quarter- and year-ends.

[Figure 4, about here]

Figures 4a and 4b plot the quoting intensity of smaller dealers in the swap market against CIP deviations that take account of transaction costs (measured by bid-ask spreads). The figures show that quoting intensity in FX swaps by Tier-3 (small) dealers, $Q_t^{F,T3}/N_t^{F,T3}$, is inversely related to liquidity conditions in FX swaps. Whenever bid-ask spreads and forwards spreads widen, as measured by the transaction cost-adjusted CIP deviations, small dealers tend to increase their quoting intensity. This was temporarily the case during the euro area sovereign debt crisis, but became more persistent since about mid-2014 as price-based measures of FX liquidity conditions deteriorated first in JPY/USD and then in EUR/USD. One possibility is that smaller institutions, not constrained by G-SIB surcharge or that have greater balance sheet availability, are trying to take advantage of the dislocations in FX swap markets.[13]

[12] Recall, our data only covers instruments for which quotes were supplied to Reuters Datascope and only FX swaps of 1-month tenor. Therefore, the Venn diagrams are by no means meant to be representative of the entire FX swap and spot business of dealers in our sample.

[13] We also examined the possibility that small dealers may be posting skewed bid and ask quotes in FX swaps, which would suggest FX swap use for funding purposes rather than passive liquidity provision. We found not evidence of quote skewing.

5 Intraday FX liquidity Dynamics

In this section, we move to the analysis at the hourly frequency, using measures constructed from tick-level data and described in Table 2. Figures 5 and 6 show the variation in FX market and funding liquidity in spot and swap markets during the trading hours for the two sub-sample periods for JPY/USD and EUR/USD, respectively. Market liquidity (measured by bid-ask spreads) tends to be lower during the beginning and end of the trading day, resembling a U-shaped form of liquidity (blue bars). Measures of FX funding liquidity, both $Fdiscount$ and $CIPdev$, also exhibit a U-shape, indicating worse liquidity conditions when London and New York based dealers are absent.

Red lines indicate averages for each trading hour during quarter-end months. As shown in Figure 5a, market liquidity changed little during quarter-ends in the February 2010 to June 2014 period, but FX funding liquidity conditions were usually worse. During the second sub-sample period, from July 2014 to May 2017, shown in Figure 5b, FX funding liquidity measures are considerably worse in levels (blue bars), and their deterioration at quarter-ends is much larger in relative terms, with spreads in both $Fdiscount$ and $CIPdev$ about two times wider (red lines). Furthermore, unlike the earlier period, bid-ask spreads exhibit widening at quarter ends for both spot at swap markets, indicating possible spillovers from FX funding to FX market liquidity at quarter-ends during the most recent period. Figures 6a and 6b show qualitatively similar results for EUR/USD.

[Figures 5 and 6, about here]

Statistical tests confirm that intraday co-movement between FX market and funding liquidity has strengthened since the appearance of quarter-end anomalies in funding markets in mid-2014 for JPY/USD and early 2015 for EUR/USD. Table 5 shows that pairwise correlations as well as percentage of variation explained by a common factor has increased across all combinations of bid-ask spreads in spot and swaps with FX funding liquidity measures, for both currency pairs.

[Table 5, about here]

5.1 Hourly liquidity dynamics in the two sub-periods

The descriptive statistics point towards time-varying liquidity dynamics across sub-sample periods. They also indicate that the co-movement between FX market and FX funding liquidity conditions intensified in the last sub-sample period. While funding liquidity has tended to deteriorate at quarter-ends even in the pre-2014 period, these funding liquidity droughts have intensified since mid-2014. Furthermore, it is only in the latest sub-sample period that FX funding liquidity droughts appear to spillover to market liquidity conditions.

To formally examine the relationship between liquidity conditions in spot and swap markets, and the interaction between their market liquidity and funding liquidity components, we estimate a conditional error correction model (ECM), derived from an autoregressive distributed lag model specification for the two sub-sample periods. Following Pesaran, Shin, and Smith (2001) the specification allows to assess the long- and short-run specification between a set of variables independent of the order of integration of the variables in our system. As the dynamics of variables vary across the sample period, displaying mean-reversion in some months but high persistence in others, inferences about non-stationarity from standard unit root tests are highly dependent on the chosen time-period. Modelling the relationship between dealer activity and liquidity in an ARDL model, however, allows us to take an agnostic view about the order of integration, and to model long- and short-run dynamics without classifying variables as either stationary or non-stationary We formulate the following two conditional ECMs as:

$$\Delta Spread_h^P = \alpha + \sum_{i=1}^{23} \delta_i H_i + \theta_0 Spread_{h-1}^P + \boldsymbol{\theta x_{h-1}^P} + \sum_{i=1}^{p-1} \boldsymbol{\gamma_i \Delta z_{h-i}^P} + \boldsymbol{\beta \Delta x_h^P} + u_h \tag{5}$$

where $\mathbf{z_h^P} = (Spread_h^P, |Fdiscount|_h, Q_{T1,h}^P/N_{T1,h}^P, Q_{T2,T3,h}^P/N_{T2,T3,h}^P, Vol_h^P) = (Spread_h^P, \mathbf{x_h^P})'$ is a vector of endogenous variables. $T1$, $T2, T3$ denote G-SIB and non G-SIB dealers, for both spot and swap quotes, $P = S, F$. The vector contains bid-ask spread as a measure of market liquidity, absolute forward points as a measure of funding liquidity (funding costs), quoting intensity of large and smaller dealers, and realized volatility as control variables. α denotes an intercept and the term $\sum_{i=1}^{23} \delta_i H_i$ refers to hourly dummy variables and their associated coefficients. Long-run dynamics are captured by the lagged terms of the dependent and independent variables while short run dynamics are driven by the contemporaneous and lagged differenced terms. We test for the existence of a long-run relationship applying Pesaran, Shin, and Smith (2001) bound testing procedure. First, we test if all long-run coefficients are significantly different from zero using a F-test ($H_0 : \theta_i = 0$). Second, we test if the coefficient of the cointegrating relationship is smaller and significantly different from zero. We estimate the identical model specification for every sub-sample period and only vary the number of lags p. Then we examine the significance of the long-run coefficients.

If both null hypotheses are rejected, we conclude that there exists a long-run relationship between variables in vectors $\boldsymbol{z^S}$ in spot and $\boldsymbol{z^F}$ in FX swaps.

Table 6 shows the coefficient estimates of the long-run equations, expressed in terms of economic magnitudes by scaling by the standard deviations of the regressors.[14] The reported F-statistics of the Pesaran, Shin, and Smith (2001) bounds test exceed I(1) critical values for all equations, indicating the presence of a statistically significant long-run relationship among the selected measures of liquidity and volatility. The results are obtained controlling for time-of-day effects with hourly dummies, as well as for intraday volatility in both spot and swap markets.

[Tables 6, about here]

The ECM-ARDL model estimation results point at several takeaways. First, there is a strong and robust relationship between FX market liquidity, as proxied by bid-ask spreads in both swap ($Spread^F$) and spot ($Spread^S$), with FX funding liquidity, as proxied by the absolute forward discount ($Fdiscount$). For example, a one standard deviation widening in $Fdiscount$ is associated with $41.6bp$ ($26.5bp$) wider bid-ask in JPY/USD (EUR/USD) swap, and a $64.9bp$ ($8.4bp$) wider bid-ask spread in JPY/USD (EUR/USD) spot. The link between funding and market liquidity strengthens in the second sub-sample period, particularly for JPY/USD where the economic magnitude of the coefficient on $Fdiscount$ increases more than three-fold in the swap bid-ask spread equation. For EUR/USD we also observe a substantial strengthening of the liquidity relationship from $6.9bp$ to $26.5bp$ in the swap market, while the relationship in spot increases only slightly and remains comparably low.

Second, the positive net effect of dealer competition on market liquidity in FX swaps has all but disappeared. A one standard deviation increase in the quoting intensity by G-SIB dealers in the swap market, Q^F_{T1}/N^F_{T1} used to be associated with a $28.7bp$ ($14.7bp$) narrowing of bid-ask spreads on JPY/USD forward rate spread (EUR/USD forward rate spread) in the 2010 to mid-2014 (December 2015 for EUR/USD), but the effect becomes small (and also not statistically significant for EUR/USD) in the second period. In contrast, the negative association between quoting intensity of non G-SIB (Tier-2 and Tier-3) dealers, $Q^F_{T2,T3}/N^F_{T2,T3}$, and market liquidity in FX swaps has persisted for both currency pairs, and even strengthened significantly in the case of EUR/USD. Thus, a one standard deviation increase in $Q^F_{T2,T3}/N^F_{T2,T3}$ is associated with $0.31bp$ ($0.04bp$) wider bid-ask spread in FX swap market for JPY/USD (EUR/USD).

[14] Appendix Table A5 and Table A6 show the complete test results for the long-run relationship among the variables for JPY/USD and EUR/USD, respectively.

Third, in contrast to the swap market, dealer competition in the spot market has continued to contribute to significant narrowing of bid-ask spreads also in the post-2014 period. A one standard deviation increase in quoting intensity by G-SIB dealers in spot, Q^S_{T1}/N^S_{T1}, is associated with 20.5*bp* (35.9*bp*) narrower bid-ask spreads in JPY/USD (EUR/USD) spot.

Fourth, rises in non G-SIB dealer activity in swaps appears to have negative spillovers on spot market liquidity. Specifically, even though non G-SIB dealer competition in spot markets does not seem to have a statistically significant effect on market liquidity in JPY/USD and EUR/USD, higher quoting intensity by Tier-2 and Tier-3 dealers in swaps is associated with wider bid-ask spreads in the spot (Table 6, last column). Similarly, when small dealer quoting intensity in EUR/USD spot is replaced with small dealer quoting intensity in swaps in the $Spread^S$ equation, the coefficient is two times larger in magnitude and takes on a positive sign.[15]

5.2 Isolating small dealer impact

While we have separated tier-1, G-SIB, banks from the remaining dealer universe in the previous estimations, in this analysis we further account for the difference within the remaining dealers between those that make it into the *Euromoney Survey*, tier-2, and small FX dealers that do not, tier-3. We re-examine the estimation of the ARDL-ECM model of Equation 5 and then discuss the impact of dealers' quoting intensity on the forward spread dispersion. Table 7 displays the economic impact of a change in dealer quoting intensity for each of the three dealer types. Coefficients are scaled by the sample standard deviation.[16]

Focusing on the second sub-sample, the positive impact of quoting intensity of the three different groups on market liquidity conditions declines almost monotonically in magnitude or statistical significance from tier-1 to tier-3 banks. For example, for JPY/USD an increase in tier-1 quoting intensity leads to a decline in market liquidity in the swap market by 10.2*bp*, tier-2 dealers lower the spread, though the effect is not significant, and a one standard deviation increase of tier-3 dealer quoting intensity significantly worsens market liquidity conditions by 66.2*bp*. Further, we find that activity of tier-3 dealers (40.5*bp*) deteriorates liquidity conditions in the spot market by a factor more than six times as large as the quoting intensity of tier-2 dealers (6.1*bp*). For EUR/USD, we document similar market characteristics, though the impact of quoting intensity of tier-2 and tier-3 dealers on market

[15]The results are also robust to measuring FX funding liquidity using CIP deviations instead of the unadjusted forward discount (see Appendix Tables A7 and A8).

[16]The raw regression coefficients and cointegration parameters for both currency pairs are shown in Appendix Tables A9 and A10.

liquidity dynamics is lower than for JPY/USD.[17]

[Table 7, about here]

5.3 Adverse liquidity effects of shift towards small dealers

What are the possible economic reasons behind the negative relationship between FX market liquidity and small dealer competition? The first reason is that small dealers charge higher spreads. This can be gleaned from Table 8, which shows simple average of the median hourly bid-ask spreads and forward discounts computed from forward quotes by large and small dealers. For both JPY/USD and EUR/USD, the bid-ask spreads of forward rates (expressed as a percentage of mid-forward rate, in basis points) are significantly higher for small dealers compared to large (Tier-1 and Tier-2) dealers. Similarly, the forward discount (forward spread, expressed as a percentage of mid-spot rate) is also somewhat wider for small dealers compared to larger dealers. This is consistent with small dealers facing higher hurdle rates to enter as market-makers in the swap market, presumably due to being smaller volume players. Hence, their competition does not lead to the narrowing of the spreads to the levels that can be supported by large dealers.

[Table 8, about here]

The second reason for the negative relationship between FX market liquidity and small dealer competition in the swap market relates to the relative informational disadvantage of small dealers compared to large dealers. Bjonnes, Osler, and Rime (2009) find that order flow of large dealer banks is more informative than that of small banks, in terms of return predictability. Menkhoff, Sarno, Schmeling, and Schrimpf (2016) find evidence that informative order-flow of sophisticated investors affects foreign exchange rate via the intermediation of large dealers. Our logic is consistent with this literature. Large dealers intermediate the lion share of customer flows inside their internal liquidity pools. This would suggest that, on average, large dealers possess more precise information about the "true" market forward exchange rate at any point in time, because they intermediate FX swap buying and selling by a large and diverse client base.

In order to test this, we follow recent studies which assess the distribution of quote submissions. For example, Corsetti, Lafarguette, and Mehl (2017) use information on both

[17] Appendix Tables A11 and A12 that the results are qualitatively similar if funding costs are measured by CIP deviations instead of by the forward spread.

quotes and trades to construct a quote dispersion measure that accounts for market participants' reaction to new information based on the speed of trade execution. As we do not possess information on trades but only on quote submissions, our measure of dispersion follows Jankowitsch, Nashikkar, and Subrahmanyam (2011) and is applied to forward quotes within each hour:

$$Disp_h^F = \sqrt{\sum_{i=1}^{h_i} \frac{q_i^F}{Q_h^F} \left(\frac{F_i - \bar{F}_h}{\bar{F}_h} \right)} \tag{6}$$

where q_i^F accounts for the number of forward quote submissions within a minute, Q_h^F denotes the total number of submissions within the hour, F_i denotes the forward mid price in minute i and $\bar{F}_h$ is the average forward price of each hour. In times of higher volatility and low liquidity, we expect the dispersion of quotes to be comparably larger and $Disp_h^F$ to increase.

We then once again formulate a conditional ECM, but for the system that includes $Disp_h^F$, quoting intensity by large and small dealers, and hourly volatility of the forward rate, Vol_h^P, as control:

$$\Delta Disp_h^F = \alpha + \sum_{i=1}^{23} \delta_i H_i + \theta_0 Disp_{h-1}^F + \boldsymbol{\theta x_{h-1}} + \sum_{i=1}^{p-1} \boldsymbol{\gamma_i \Delta z_{h-i}^P} + \boldsymbol{\beta \Delta x_h^P} + u_h \tag{7}$$

$\mathbf{z_h^F} = (Disp_h^F, Q_{j,h}^F / N_{j,h}^F, Vol_h^F) = (Disp_h^F, \mathbf{x_h^F})'$ and $j = T1, T2, T3$, denotes Tier-1 (G-SIB), Tier-2 (non G-SIB large), and Tier-3 (small) dealer quoting intensity, respectively. Table 9 shows the results.

In the top panel, coefficients are scaled by the variables' standard deviation, while the bottom part of the table displays the raw long-run coefficients of Equation 7. Consistent with the hypothesis outlined above, higher quoting intensity by G-SIB bank dealers leads to a significant decline in the dispersion of forward quotes of 14.4*bp* for JPY/USD and 10.4*bp* for EUR/USD. Quoting intensity by non G-SIB large FX dealers (Tier-2) does not lower the quote dispersion for JPY/USD, while it does lower dispersion for EUR/USD, but to a lesser degree compared to the effect of G-SIB dealer quoting activity (7.7*bp*). Notably, coefficients of small dealer (Tier-3) quoting intensity are positive for both currency pairs, indicating that banks with a smaller customer base and those that are likely exposed to lower volumes of customer order flow contribute to a wider dispersion of forward quote submissions. This effect is particularly large for JPY/USD (33.3bp) while smaller and not significant for EUR/USD (1.4bp).

[Table 9, about here]

To summarise, the results reported in Tables 8 and 9 indicate that two effects are at play in generating the negative relationship between liquidity in the FX swap market and competition by small dealers. The first one relates to their wider required intermediation spreads, both bid-ask spreads and the forward spread (forward discount). The second one relates to their informational disadvantage and hence greater uncertainty about the actual market mid-rate for pricing FX swaps, which leads to greater dispersion and volatility of the forward quotes.

5.4 Quarter-end contagion from FX funding liquidity to market liquidity in spot

In this subsection, we test for the presence of contagion from funding markets to market liquidity at quarter-end balance sheet reporting periods, when large dealers pull back and small dealers increase their quoting intensity in FX swaps.

We follow Forbes and Rigobon (2002) and calculate an adjusted correlation coefficient using hourly data. We then test for regime shifts between quarter-end and non-quarter end months.[18] Adjusting the correlation coefficient for heteroskedastic levels of volatility allows us to make further statements about contagions and spillovers, rather than simple co-movement. To this end, we estimate the following bivariate vector autoregressive model:

$$\Delta y_h = \phi(L)\Delta y_{h-1} + \eta_h \tag{8}$$

$$\Delta y_h = \left[\Delta F discount_h, \Delta Spread_h^P\right] \text{ where } P = F, S \tag{9}$$

where Δy_h refers to the first differenced and de-seasonalized measures of funding and market liquidity. First, we de-seasonalise the FX liquidity metrics by regressing their changes on hourly dummies. Second, we estimate Equation (8) using a 200-hour rolling window

[18] Using a vector autoregression framework, Moinas, Nguyen, and Valente (2017) exploit regime shifts of volatility levels to examine liquidity dynamics in the European treasury bond markets.

and store the variance-covariance matrix for every single estimation.[19] Third, based on the obtained variance-covariance matrices from the hourly VAR regressions, we follow the approach in Forbes and Rigobon (2002) and construct an unconditional correlation coefficient as follows:

$$\rho = \frac{\rho^*}{\sqrt{(1 + \delta[1 - (\rho^*)^2])}} \tag{10}$$

$$\text{with } \delta = \frac{\sigma^{QE}_{Fdiscount}}{\sigma^{NQE}_{Fdiscount}} - 1$$

where ρ^* refers to the standard correlation coefficient between funding and market liquidity, and $\sigma^{QE}_{Fdiscount}$ and $\sigma^{NQE}_{Fdiscount}$ refer to the average variance of FX funding liquidity in quarter-end months (QE) and the two preceding non quarter-end months (NQE), respectively. Since the intra-day data allows us to construct the measure of co-movement for every rolling window estimation, we are able to obtain a time series of unconditional correlation coefficients for each QE and NQE period.

Having obtained the time-series of the adjusted correlation coefficients between funding and market liquidity measures in quarter-end months and the preceding two months, we then employ a one-sided t-test to examine the following hypothesis:

$$H_0\colon \rho_{NQE} < \rho_{QE} \mid \rho_{QE} < 0 \qquad\qquad H_A\colon \rho_{NQE} > \rho_{QE} \mid \rho_{QE} < 0$$

where ρ_{NQE} and ρ_{QE} refer to the average of the adjusted correlation coefficients in the non-quarter-end and quarter-end months. Rejecting the null hypothesis indicates that the shocks to $Fdiscount$ in a quarter-end month lead to spillover to bid-ask spreads, even after adjusting for the higher level of volatility of funding conditions during these periods.[20]

[Table 10, about here]

Table 10 shows the results for JPY/USD. The average adjusted correlation coefficient is negative in a number of quarter-end as well as non-quarter-end months in both spot (upper

[19]Every rolling estimation initially allows for 8 lags but we increase the lag length in a step-wise fashion until residuals are free of serial correlation.

[20]Qualitatively the same conclusions are drawn when shocks to CIP deviations at quarter-end months are considered. Results are summarized in Table A13 and A14 for JPY/USD and EUR/USD, respectively.

panel) and swaps (lower panel). Based on the t-test conducted on the adjusted correlation coefficients, we are able to reject the null of no spillovers in 3 out of 11 quarter-end months considered for spot, and 4 out of 11 quarter-end months for forwards. Hence, the evidence in favour of contagion from FX funding to FX market liquidity in JPY/USD is strongest for December 2015, June 2016, and December 2016.

[Table 11, about here]

Table 11 shows the analogous test results for EUR/USD. Similar to JPY/USD, the number of months in which the null is reject in favour of contagious spillovers is higher for swap bid-ask spreads than for spot bid-ask spreads. At the same time, the overall number of months, in which the results point towards contagion from FX funding liquidity to FX market liquidity, is slightly less that for JPY/USD. Still, both December 2015 and December 2016 turn out to be the quarter-end periods with the most robust evidence in favour of contagions, rather than simple co-movement. It is noteworthy that these months also fall on year-ends, when additional G-SIB surcharges apply to large dealer banks' balance sheets.

Overall, the empirical evidence suggests that a deterioration in funding liquidity at quarter-ends can spillover to market liquidity in spot and swap market. Taken together with our previous results on dealer activity, these findings suggest that the pull-back by G-SIBs from dealing in FX swaps at quarter- and year-ends can have a particularly contagious implications for spot market liquidity.

5.5 Small dealer market-making: case study of December 2016

In this sub-section we provide evidence that smaller dealers (non G-SIB banks) displaced large dealers (G-SIB banks) as market-makers in FX swaps for both currency pairs and also in spot markets for EUR/USD in December 2016. However, because these smaller volume players require higher hurdle rates, in terms of both bid-ask spreads on the forward points that they quote as well as wider forward discount, the increased competition by smaller dealers allows the low FX liquidity environment to persist. In contrast, large banks continued to dominate as market-makers in spot for JPY/USD and differences are very small for EUR/USD, indicating that it is likely their balance sheet constraints on the exposures to FX derivatives that explains their pull-back from quoting inside spreads in the swap market.

The left-hand panels of Figures 7 and 8 show the median hourly JPY/USD quotes of smaller (Tier-2 & Tier-3, non G-SIB) dealers and large dealers (Tier-1, G-SIB) during December 2016, for spot and forward points, respectively. The top graph displays ask and the bottom graph the associated bid quotes. The right-hand panels show the hypothetical location of small dealer quotes relative to large dealer quotes in the case that small dealers are actively making markets by quoting inside spreads. If the actual quotes correspond to the inside spread scenario, then this indicates that small dealers, not large dealers, would have been making markets on average during this month. The comparison of actual data (left) to the scenarios (right) in Figure 7 indicates that in December 2016, despite the pull-back by G-SIB dealers form the market in the aggregate, they continued to make markets in spot. However, the comparison of actual data (left) to the scenarios (right) in Figure 8 of the FX swap quotes indicates that non G-SIB bank dealers displaced G-SIB bank dealers as market-makers to clients in the FX swap market.

The results for EUR/USD, shown in Figure 9 and 10, are qualitatively similar for the FX swap market and small players appear to act as market-makers. In the spot market, differences in the submitted quotes of small and large dealers are low in magnitude and spreads in spot and swap markets by the different dealer segments are very similar. Yet, in contrast to JPY/USD it appears that during the majority of the day small dealers also act as market makers in this market segment.

A hypothesis that we so far reject is that smaller banks enter the FX swap market to source liquidity in one of the currencies. If this was the case, our test of inside versus outside spread by dealer category would have shown smaller dealers providing skewed quotes relative to large dealers. Data indicate that this is not the case.

Such entry of smaller dealers in FX swaps rather than spot as market-makers is consistent with dealers belonging to the largest banks pulling back from trading in FX derivatives, but continuing to make markets in spot. Hence, the results indicate that smaller dealers can play an important role in market-making in FX swaps when large dealers manage down their balance sheets, funding conditions are tight, and spreads are wide enough for smaller-volume players to profitably engage as market-makers. In this context, special periods, like quarter-ends, can be used for identification of funding liquidity effect on dealer competition and FX market activity.

6 Conclusion

In this paper, we analyse the joint evolution of FX spot and swap market liquidity conditions. We also draw on the pricing of both types of instruments to study the relationship between FX market liquidity and FX funding liquidity. The assessment of liquidity conditions also takes into account information on the number of dealers active at a given point in time, their quoting intensity, as well as dealer characteristics such as size. The empirical strategy makes particular use of month-end and quarter-end dynamics in the FX swap market for the identification of exogenous FX funding liquidity shocks, and their impact on FX market liquidity.

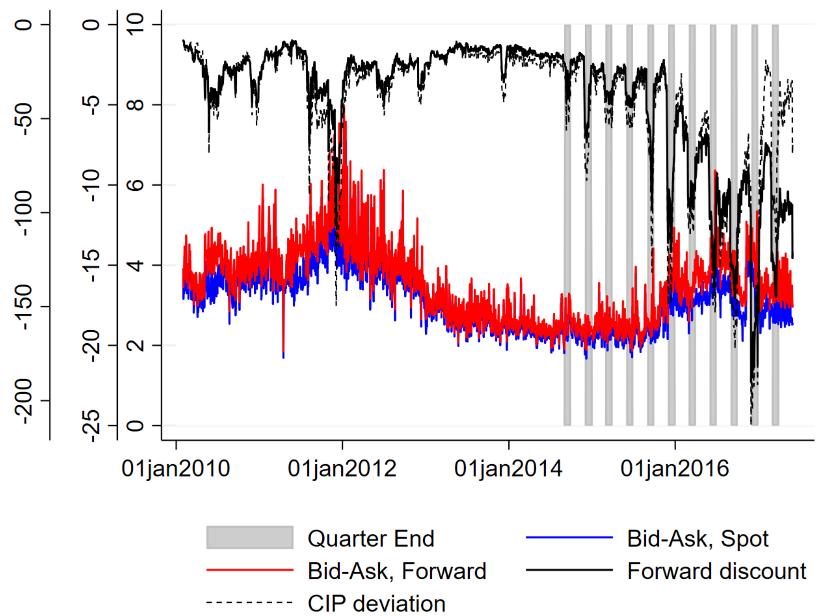
The results, based on hourly frequency for JPY/USD and EUR/USD, show that FX spot and swap market liquidity are intimately linked. The co-movement between market and funding liquidity has increased in recent years, and the instances of extreme liquidity droughts have also risen. Statistical tests also point towards contagion of adverse FX funding liquidity shocks to market liquidity in both FX swap and spot markets in the most extreme periods, particularly at year-ends.

Competition by FX dealers plays an important role in these liquidity dynamics. We find that the positive impact of dealer competition on FX market liquidity has decreased over time. The structural break in the relationship between FX swap and spot market liquidity conditions, and with dealer activity, appears related to the window dressing behaviour of large FX swap dealers, particularly desks of banks classified as G-SIBs. While large dealers still dominate market-making in spot markets at all times, and their quoting intensity is associated with improved liquidity dynamics, they have exhibited a tendency to pull back from posting price quotes in FX swaps around balance sheet reporting periods. Yet, as large dealers are displaced by smaller, and as such more expensive and less informed, dealers in the swap markets, spot market liquidity appears to also suffer because liquidity conditions in spot and swap markets are tightly linked.

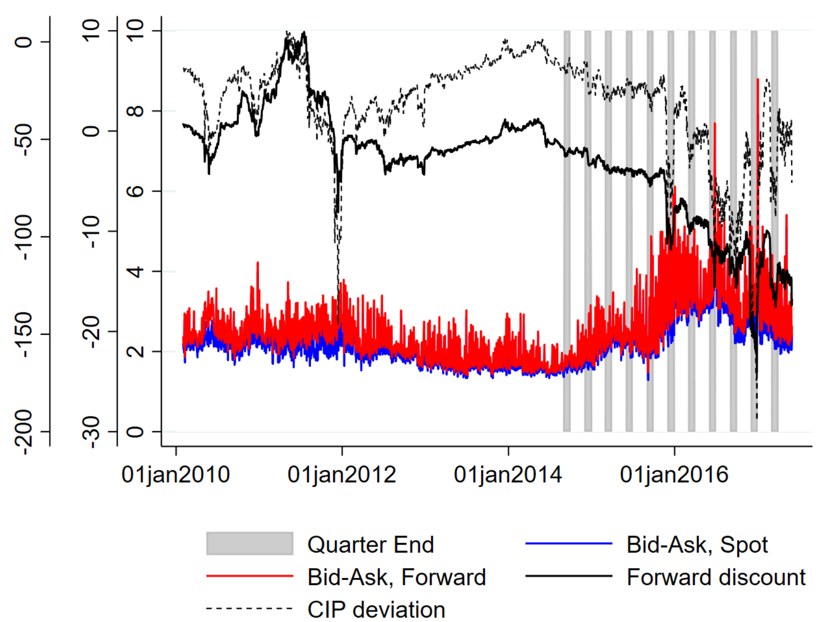
Hence, funding liquidity is now arguably a more important economic factor in understanding bid-ask spreads in spot FX. As such, window dressing by large dealers in FX swaps has been disruptive not only to swap market liquidity but also to liquidity in spot.

Figure 1: Bid-ask spreads in spot and forward rate, forward discount, and CIP deviations

(a) JPY/USD



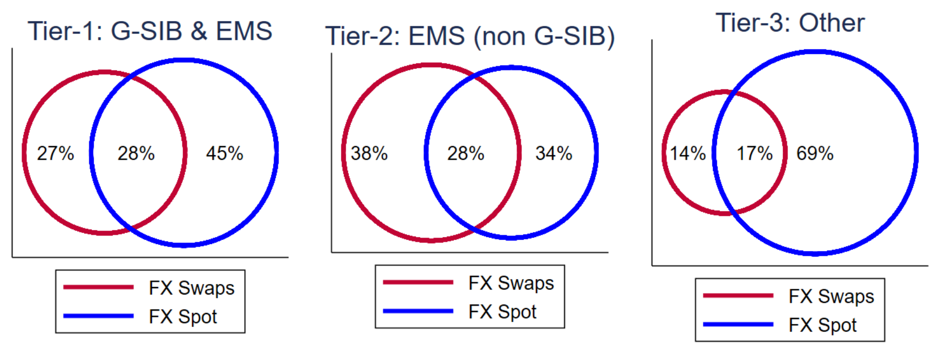
(b) EUR/USD



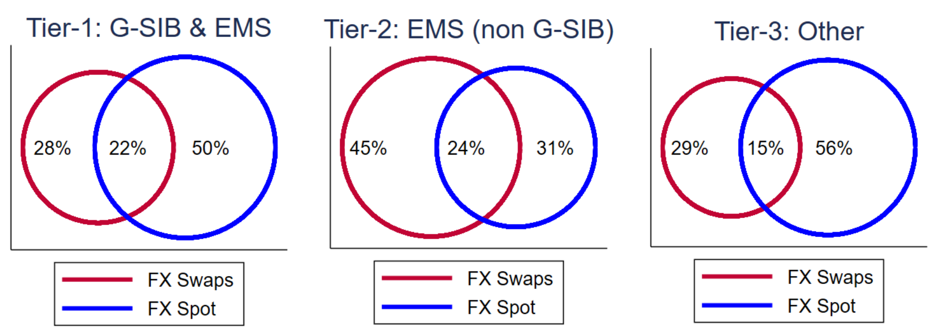
The outside y-axis shows OIS-based 1-month CIP deviations, in basis points; the middle y-axis shows 1-month forward discount, in basis points as a percentage of spot price; the inner y-axis shows bid-ask spreads, in basis points as a percentage of mid price.

Figure 2: Activity of small and large dealers by market segment in JPY/USD

(a) Average share of dealers active in spot and derivative markets: Feb 2010 - Jun 2014



(b) Average share of dealers active in spot and derivative markets: Jul 2014 - May 2017



(c) Percentage of G-SIB activity in spot and derivative markets

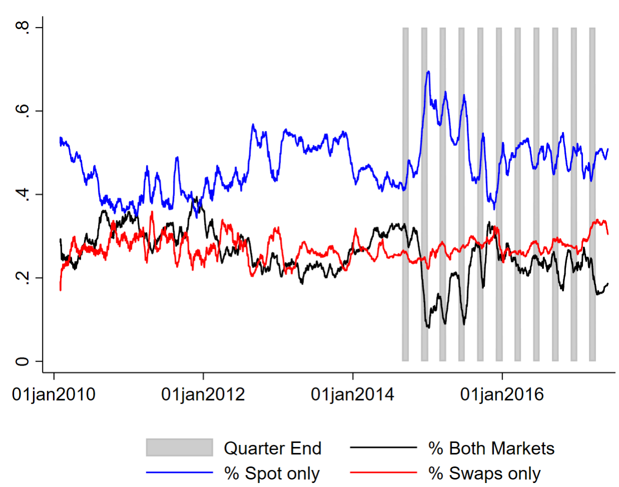
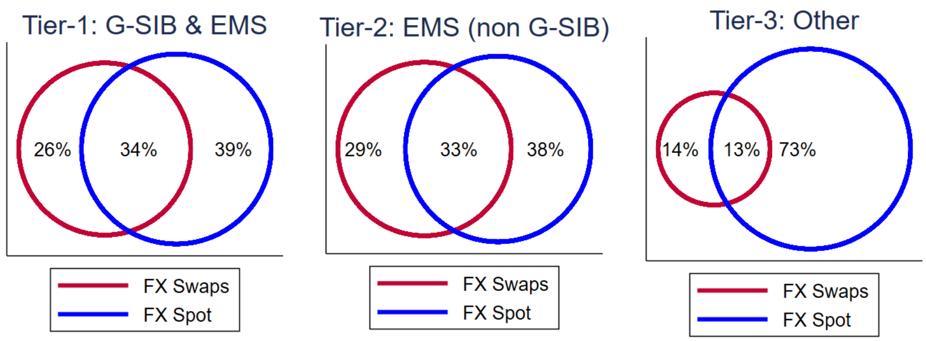


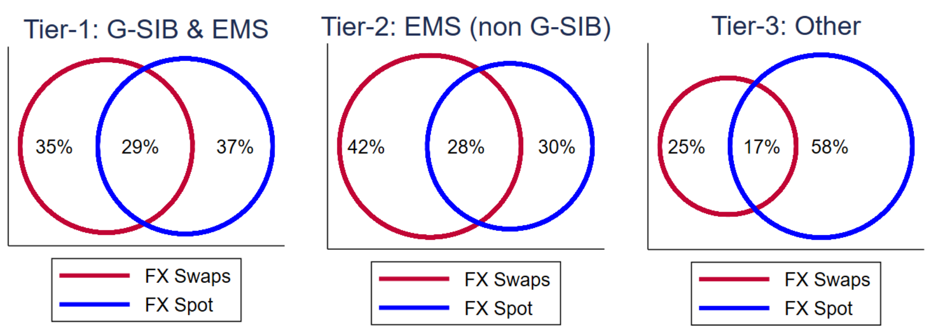
Figure 2a and 2b show the average share of dealers active in different market segments for the period February 2010 - June 2014 and July 2014 to May 2017, respectively. The red line refers to dealers that are only active in the swap market, the blue line refers to dealers active only in spot markets, and the intersection refers to dealers that are active in both markets. Figure 2c shows the 25-day moving average of G-SIB (tier-1) dealers that are only active in spot markets, only in swap markets, and in both markets.

Figure 3: Activity of small and large dealers by market segment in EUR/USD

(a) Average share of dealers active in spot and derivative markets: Feb 2010 - Jun 2014



(b) Average share of dealers active in spot and derivative markets: Jul 2014 - May 2017



(c) Percentage of G-SIB activity in spot and derivative markets

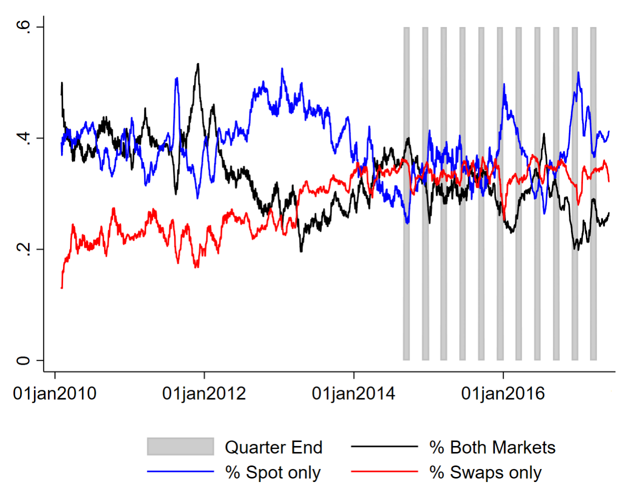
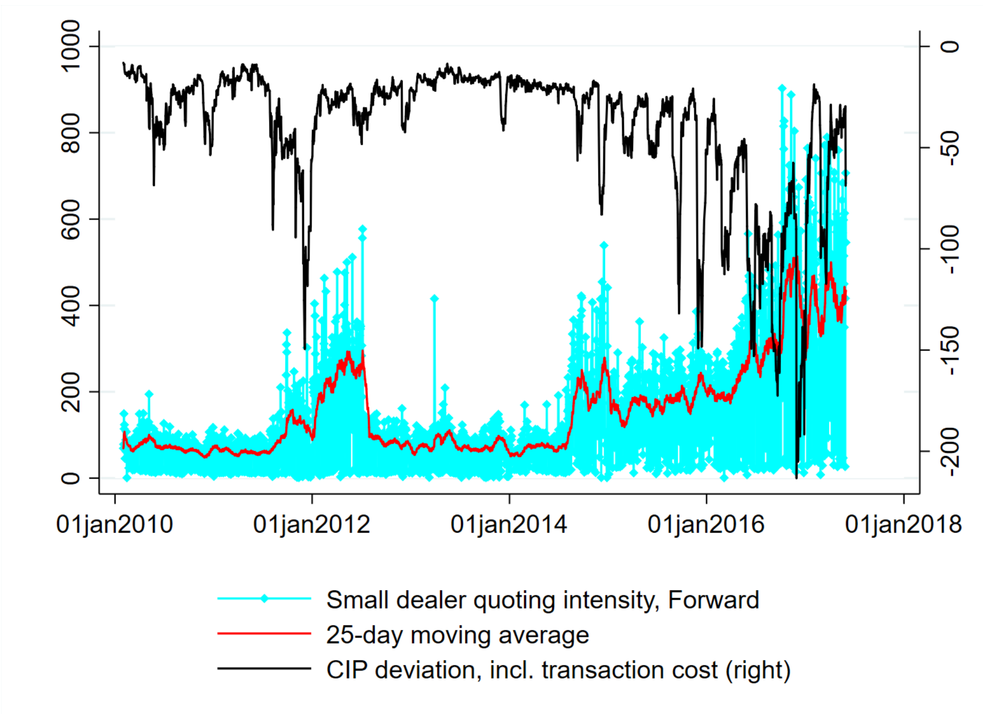


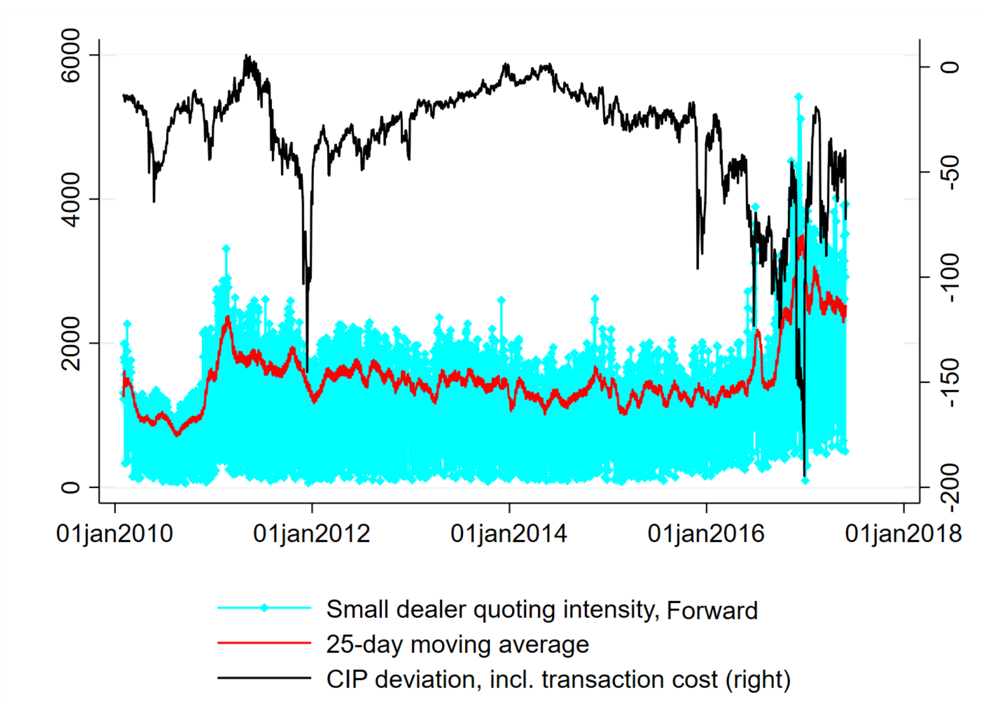
Figure 3a and 3b show the average share of dealers active in different market segments for the period February 2010 - June 2014 and July 2014 to May 2017, respectively. The red line refers to dealers that are only active in the swap market, the blue line refers to dealers active only in spot markets, and the intersection refers to dealers that are active in both markets. Figure 3c shows the 25-day moving average of G-SIB (tier-1) dealers that are only active in spot markets, only in swap markets, and in both markets.

Figure 4: Small dealer quoting intensity in FX swaps

(a) JPY/USD



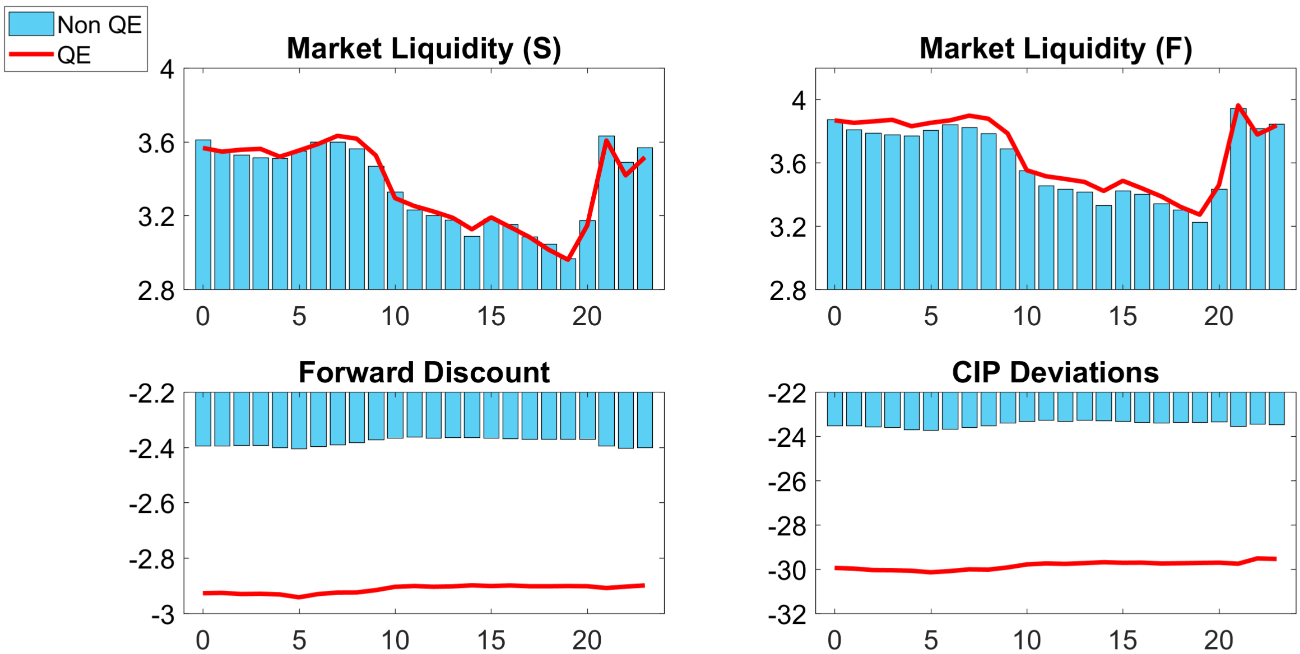
(b) EUR/USD



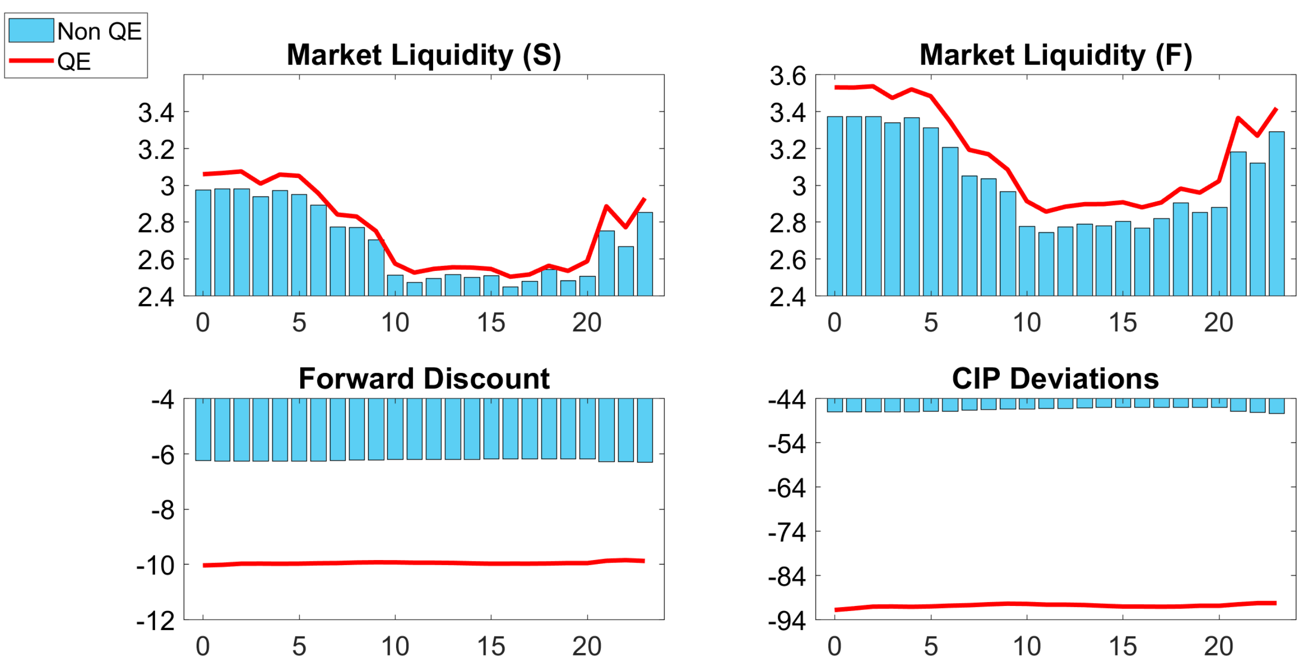
The figure shows daily dealer quoting intensity of small dealers in forwards, defined as the total number of quotes divided by the total number of active dealers in a given day t, $Q_t^{F,T3}/N_t^{F,T3}$; all measures based on the top of the order book.

Figure 5: Intraday liquidity dynamics: JPY/USD

(a) Feb 2010 - Jun 2014



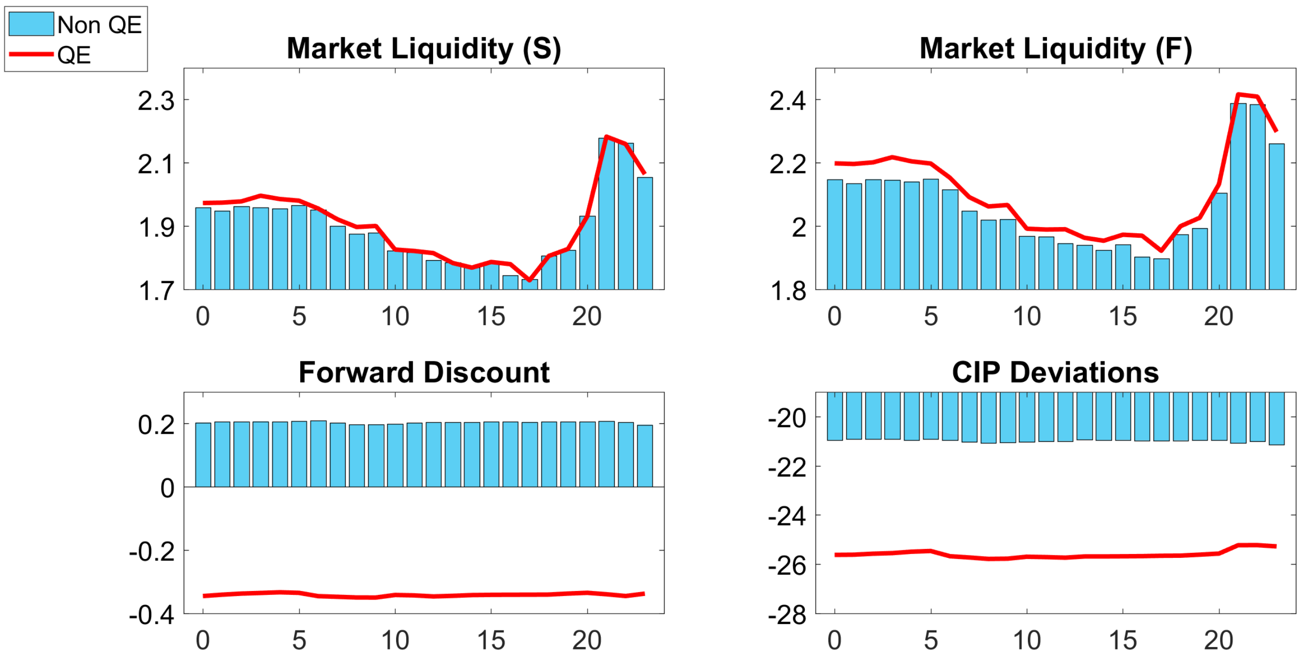
(b) Jul 2014 - May 2017



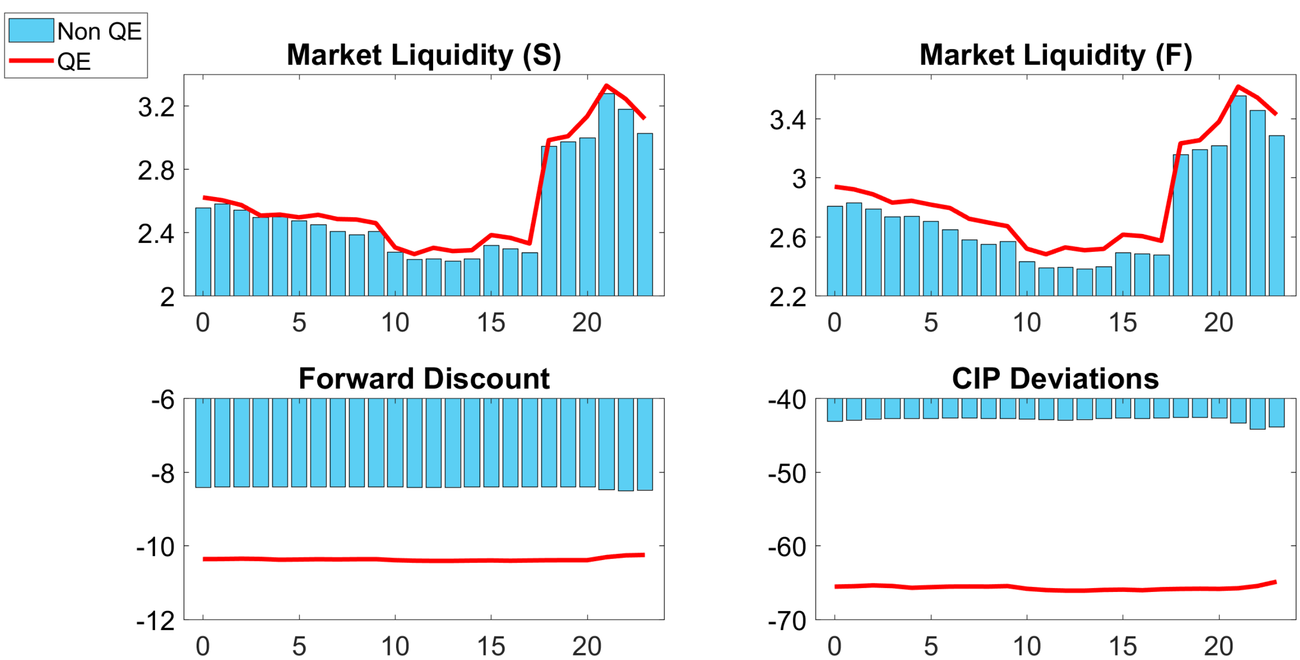
Figures (5a) and (5b) display average intraday levels of market liquidity in spot and swap markets, measured by spot rate bid-ask spread (S, top left), forward rate bid-ask spread (F, top right), funding liquidity ($Fdiscount$, bottom left) and CIP deviations ($CIPdev$, bottom right). Blue bars refer to non quarter-end months wand red lines refer quarter-end months; GMT time-stamps.

Figure 6: Intraday liquidity dynamics: EUR/USD

(a) Feb 2010 - Dec 2014

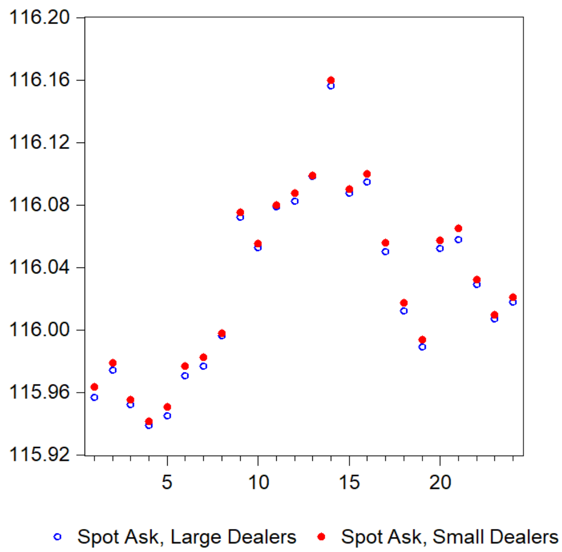


(b) Jan 2015 - May 2017



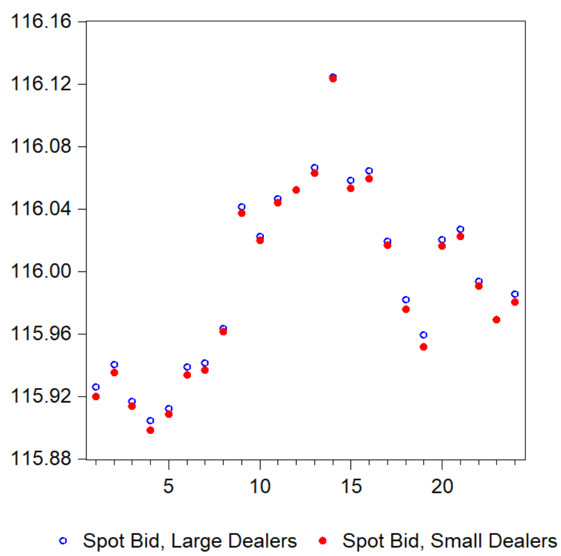
Figures (5a) and (5b) display average intraday levels of market liquidity in spot and swap markets, measured by spot rate bid-ask spread (S, top left), forward rate bid-ask spread (F, top right), funding liquidity ($Fdiscount$, bottom left) and CIP deviations ($CIPdev$, bottom right). Blue bars refer to non quarter-end months wand red lines refer quarter-end months; GMT time-stamps.

Figure 7: Median quote submissions in JPY/USD spot (December 2016)



(a) Actual spot ASK

(b) Hypothetical: Smaller Dealers Short USD spot

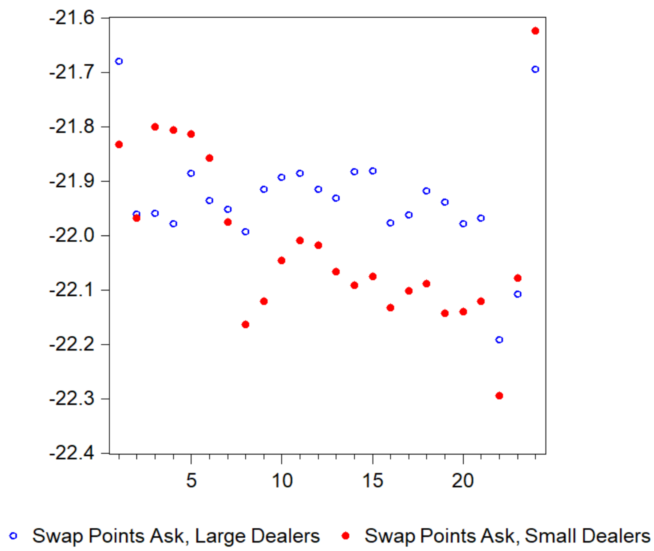


(c) Actual Spot BID

(d) Hypothetical: Smaller Dealers Long USD spot

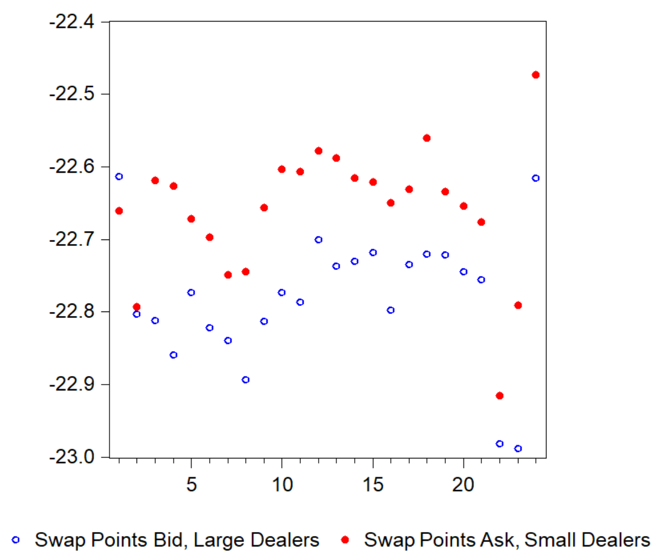
Spot quotes of smaller dealers (non G-SIB banks) compared to spot quotes of large dealers (G-SIB banks). Left-hand side figures indicate that non G-SIB bank dealers did not act as market-makers in spot in December 2016. *Top-left:* Actual spot ask; *Top-right:* Hypothetical: Smaller Dealers Short USD spot scenario (ASK: SELL USD @ 116.160). *Bottom-left:* Actual spot bid; *Bottom-right:* Hypothetical: Smaller Dealers Long USD spot scenario (BID: BUY USD @ 116.124). GMT time-stamps.

Figure 8: Median quote submissions in JPY/USD forward points (December 2016)

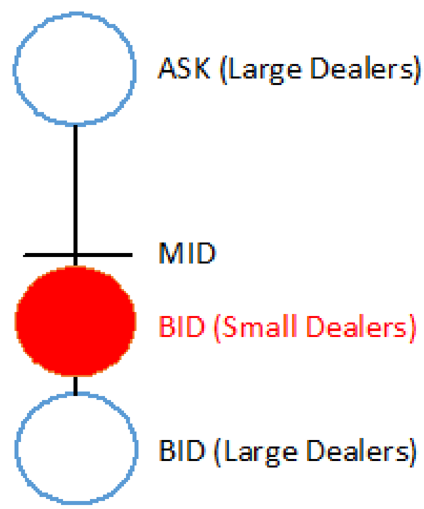


(a) Actual forward points ASK

(b) Hypothetical: Smaller Dealers Short USD forward



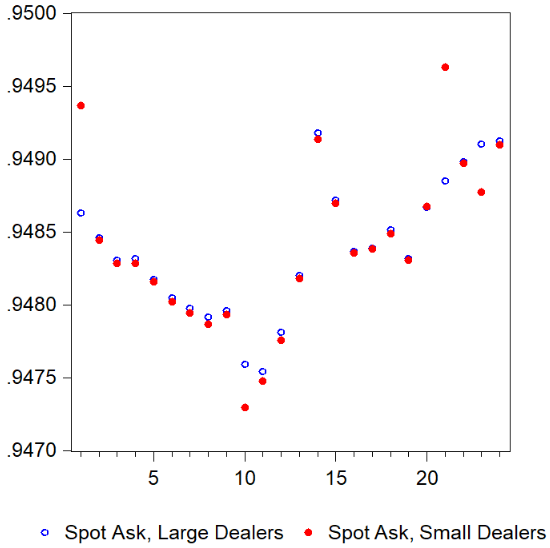
(c) Actual forward points BID



(d) Hypothetical: Smaller Dealers Long USD forward

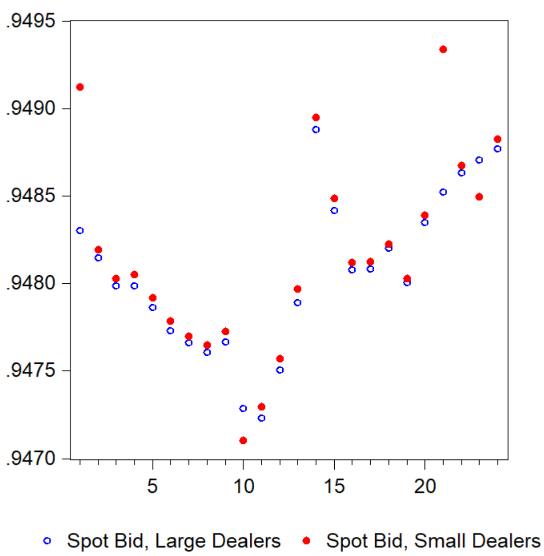
Forward quotes of smaller dealers (non G-SIB banks) compared to forward quotes of large dealers (G-SIB banks). Indicates that non G-SIB bank dealers displaced G-SIB bank dealers as market-makers in FX swap markets in December 2016. *Top-left:* Actual forward points ask; *Top-right:* Hypothetical: Smaller Dealers Short USD forward scenario (ASK: SELL USD @ 116.160 - 0.221). *Bottom-left:* Actual forward points bid; *Bottom-right:* Hypothetical: Smaller Dealers Long USD forward scenario (BID: BUY USD @ 116.124 - 0.226). GMT time-stamps.

Figure 9: Median quote submissions in EUR/USD spot (December 2016)

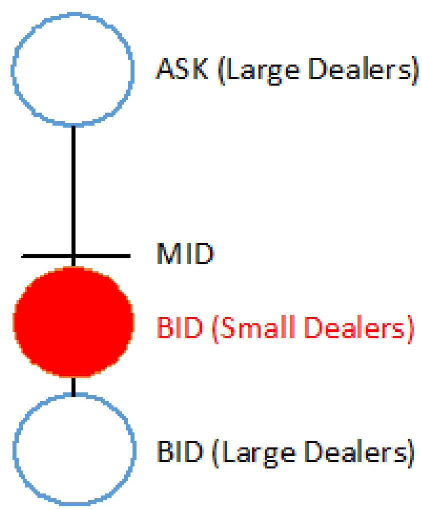


(a) Actual Spot ASK

(b) Hypothetical: Smaller Dealers Short USD spot



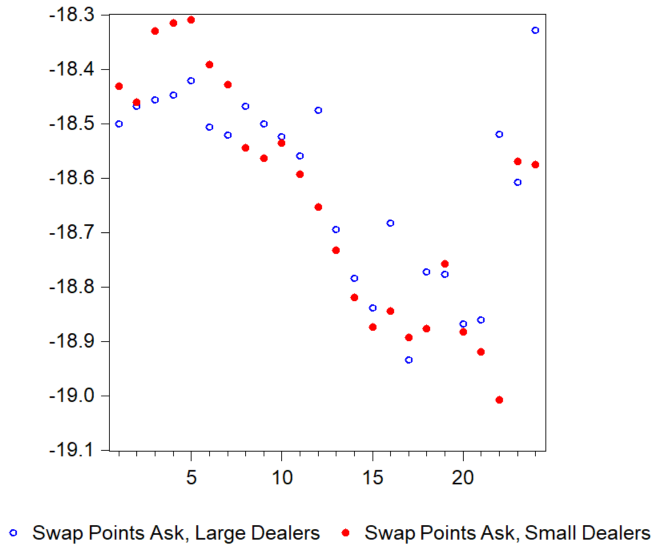
(c) Actual Spot BID



(d) Hypothetical: Smaller Dealers Long USD spot

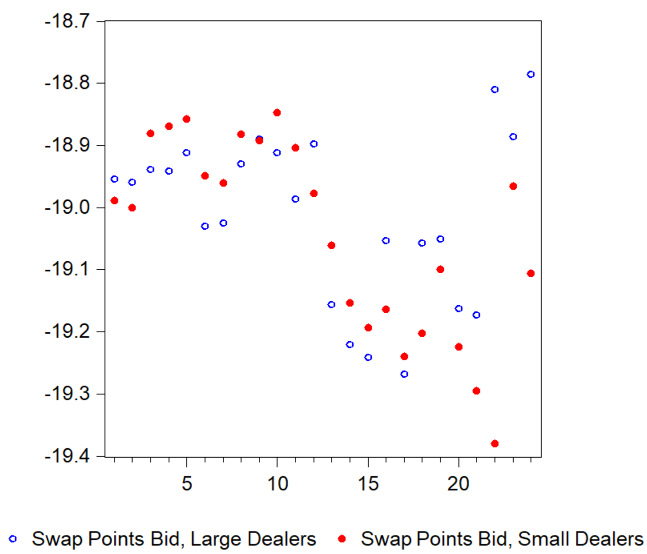
Spot quotes of small dealers (non G-SIB banks) compared to spot quotes of large dealers (G-SIB banks). Indicates that both types of dealers acted as market-makers in spot in December 2016. *Top-left:* Actual spot ask; *Top-right:* Hypothetical: Smaller Dealers Short USD spot scenario (ASK: SELL USD @ 0.9491). *Bottom-left:* Actual spot bid; *Bottom-right:* Hypothetical: Smaller Dealers Long USD spot scenario (BID: BUY USD @ 0.9489). GMT time-stamps.

Figure 10: Median quote submissions in EUR/USD forward points (December 2016)

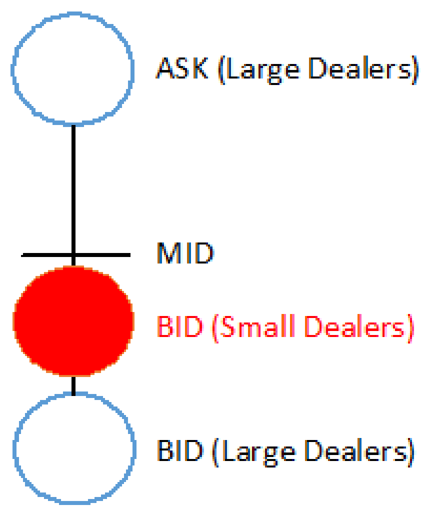


(a) Actual Forward Points ASK

(b) Hypothetical: Smaller Dealers Short USD spot



(c) Actual Forward Points BID



(d) Hypothetical: Smaller Dealers Long USD spot

Forward quotes of smaller dealers (non G-SIB banks) compared to forward quotes of large dealers (G-SIB banks). Indicates that non G-SIB bank dealers displaced G-SIB bank dealers market-makers in FX swap markets in December 2016. *Top-left:* Actual forward points ask; *Top-right:* Hypothetical: Smaller Dealers Short USD forward scenario (ASK: SELL USD @ 0.9491 - 0.00188). *Bottom-left:* Actual forward points bid; *Bottom-right:* Hypothetical: Smaller Dealers Long USD forward scenario (BID: BUY USD @ 0.9489 - 0.00192). GMT time-stamps.

Tables

Table 1: **Example: two-second window for JPY/USD spot on 5 May 2017**

INSTRUMENT	DATE	TIME	DEALER	BID	ASK
'JPY='	'5-May-17'	'14:47:29.348944'	'BKofNYMellon NYC'	112.620003	112.6399994
'JPY='	'5-May-17'	'14:47:29.381124'	'BARCLAYS LON'	112.610001	112.6399994
'JPY='	'5-May-17'	'14:47:29.640943'	'SOC GENERALE PAR'	112.599998	112.6399994
'JPY='	'5-May-17'	'14:47:30.065053'	'KASPI BANK ALA'	112.620003	112.6399994
'JPY='	'5-May-17'	'14:47:31.277082'	'SEB STO'	112.599998	112.6500015
'JPY='	'5-May-17'	'14:47:32.260157'	'RBS LON'	112.599998	112.6399994
'JPY='	'5-May-17'	'14:47:32.301189'	'RABOBANKGFM LON'	112.589996	112.6399994

Source: Thomson Reuters Tick History (TRTH) data, available via Reuters Datascope.

Table 2: **Benchmark hourly measures and their daily transformations**

Measure (hourly)	Definition	Daily
$Spread_h^S = \frac{S_h^{ask} - S_h^{bid}}{S_h^{mid}}$	market liquidity, S; $S_h^{ask} \equiv 1/h_i \sum_{i=1}^{h_i} S_i^{ask}$	mean
$Spread_h^F = \frac{F_h^{ask} - F_h^{bid}}{F_h^{mid}}$	market liquidity, F; $F_h^{bid} = S_h^{bid} + FP_h^{bid} \times 10^{-2}$	mean
$Fdiscount_h = \frac{F_h^{mid} - S_h^{mid}}{S_h^{mid}}$	FX funding liquidity	mean
$CIPdev_h = (1 + \frac{r_h^{mid}}{100}) - (1 + \frac{r_h^{mid*}}{100}) \times \left(\frac{F_h^{mid}}{S_h^{mid}}\right)^{360/30}$		mean
$Q_h^P = \#Quotes_h^P$	dealer competition, *intensive margin*	sum
$N_h^P = \#Dealers_h^P$	dealer competition, *extensive margin*	sum
Q_h^P / N_h^P	dealer competition, *quoting intensity*	sum
$Disp_h^P = \sqrt{\sum_{i=1}^{h_i} \frac{q_i}{Q_h} \left(\frac{P_i - \bar{P}_h}{\bar{P}_T}\right)}$	weighted quote dispersion; $P \equiv S, F$	mean
$Vol_h^P = \frac{\sum (r_P - \bar{r}_{P,h})^2}{n-1}$	hourly variance; $r_P = ln(P_h) - ln(P_{h-1})$; $P \equiv S, F$	-

Table 3: **Summary Statistics: Liquidity dynamics (price-based) at quarter end**

This table reports the average (top panel) and standard deviation (bottom panel) of spot market and swap market liquidity, measured by the bid-ask spread of the spot ($Spread^S$) and forward rate ($Spread^F$), and funding liquidity, measured by the forward discount ($Fdiscount$) and CIP deviations ($CIPdev$) for JPY/USD and EUR/USD for two different sub-sample periods. The column QE refers to the average (top) or standard deviation (bottom) of each liquidity measure during quarter-end months; QE-NQE refers to the difference of averages (or standard deviations) between quarter-end months and non-quarter end months (NQE); pval reports the p-value of a one-sided t-test with the null hypothesis that liquidity measures are larger (in absolute magnitude) in quarter end-month than in the remaining months of each sub-sample. In the bottom panel, numbers in parentheses denote the p-value of a variance ratio test.

	JPY/USD						EUR/USD					
	02/2010 - 06/2014			07/2014 - 05/2017			02/2010 - 12/2015			01/2015 - 05/2017		
Average	QE	QE-NQE	pval	QE	QE-NQE	pval	QE	QE-NQE	pval	QE	QE-NQE	pval
$Fdiscount$	-2.91	-0.52	(0.00)	-9.94	-3.68	(0.00)	-0.37	-0.59	(0.00)	-10.38	-1.96	(0.00)
$CIPDev$	-29.83	-6.25	(0.00)	-91.86	-44.93	(0.00)	-25.36	-4.37	(0.00)	-65.96	-22.87	(0.00)
$Spread_S$	3.41	-0.03	(0.70)	2.79	0.07	(0.05)	1.97	0.00	(0.45)	2.74	0.02	(0.38)
$Spread_F$	3.72	0.02	(0.35)	3.21	0.12	(0.00)	2.18	0.04	(0.12)	3.02	0.07	(0.15)

	JPY/USD						EUR/USD					
	02/2010 - 06/2014			07/2014 - 05/2017			02/2010 - 12/2015			01/2015 - 05/2017		
Std. Dev.	QE	QE-NQE	pval	QE	QE-NQE	pval	QE	QE-NQE	pval	QE	QE-NQE	pval
$Fdiscount$	1.76	0.68	(0.00)	5.23	1.34	(0.00)	2.89	-0.08	(0.76)	5.37	1.18	(0.00)
$CIPDev$	21.41	8.59	(0.00)	44.70	15.72	(0.00)	0.39	-6.84	(0.11)	0.69	-11.36	(0.68)
$Spread_S$	0.78	-0.03	(0.78)	0.58	0.08	(0.00)	0.47	0.06	(0.09)	0.84	0.09	(0.07)
$Spread_F$	0.90	-0.04	(0.81)	0.77	0.11	(0.00)	21.86	15.29	(0.00)	39.21	26.24	(0.00)

Notes: Results are based on daily data. The sample period is February 2010 to May 2017.

Table 4: **G-SIB classification vs 2016 Euromoney FX Survey rankings**

This table provides a comparison of banks that are categorized as "large dealers" according to the "G-SIB" classification and according to the "Euromoney FX Survey (EMS), respectively.

2016 G-SIB Classification	2016 Euromoney FX Survey (EMS)
Agricultural Bank of China	Alfa Bank
Bank of America Merrill Lynch	ANZ Banking Group
Bank of China	Bank of Montreal
Bank of New York Mellon	BBVA
Barclays	CIBC
BNP Paribas	Citadel Securities
China Construction Bank	Commerzbank
Citigroup	Commonwealth Bank of Australia
Credit Suisse	Danske Bank
Deutsche Bank	Den norske Bank
Goldman Sachs	Jump Trading
Groupe BPCE	Lloyds Banking Group
Groupe Credit Agricole	Lucid Markets
HSBC	National Australia Bank
ICBC	Natixis
ING Bank	Nomura
JP Morgan Chase	Rabobank
Mitsubishi UFJ FG	RBC Capital Markets
(Mizuho FG)	Saxo Bank
Morgan Stanley	Scotiabank
Nordea	SEB
Royal Bank of Scotland	TD Securities
Santander	Tower Research Capital
Societe Generale	Virtu Financial
Standard Chartered	Westpac Banking
State Street	XTX Markets
Sumitomo Mitsui FG	Zurich Cantonalbank
UBS	
Unicredit Group	
Wells Fargo	

Notes: Banks that are classified as large dealers according to G-SIB classification are also considered as large dealers according to the *Euromoney* FX Survey (EMS). Banks marked in grey are not available in our database and banks that are only part of the G-SIB classification but not listed in EMS are marked with parenthesis. We derive banks' name from abbreviations in the TRTH database. If abbreviations could not be matched with a bank, then the bank is classified as "other".

Table 5: **Intraday conditional co-movement of liquidity measures**

This table reports the average co-movement between spot market and swap market liquidity, measured by the bid-ask spread of spot rate ($Spread^S$) and forward rate ($Spread^F$), and funding liquidity, measured by forward discount ($Fdiscount$) and CIP deviations ($CIPdev$) for JPY/USD and EUR/USD. Funding liquidity is measured either by forward points or by CIP deviations. ρ refers to the average correlation coefficients across trading hours and PCA refers to the proportion of variation explained by the first principal component.

	JPY/USD			
	02/2010 00:00:00 - 06/2014 23:00:00		07/2014 00:00:00 - 05/2017 23:00:00	
	$Spread^S$	$Spread^F$	$Spread^S$	$Spread^F$
$\rho_{Fdiscount}$	-0.44	-0.50	-0.51	-0.63
ρ_{CIPdev}	-0.41	-0.46	-0.47	-0.57
$PCA_{Fdiscount}$	72.22	74.80	75.62	81.66
PCA_{CIPdev}	70.52	73.16	73.73	78.26
	EUR/USD			
	02/2010 00:00:00 - 12/2014 23:00:00		01/2015 00:00:00 - 05/2017 23:00:00	
	$Spread^S$	$Spread^F$	$Spread^S$	$Spread^F$
$\rho_{Fdiscount}$	0.24	0.27	-0.28	-0.40
ρ_{CIPdev}	-0.34	-0.46	-0.32	-0.43
$PCA_{Fdiscount}$	62.00	63.54	64.16	69.81
PCA_{CIPdev}	67.15	72.85	65.89	71.74

Notes: Hourly sample; GMT time-stamps.

Table 6: **Intraday conditional co-movement of liquidity measures**

This table is based on estimation results of the long-run equation of a conditional error correction model (ECM) derived from an autoregressive distributed lag (ARDL) model specification. Specifically, for the two sub-sample periods and for spot and swap market liquidity, measured by spot rate $Spread^S$ and forward rate $Spread^F$ bid ask spreads, $P = S, F$, we estimate:

$$\Delta Spread_h^P = \alpha + \sum_{i=1}^{23} \delta_i H_i + \theta_0 Spread_{h-1}^P + \boldsymbol{\theta x_{h-1}} + \sum_{i=1}^{p-1} \boldsymbol{\gamma_i \Delta z_{h-i}^P} + \boldsymbol{\beta \Delta x_h^P} + u_t$$

where a vector $\mathbf{z_h^S} = (Spread_h^P, |Fdiscount|_t, Q_{j,h}^P/N_{j,h}^P, Vol_h^P) = (Spread_h^P, \mathbf{x_h^P})'$ and $j = T1, (T2, T3)$, denote quoting activity of G-SIB and non-G-SIB dealers, respectively. The coefficients are scaled by the standard deviation of the explanatory variables in each sub-sample.

	JPY/USD					
	02/2010 00:00:00 - 06/2014 23:00:00			07/2014 00:00:00 - 05/2017 23:00:00		
Variable	$Spread^F$	$Spread^S$	$Spread^S$	$Spread^F$	$Spread^S$	$Spread^S$
$\|Fdiscount\|$	0.380***	0.213***	0.193***	0.416***	0.301***	0.649***
Q_{T1}^F/N_{T1}^F	-0.287***			-0.100***		
$Q_{T2,T3}^F/N_{T2,T3}^F$	0.350***		0.202***	0.180***		0.311***
Vol^F	0.183***			0.427***		
Q_{T1}^S/N_{T1}^S		-0.180***	-0.148***		-0.064***	-0.205***
$Q_{T2,T3}^S/N_{T2,T3}^S$		0.124***			0.039	
Vol^S		0.143***	0.154***		0.382***	0.271***

	EUR/USD					
	02/2010 00:00:00 - 12/2014 23:00:00			01/2015 00:00:00 - 05/2017 23:00:00		
Variable	$Spread^F$	$Spread^S$	$Spread^S$	$Spread^F$	$Spread^S$	$Spread^S$
$\|Fdiscount\|$	0.069***	0.085***	0.076***	0.265***	0.051	0.084***
Q_{T1}^F/N_{T1}^F	-0.147***			0.011		
$Q_{T2,T3}^F/N_{T2,T3}^F$	0.000		-0.026***	0.080*		0.043*
Vol^F	0.407***			0.295***		
Q_{T1}^S/N_{T1}^S		-0.161***	-0.179***		-0.374***	-0.359***
$Q_{T2,T3}^S/N_{T2,T3}^S$		-0.025*			0.062	
Vol^S		0.303***	0.356***		0.158***	0.156***

Hourly sample; GMT time-stamps. ARDL lags chosen based on the Schwarz (Bayes) criterion (SC). P-values assigned based on HAC robust standard errors: *** p<0.01, ** p<0.05, * p<0.1.

Table 7: **Intraday conditional co-movement of liquidity measures (By Bank Tiers)**

This table is based on estimation results of the long-run equation of a conditional error correction model (ECM) derived from an autoregressive distributed lag (ARDL) model specification. Specifically, for the two sub-sample periods and for spot and swap market liquidity, measured by spot rate $Spread^S$ and forward rate $Spread^F$ bid ask spreads, $P = S, F$, we estimate:

$$\Delta Spread_h^P = \alpha + \sum_{i=1}^{23} \delta_i H_i + \theta_0 Spread_{h-1}^P + \boldsymbol{\theta x_{h-1}} + \sum_{i=1}^{p-1} \boldsymbol{\gamma_i \Delta z_{h-i}^P} + \boldsymbol{\beta \Delta x_h^P} + u_t$$

where a vector $\mathbf{z_h^S} = (Spread_h^P, |Fdiscount|_t, Q_{j,h}^P/N_{j,h}^P, Vol_h^P) = (Spread_h^P, \mathbf{x_h^P})'$ and $j = T1, T2, T3$, denotes Tier-1, Tier-2, and Tier-3 dealer quoting intensity, respectively. The coefficients are scaled by the standard deviation of the explanatory variables in each sub-sample.

	JPY/USD					
	02/2010 00:00:00 - 06/2014 23:00:00			07/2014 00:00:00 - 05/2017 23:00:00		
Variable	$Spread^F$	$Spread^S$	$Spread^S$	$Spread^F$	$Spread^S$	$Spread^S$
$\|Fdiscount\|$	0.372***	0.196***	0.198***	0.265***	0.322***	0.194***
Q_{T1}^F/N_{T1}^F	-0.254***			-0.102***		
Q_{T2}^F/N_{T2}^F	0.372***		0.181***	-0.032		0.061**
Q_{T3}^F/N_{T3}^F	0.419***		0.171***	0.662***		0.405***
Vol^F	0.156***			0.393***		
Q_{T1}^S/N_{T1}^S		-0.471***	-0.481***		-0.241***	-0.164***
Q_{T2}^S/N_{T2}^S		-0.143***			0.105***	
Q_{T3}^S/N_{T3}^S		0.122*			-0.035	
Vol^S		0.139***	0.144***		0.353***	0.370***
	EUR/USD					
	02/2010 00:00:00 - 12/2014 23:00:00			01/2015 00:00:00 - 05/2017 23:00:00		
Variable	$Spread^F$	$Spread^S$	$Spread^S$	$Spread^F$	$Spread^S$	$Spread^S$
$\|Fdiscount\|$	0.072***	0.074***	0.079***	0.277***	0.145***	0.097***
Q_{T1}^F/N_{T1}^F	-0.154***			0.012		
Q_{T2}^F/N_{T2}^F	0.088***		-0.014	-0.145		-0.208
Q_{T3}^F/N_{T3}^F	-0.064*		-0.029**	0.022**		0.015*
Vol^F	0.405***			0.294***		
Q_{T1}^S/N_{T1}^S		-0.048***	-0.100***		-0.228***	-0.292***
Q_{T2}^S/N_{T2}^S		-0.052***			0.211***	
Q_{T3}^S/N_{T3}^S		0.013			-0.265***	
Vol^S		0.266***	0.357***		0.111***	0.155

Hourly sample; GMT time-stamps. ARDL lags chosen based on the Schwarz (Bayes) criterion (SC). P-values assigned based on HAC robust standard errors: *** p<0.01, ** p<0.05, * p<0.1.

Table 8: **Forward rate bid-ask spreads and forward discounts quoted by large vs small dealers**

	JPY/USD		EUR/USD	
Dealer category:	$Spread^F$	$Fdiscount$	$Spread^F$	$Fdiscount$
Tier-1 & Tier-2 dealers	3.322bp	-4.471bp	2.218bp	-2.990bp
Tier-3 dealers	3.648bp	-4.579bp	2.247bp	-2.993bp

Notes: Average median hourly quotes. Tier-1 dealers belong to banks classified as G-SIBs and appearing in the Euromoney FX Survey rankings, Tier-2 dealers belong to non G-SIB banks appearing in the Euromoney FX Survey rankings, and Tier-3 are small dealers not appearing in the Euromoney rankings. 2/01/2010 00:00 to 5/31/2017 23:00 sample period.

Table 9: **Forward quote dispersion (By Bank Tiers)**

This table reports coefficients from the long-run equation of a conditional error correction model (ECM) derived from an autoregressive distributed lag (ARDL) model specification. In the top part of the table coefficients are scaled by the sample standard deviation, while raw regression estimates are displayed in the bottom part. Specifically, for the second sub-sample period (JPY/USD: July 2014 to May 2017; EUR/USD: January 2015 to May 2017) we estimate:

$$\Delta Disp_h^F = \alpha + \sum_{i=1}^{23} \delta_i H_i + \theta_0 Disp_{h-1}^F + \boldsymbol{\theta x_{t-1}} + \sum_{i=1}^{p-1} \boldsymbol{\gamma_i \Delta z_{h-i}^F} + \boldsymbol{\beta \Delta x_h^F} + u_t$$

where a vector $\mathbf{z_h^F} = (Disp_h^F, Q_{j,h}^F/N_{j,h}^F, Vol_h^F) = (Disp_h^F, \mathbf{x_h^F})'$ and $j = T1, T2, T3$, denotes Tier-1, Tier-2, and Tier-3 dealer quoting intensity, respectively. F-statistics based on the results of the bound testing procedure for long-run relationship, robust to variables being in between I(0) and I(1). Constant and coefficients on short-run effects omitted for brevity.

	JPY/USD	EUR/USD
Q_{T1}^F/N_{T1}^F	-0.144 ***	-0.104***
Q_{T2}^F/N_{T2}^F	0.073	-0.77**
Q_{T3}^F/N_{T3}^F	0.333***	0.014
Vol^F	3.410***	3.239***
Q_{T1}^F/N_{T1}^F	-0.003***	-0.002***
	(0.00)	(0.00)
Q_{T2}^F/N_{T2}^F	0.002	-0.005**
	(0.00)	(0.00)
Q_{T3}^F/N_{T3}^F	0.012***	0.000
	(0.00)	(0.00)
Vol^F	18.314***	41.578***
	(4.20)	(2.78)
θ	-0.32***	-0.61***
$F - Stat$	97.08	518.69
Hour dummies	yes	yes
Adj. R^2	0.60	0.68
Obs	17050	14247

Hourly sample: 1/06/2014 00:00 to 5/31/2017 23:00; GMT time-stamps. *** p<0.01, ** p<0.05, * p<0.1.

Table 10: **Quarter-end contagion from FX funding to market liquidity in spot, JPY/USD**

The table shows tests for contagion from FX funding liquidity to FX market liquidity in spot and swap markets. We follow Forbes and Rigobon (2002), and conduct a t-test of whether the correlations between $\Delta Fdiscount$ and $\Delta Spread^P$ is significantly more negative at quarter-ends, where $P = S, F$. The correlation coefficients are estimated using a 200-hour rolling window bivariate VAR, and adjusted for heteroskedastic levels of volatility, thus allowing to make statements about contagions rather than a simple co-movement.

To spot market:	$\Delta Fdiscount \rightarrow \Delta Spread^S$					
	Q-end month		Prior 2 months		Contagion	
QEs:	ρ_{QE}	σ_{QE}	ρ_{NQE}	σ_{NQE}	t-stat	Reject H_0
09/14	0.004	0.009	-0.004	0.006	-14.13	
12/14	0.015	0.020	-0.019	0.015	-25.18	
03/15	0.075	0.022	0.018	0.046	-27.35	
06/15	-0.023	0.051	0.009	0.064	8.94	Yes
09/15	0.008	0.008	-0.011	0.020	-22.89	
12/15	0.020	0.057	0.013	0.066	-1.61	
03/16	0.067	0.042	-0.009	0.100	-17.41	
06/16	-0.078	0.062	-0.012	0.021	18.66	Yes
09/16	-0.007	0.053	-0.093	0.094	-19.36	
12/16	-0.044	0.046	0.014	0.058	17.36	Yes
03/17	0.024	0.081	-0.053	0.072	-15.36	
Avg. contagion	**-0.048**	**0.053**			**14.987**	**3/11 QEs**

To forward market:	$\Delta Fdiscount \rightarrow \Delta Spread^F$					
	Q-end month		Prior 2 months		Contagion	
QEs:	ρ_{QE}	σ_{QE}	ρ_{NQE}	σ_{NQE}	t-stat	Reject H_0
09/14	0.002	0.008	-0.005	0.007	-13.44	
12/14	0.012	0.019	-0.021	0.015	-25.1	
03/15	0.078	0.023	0.023	0.047	-25.66	
06/15	-0.028	0.052	0.011	0.061	10.71	Yes
09/15	0.016	0.014	-0.013	0.02	-26.63	
12/15	-0.011	0.025	0.03	0.067	14.61	Yes
03/16	0.053	0.057	-0.023	0.106	-15.23	
06/16	-0.078	0.061	-0.008	0.022	20.17	Yes
09/16	-0.008	0.076	-0.071	0.084	-12	
12/16	-0.06	0.05	-0.009	0.071	13.37	Yes
03/17	0.021	0.077	-0.059	0.066	-16.95	
Avg. contagion	**-0.044**	**0.047**			**14.715**	**4/11 QEs**

Hourly samples. Bivariate VAR, $\Delta y_h = \phi(L)\Delta y_{h-1} + \eta_h$ with $\Delta y_h = \left[\Delta Fdiscount_h, \Delta Spread_h^P\right]$, where $P = F, S$ and all endogenous variables de-seasonalised of hourly effects.

Table 11: **Quarter-end contagion from FX funding to market liquidity in spot, EUR/USD**

The table shows tests for contagion from FX funding liquidity to FX market liquidity in spot and swap markets. We follow Forbes and Rigobon (2002), and conduct a t-test of whether the correlations between $\Delta Fdiscount$ and $\Delta Spread^P$ is significantly more negative at quarter-ends, where $P = S, F$. The correlation coefficients are estimated using a 200-hour rolling window bivariate VAR, and adjusted for heteroskedastic levels of volatility, thus allowing to make statements about contagions rather than a simple co-movement.

To spot market:	$\Delta Fdiscount \rightarrow \Delta Spread^S$					
	Q-end month		Prior 2 months		Contagion	
QEs:	ρ_{QE}	σ_{QE}	ρ_{NQE}	σ_{NQE}	t-stat	Reject H_0
03/15	0.029	0.052	-0.055	0.09	-19.33	
06/15	0.086	0.089	0.082	0.126	-0.65	
09/15	0.041	0.027	-0.012	0.048	-22.99	
12/15	-0.027	0.036	-0.006	0.069	6.44	Yes
03/16	0.123	0.062	0.053	0.049	-17.68	
06/16	0.011	0.007	-0.002	0.025	-13.6	
09/16	0.039	0.03	-0.082	0.064	-42.74	
12/16	-0.106	0.081	0.039	0.047	29.35	Yes
03/17	-0.031	0.096	-0.113	0.161	-10.77	
Avg. contagion	**-0.067**	**0.059**			**17.90**	**2/9 QEs**

To forward market:	$\Delta Fdiscount \rightarrow \Delta Spread^F$					
	Q-end month		Prior 2 months		Contagion	
QEs:	ρ_{QE}	σ_{QE}	ρ_{NQE}	σ_{NQE}	t-stat	Reject H_0
03/15	0.031	0.049	-0.075	0.1	-23.54	
06/15	0.077	0.096	0.005	0.102	-11.08	
09/15	0.04	0.028	-0.04	0.058	-31.32	
12/15	-0.026	0.034	-0.025	0.066	0.32	Yes
03/16	0.152	0.067	0.052	0.046	-23.83	
06/16	-0.01	0.029	-0.003	0.027	3.58	Yes
09/16	0.053	0.031	-0.078	0.058	-48.82	
12/16	-0.105	0.08	0.025	0.047	26.43	Yes
03/17	-0.017	0.098	-0.113	0.171	-12.04	
Avg. contagion	**-0.047**	**0.048**			**10.11**	**3/9 QEs**

Hourly samples. Bivariate VAR, $\Delta y_h = \phi(L)\Delta y_{h-1} + \eta_h$ with $\Delta y_h = \left[\Delta Fdiscount_h, \Delta Spread_h^P\right]$, where $P = F, S$ and all endogenous variables de-seasonalised of hourly effects.

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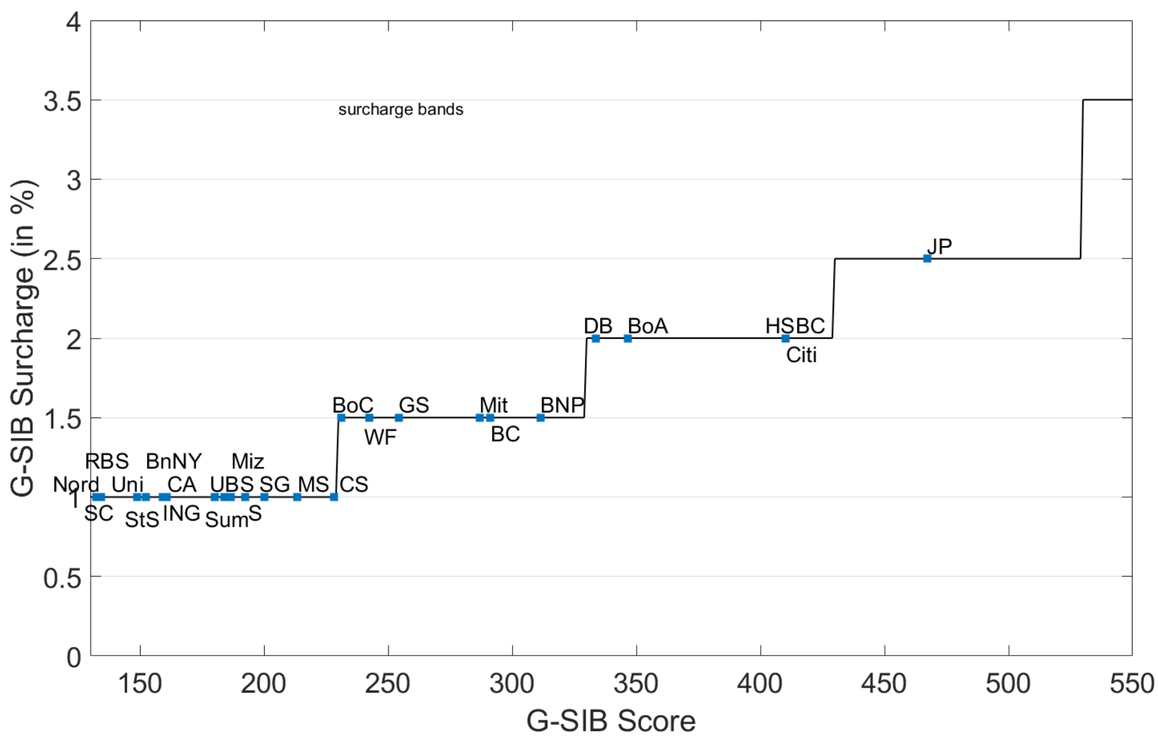
A Additional figures, tables & robustness checks

Figure A1: G-SIB surcharge and bucket cut-off points (2016/2017)



The figure shows G-SIB banks included in our sample for JPY/USD as they are positioned according to their G-SIB score at end-2016 and their proximity to the next G-SIB bucket as of beginning 2017.

Table A1: **Intraday correlation coefficient of liquidity measures by trading hour**

This table reports the average correlation coefficient by trading hour between spot market and funding liquidity ($\rho^{Fdiscount}_{Spread^S}$) and swap market and funding liquidity ($\rho^{Fdiscount}_{Spread^F}$) in two sub-sample periods for the JPY/USD and EUR/USD exchange rates.

	JPY/USD				EUR/USD			
GMT	Feb 2010 - Jun 2014		Jul 2014 - May 2017		Feb 2010 - Dec 2014		Jan 2015 - May 2017	
	$\rho^{Fdiscount}_{Spread^S}$	$\rho^{Fdiscount}_{Spread^F}$	$\rho^{Fdiscount}_{Spread^S}$	$\rho^{Fdiscount}_{Spread^F}$	$\rho^{Fdiscount}_{Spread^S}$	$\rho^{Fdiscount}_{Spread^F}$	$\rho^{Fdiscount}_{Spread^S}$	$\rho^{Fdiscount}_{Spread^F}$
0.00	-0.37	-0.43	-0.50	-0.59	-0.41	-0.50	-0.30	-0.42
1.00	-0.41	-0.47	-0.49	-0.58	-0.41	-0.50	-0.31	-0.44
2.00	-0.42	-0.47	-0.50	-0.59	-0.38	-0.48	-0.32	-0.45
3.00	-0.41	-0.46	-0.46	-0.57	-0.42	-0.51	-0.27	-0.41
4.00	-0.41	-0.46	-0.50	-0.59	-0.40	-0.49	-0.27	-0.42
5.00	-0.36	-0.41	-0.48	-0.57	-0.40	-0.51	-0.25	-0.41
6.00	-0.39	-0.44	-0.49	-0.58	-0.38	-0.50	-0.30	-0.46
7.00	-0.43	-0.47	-0.39	-0.53	-0.33	-0.46	-0.23	-0.40
8.00	-0.41	-0.45	-0.32	-0.48	-0.30	-0.42	-0.26	-0.41
9.00	-0.46	-0.49	-0.36	-0.50	-0.28	-0.41	-0.23	-0.38
10.00	-0.45	-0.48	-0.48	-0.56	-0.29	-0.41	-0.38	-0.49
11.00	-0.42	-0.45	-0.49	-0.56	-0.36	-0.46	-0.42	-0.52
12.00	-0.41	-0.46	-0.51	-0.58	-0.35	-0.47	-0.40	-0.51
13.00	-0.40	-0.46	-0.47	-0.55	-0.33	-0.46	-0.35	-0.46
14.00	-0.40	-0.47	-0.48	-0.54	-0.27	-0.40	-0.35	-0.46
15.00	-0.36	-0.43	-0.50	-0.56	-0.27	-0.41	-0.41	-0.50
16.00	-0.41	-0.47	-0.53	-0.59	-0.37	-0.49	-0.49	-0.56
17.00	-0.41	-0.48	-0.53	-0.59	-0.38	-0.50	-0.51	-0.57
18.00	-0.43	-0.49	-0.52	-0.58	-0.33	-0.47	-0.33	-0.41
19.00	-0.43	-0.49	-0.50	-0.56	-0.32	-0.46	-0.34	-0.41
20.00	-0.40	-0.46	-0.48	-0.56	-0.33	-0.45	-0.27	-0.36
21.00	-0.38	-0.44	-0.44	-0.55	-0.28	-0.39	-0.27	-0.35
22.00	-0.46	-0.51	-0.48	-0.58	-0.29	-0.39	-0.21	-0.32
23.00	-0.42	-0.46	-0.49	-0.59	-0.33	-0.43	-0.17	-0.30
Avg.	**-0.44**	**-0.50**	**-0.51**	**-0.63**	**0.24**	**0.27**	**-0.28**	**-0.40**

Hourly sample: 2/01/2010 00:00 to 5/31/2017 23:00; GMT time-stamps.

Table A2: **Intraday correlation coefficient of liquidity measure, by trading hour incl. CIP deviations**

This table reports the average correlation coefficient by trading hour between spot market and funding liquidity ($\rho^{CIPdev}_{Spread^S}$) and swap market and funding liquidity ($\rho^{CIPdev}_{Spread^F}$) in two sub-sample periods for the JPY/USD and EUR/USD exchange rates.

	JPY/USD				EUR/USD			
GMT	Feb 2010 - Jun 2014		Jul 2014 - May 2017		Feb 2010 - Dec 2014		Jan 2015 - May 2017	
	$\rho^{CIPdev}_{Spread^S}$	$\rho^{CIPdev}_{Spread^F}$	$\rho^{CIPdev}_{Spread^S}$	$\rho^{CIPdev}_{Spread^F}$	$\rho^{CIPdev}_{Spread^S}$	$\rho^{CIPdev}_{Spread^F}$	$\rho^{CIPdev}_{Spread^S}$	$\rho^{CIPdev}_{Spread^F}$
0	-0.37	-0.43	-0.50	-0.59	-0.41	-0.50	-0.30	-0.42
1	-0.41	-0.47	-0.49	-0.58	-0.41	-0.50	-0.31	-0.44
2	-0.42	-0.47	-0.50	-0.59	-0.38	-0.48	-0.32	-0.45
3	-0.41	-0.46	-0.46	-0.57	-0.42	-0.51	-0.27	-0.41
4	-0.41	-0.46	-0.50	-0.59	-0.40	-0.49	-0.27	-0.42
5	-0.36	-0.41	-0.48	-0.57	-0.40	-0.51	-0.25	-0.41
6	-0.39	-0.44	-0.49	-0.58	-0.38	-0.50	-0.30	-0.46
7	-0.43	-0.47	-0.39	-0.53	-0.33	-0.46	-0.23	-0.40
8	-0.41	-0.45	-0.32	-0.48	-0.30	-0.42	-0.26	-0.41
9	-0.46	-0.49	-0.36	-0.50	-0.28	-0.41	-0.23	-0.38
10	-0.45	-0.48	-0.48	-0.56	-0.29	-0.41	-0.38	-0.49
11	-0.42	-0.45	-0.49	-0.56	-0.36	-0.46	-0.42	-0.52
12	-0.41	-0.46	-0.51	-0.58	-0.35	-0.47	-0.40	-0.51
13	-0.40	-0.46	-0.47	-0.55	-0.33	-0.46	-0.35	-0.46
14	-0.40	-0.47	-0.48	-0.54	-0.27	-0.40	-0.35	-0.46
15	-0.36	-0.43	-0.50	-0.56	-0.27	-0.41	-0.41	-0.50
16	-0.41	-0.47	-0.53	-0.59	-0.37	-0.49	-0.49	-0.56
17	-0.41	-0.48	-0.53	-0.59	-0.38	-0.50	-0.51	-0.57
18	-0.43	-0.49	-0.52	-0.58	-0.33	-0.47	-0.33	-0.41
19	-0.43	-0.49	-0.50	-0.56	-0.32	-0.46	-0.34	-0.41
20	-0.40	-0.46	-0.48	-0.56	-0.33	-0.45	-0.27	-0.36
21	-0.38	-0.44	-0.44	-0.55	-0.28	-0.39	-0.27	-0.35
22	-0.46	-0.51	-0.48	-0.58	-0.29	-0.39	-0.21	-0.32
23	-0.42	-0.46	-0.49	-0.59	-0.33	-0.43	-0.17	-0.30
Avg.	**-0.41**	**-0.46**	**-0.47**	**-0.57**	**-0.34**	**-0.46**	**-0.32**	**-0.43**

Hourly sample: 2/01/2010 00:00 to 5/31/2017 23:00; GMT time-stamps.

Table A3: **First principal component of liquidity measures by trading hour**

This table reports the variation explained by the first principal component by trading hour between spot market and funding liquidity ($\frac{Fdiscount}{Spread^S}$) and swap market and funding liquidity ($\frac{Fdiscount}{Spread^F}$) in two sub-sample periods for the JPY/USD and EUR/USD exchange rates.

	JPY/USD				EUR/USD			
GMT	Feb 2010 - Jun 2014		Jul 2014 - May 2017		Feb 2010 - Dec 2014		Jan 2015 - May 2017	
	$\frac{Fdiscount}{Spread^S}$	$\frac{Fdiscount}{Spread^F}$	$\frac{Fdiscount}{Spread^S}$	$\frac{Fdiscount}{Spread^F}$	$\frac{Fdiscount}{Spread^S}$	$\frac{Fdiscount}{Spread^F}$	$\frac{Fdiscount}{Spread^S}$	$\frac{Fdiscount}{Spread^F}$
0	70.42	73.29	75.11	82.15	65.00	65.17	63.99	69.95
1	72.09	75.13	74.21	81.44	64.02	64.68	64.56	70.27
2	72.16	74.77	73.82	81.42	65.14	65.32	63.75	69.79
3	71.83	74.60	72.44	81.03	64.45	64.77	60.75	67.43
4	71.52	74.46	74.18	82.17	64.94	65.23	59.94	67.09
5	69.06	72.01	73.28	81.18	60.86	61.89	59.10	66.90
6	71.13	73.60	75.53	82.18	56.05	58.37	62.92	70.56
7	73.21	75.13	69.33	77.64	55.46	58.52	57.63	66.21
8	72.27	74.25	64.96	74.64	56.75	59.84	59.24	66.56
9	74.61	76.18	67.01	75.53	57.45	60.71	57.08	64.95
10	74.56	75.65	76.70	81.58	58.83	62.12	67.07	72.74
11	73.00	74.46	77.20	81.66	59.28	62.14	70.30	75.28
12	72.28	74.62	78.52	82.74	58.76	61.24	68.94	73.95
13	71.62	74.68	77.00	81.31	59.63	61.52	65.59	70.87
14	72.04	75.14	77.45	81.72	62.73	63.95	65.80	70.95
15	70.17	73.42	79.20	82.77	66.31	67.30	68.31	73.00
16	72.93	75.66	81.27	84.14	63.00	64.59	75.87	78.97
17	72.60	75.70	81.72	84.44	63.51	65.01	78.65	80.66
18	73.33	76.09	81.32	84.16	60.07	62.63	66.58	70.32
19	73.25	76.06	79.95	83.66	61.32	63.45	67.34	70.85
20	71.95	74.95	78.17	82.86	67.23	68.08	61.57	65.74
21	70.28	73.31	75.80	83.07	66.28	66.59	65.06	69.32
22	74.50	77.04	76.14	83.79	65.06	65.83	56.92	63.29
23	72.53	74.95	74.46	82.64	65.82	66.02	52.83	59.81
Avg.	**72.22**	**74.80**	**75.62**	**81.66**	**62.00**	**63.54**	**64.16**	**69.81**

Hourly sample: 2/01/2010 00:00 to 5/31/2017 23:00; GMT time-stamps.

Table A4: **First principal component of liquidity measures, by trading hour incl. CIP deviations**

This table reports the variation explained by the first principal component by trading hour between spot market and funding liquidity ($\frac{CIPdev}{Spread^S}$) and swap market and funding liquidity ($\frac{CIPdev}{Spread^F}$) in two sub-sample periods for the JPY/USD and EUR/USD exchange rates.

	JPY/USD				EUR/USD			
GMT	Feb 2010 - Jun 2014		Jul 2014 - May 2017		Feb 2010 - Dec 2014		Jan 2015 - May 2017	
	$\frac{CIPdev}{Spread^S}$	$\frac{CIPdev}{Spread^F}$	$\frac{CIPdev}{Spread^S}$	$\frac{CIPdev}{Spread^F}$	$\frac{CIPdev}{Spread^S}$	$\frac{CIPdev}{Spread^F}$	$\frac{CIPdev}{Spread^S}$	$\frac{CIPdev}{Spread^F}$
0	68.65	71.45	75.15	79.68	70.67	74.95	64.77	71.21
1	70.67	73.61	74.42	79.07	70.40	74.95	65.56	71.80
2	70.97	73.44	75.01	79.70	69.09	74.19	66.07	72.40
3	70.39	73.04	73.14	78.51	70.77	75.33	63.34	70.41
4	70.30	73.09	74.93	79.73	69.94	74.54	63.60	71.17
5	67.85	70.63	73.79	78.67	70.23	75.67	62.37	70.30
6	69.41	71.89	74.33	79.20	68.92	75.10	65.18	73.05
7	71.64	73.57	69.63	76.47	66.52	72.81	61.32	69.93
8	70.74	72.61	66.04	74.00	64.99	71.16	63.22	70.30
9	72.82	74.34	67.94	74.84	63.88	70.50	61.33	68.92
10	72.66	73.79	74.06	78.14	64.64	70.44	68.79	74.60
11	71.06	72.62	74.41	78.11	68.01	72.97	70.84	76.19
12	70.26	72.82	75.40	78.96	67.38	73.35	70.04	75.63
13	69.83	73.13	73.72	77.34	66.48	72.89	67.58	73.19
14	70.10	73.46	73.75	77.21	63.45	70.19	67.74	73.11
15	68.16	71.70	74.92	78.20	63.73	70.54	70.30	75.16
16	70.70	73.74	76.68	79.57	68.65	74.53	74.45	78.23
17	70.44	73.83	76.68	79.48	69.23	74.94	75.66	78.40
18	71.48	74.46	76.23	79.05	66.74	73.73	66.58	70.66
19	71.56	74.59	74.79	78.25	66.18	73.02	66.88	70.58
20	69.92	73.16	74.12	78.17	66.65	72.52	63.68	67.85
21	69.04	72.09	71.85	77.50	64.15	69.42	63.32	67.42
22	72.92	75.61	74.06	78.82	64.41	69.36	60.33	66.03
23	70.86	73.15	74.53	79.57	66.58	71.37	58.28	65.15
Avg.	**70.52**	**73.16**	**73.73**	**78.26**	**67.15**	**72.85**	**65.89**	**71.74**

Hourly sample: 2/01/2010 00:00 to 5/31/2017 23:00; GMT time-stamps.

Table A5: **Long-run liquidity dynamics in JPY/USD**

This table reports coefficients from the long-run equation of a conditional error correction model (ECM) derived from an autoregressive distributed lag (ARDL) model specification. Specifically, for the two sub-sample periods and for spot and swap market liquidity, measured by spot rate $Spread^S$ and forward rate $Spread^F$ bid ask spreads, $P = S, F$, we estimate:

$$\Delta Spread_h^P = \alpha + \sum_{i=1}^{23} \delta_i H_i + \theta_0 Spread_{h-1}^P + \boldsymbol{\theta x_{t-1}} + \sum_{i=1}^{p-1} \boldsymbol{\gamma_i \Delta z_{h-i}^P} + \boldsymbol{\beta \Delta x_h^P} + u_t$$

where a vector $\mathbf{z_h^S} = (Spread_h^P, |Fdiscount|_t, Q_{j,h}^P/N_{j,h}^P, Vol_h^P) = (Spread_h^P, \mathbf{x_h^P})'$ and $j = T1, (T2, T3)$, denote the quoting intensity of G-SIB and non G-SIB dealers, respectively. F-statistics based on the results of the bound testing procedure for long-run relationship, robust to variables being in between I(0) and I(1). Constant and coefficients on short-run effects are omitted for brevity.

Sample:	2/01/2010 00:00-6/30/2014 23:00			7/01/2014 00:00-5/31/2017 23:00		
Variable:	$Spread^F$	$Spread^S$	$Spread^S$	$Spread^F$	$Spread^S$	$Spread^S$
$\|Fdiscount\|$	0.273***	0.153***	0.138***	0.089***	0.064***	0.022***
	(0.04)	(0.02)	(0.02)	(0.01)	(0.01)	(0.00)
Q_{T1}^F/N_{T1}^F	-0.006***			-0.002***		
	(0.00)			(0.00)		
$Q_{T2,T3}^F/N_{T2,T3}^F$	0.021***		0.012***	0.007***		0.012***
	(0.00)		(0.00)	(0.00)		(0.00)
Vol^F	1.734***			2.293***		
	(0.60)			(0.24)		
Q_{T1}^S/N_{T1}^S		-0.008***	-0.007***		-0.002***	-0.007***
		(0.00)	(0.00)		(0.00)	(0.00)
$Q_{T2,T3}^S/N_{T2,T3}^S$		0.003***			0.001	
		(0.00)			(0.00)	
Vol^S		1.353***	1.457***		2.053	1.457***
		(0.41)	(0.42)		(0.31)	(0.42)
θ	-0.07***	-0.12***	-0.12***	-0.09***	-0.11***	-0.12***
$F-Stat$	90.20	129.961	133.250	124.24	110.62	133.25
Hour dummies	yes	yes	yes	yes	yes	yes
Adj. R^2	0.273	0.280	0.281	0.261	0.274	0.281
Obs	26484	26484	26484	17592	17592	17592

Hourly sample; GMT time-stamps. ARDL lags chosen based on the Schwarz (Bayes) criterion (SC). HAC robust standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1. F-statistic based on the Pesaran et al (2001) bounds test: 1% critical values 3.29 for I(0) and 4.37 for I(1).

Table A6: **Long-run liquidity dynamics in EUR/USD**

This table reports coefficients from the long-run equation of a conditional error correction model (ECM) derived from an autoregressive distributed lag (ARDL) model specification. Specifically, for the two sub-sample periods and for spot and swap market liquidity, measured by spot rate $Spread^S$ and forward rate $Spread^F$ bid ask spreads, $P = S, F$, we estimate:

$$\Delta Spread_h^P = \alpha + \sum_{i=1}^{23} \delta_i H_i + \theta_0 Spread_{h-1}^P + \boldsymbol{\theta x_{t-1}} + \sum_{i=1}^{p-1} \boldsymbol{\gamma_i \Delta z_{h-i}^P} + \boldsymbol{\beta \Delta x_h^P} + u_t$$

where a vector $\mathbf{z_h^S} = (Spread_h^P, |Fdiscount|_t, Q_{j,h}^P/N_{j,h}^P, Vol_h^P) = (Spread_h^P, \mathbf{x_h^P})'$ and $j = T1, (T2, T3)$, denote the quoting intensity of G-SIB and non G-SIB dealers, respectively. F-statistics based on the results of the bound testing procedure for long-run relationship, robust to variables being in between I(0) and I(1). Constant and coefficients on short-run effects omitted for brevity.

Sample:	2/01/2010 00:00-6/30/2014 23:00			7/01/2014 00:00-5/31/2017 23:00		
Variable:	$Spread^F$	$Spread^S$	$Spread^S$	$Spread^F$	$Spread^S$	$Spread^S$
$\|Fdiscount\|$	0.035***	0.043***	0.039***	0.057***	0.011	0.006***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)
Q_{T1}^F/N_{T1}^F	-0.003***			0.000		
	(0.00)			(0.00)		
$Q_{T2,T3}^F/N_{T2,T3}^F$	0.000		-0.001***	0.003**		0.002
	(0.00)		(0.00)	(0.00)		(0.00)
Vol^F	8.821***			3.787***		
	(0.90)			(0.66)		
Q_{T1}^S/N_{T1}^S		-0.002***	-0.002***		-0.004***	-0.004*
		(0.00)	(0.00)		(0.00)	(0.00)
$Q_{T2,T3}^S/N_{T2,T3}^S$		-0.001*			0.001	
		(0.00)			(0.00)	
Vol^S		6.573***	7.721***		2.030***	2.006***
		(0.55)	(0.65)		(0.35)	(0.34)
θ	-0.10***	-0.12***	-0.130***	-0.09***	-0.11***	-0.11***
$F-Stat$	91.76	106.04	113.64	51.77	59.92	60.79
Hour dummies	yes	yes	yes	yes	yes	yes
$Adj.\ R^2$	0.277	0.275	0.275	0.347	0.355	0.349
Obs	29457	29457	29457	14619	14619	14619

Hourly sample; GMT time-stamps. ARDL lags chosen based on the Schwarz (Bayes) criterion (SC). HAC robust standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1. F-statistic based on the Pesaran et al (2001) bounds test: 1% critical values 3.29 for I(0) and 4.37 for I(1).

Table A7: **Long-run dynamics in JPY/USD incl. CIP Deviation**

This table reports coefficients from the long-run equation of a conditional error correction model (ECM) derived from an autoregressive distributed lag (ARDL) model specification. Specifically, for the two sub-sample periods and for spot and swap market liquidity, measured by spot rate $Spread^S$ and forward rate $Spread^F$ bid ask spreads, $P = S, F$, we estimate:

$$\Delta Spread_h^P = \alpha + \sum_{i=1}^{23} \delta_i H_i + \theta_0 Spread_{h-1}^P + \boldsymbol{\theta x_{h-1}} + \sum_{i=1}^{p-1} \boldsymbol{\gamma_i \Delta z_{h-i}^P} + \boldsymbol{\beta \Delta x_h^P} + u_h$$

where a vector $\mathbf{z_h^S} = (Spread_h^P, |CIPdev|_h, Q_{LD,h}^P/N_{LD,h}^P, Q_{SD,h}^P/N_{SD,h}^P, Vol_h^P) = (Spread_h^P, \mathbf{x_h^P})'$ and LD, SD denotes large and small dealers. F-statistics based on the results of the bound testing procedure for long-run relationship, robust to variables being in between I(0) and I(1). Constant and coefficients on short-run effects omitted for brevity.

	2/01/2010 00:00 6/30/2014 23:00			7/01/2014 00:00 5/31/2017 23:00		
Variable:	$Spread^F$	$Spread^S$	$Spread^S$	$Spread^F$	$Spread^S$	$Spread^S$
$\|CIPDev\|$	0.021***	0.012***	0.011***	0.009***	0.006***	0.001***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Q_{LD}^F/N_{LD}^F	-0.006***			-0.002***		
	(0.00)			(0.00)		
Q_{SD}^F/N_{SD}^F	0.022***		0.009***	0.011***		0.009***
	(0.00)		(0.00)	(0.00)		(0.00)
Vol^F	1.826***			2.537***		
	(0.63)			(0.27)		
Q_{LD}^S/N_{LD}^S		-0.008***	-0.007***		-0.002***	-0.001***
		(0.00)	(0.00)		(0.00)	(0.00)
Q_{SD}^S/N_{SD}^S		0.003***			0.002***	
		(0.00)			(0.00)	
Vol^S		1.384***	1.485***		2.098***	2.177***
		(0.42)	(0.43)		(0.33)	(0.23)
θ	-0.07***	-0.12***	-0.12***	-0.08***	-0.11***	-0.10***
$F-Stat$	88.01	129.99	132.67	120.10	107.98	92.29
Hour dummies	yes	yes	yes	yes	yes	yes
$Adj.\ R^2$	0.273	0.280	0.280	0.260	0.273	0.270
Obs	26484	26484	26484	17592	17592	17592

Hourly sample; GMT time-stamps. ARDL lags chosen based on the Schwarz (Bayes) criterion (SC). HAC robust standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1. F-statistic based on the Pesaran et al (2001) bounds test: 1% critical values 3.29 for I(0) and 4.37 for I(1).

Table A8: **Long-run dynamics in EUR/USD incl. CIP Deviation**

This table reports coefficients from the long-run equation of a conditional error correction model (ECM) derived from an autoregressive distributed lag (ARDL) model specification. Specifically, for the two sub-sample periods and for spot and swap market liquidity, measured by spot rate $Spread^S$ and forward rate $Spread^F$ bid ask spreads, $P = S, F$, we estimate:

$$\Delta Spread_h^P = \alpha + \sum_{i=1}^{23} \delta_i H_i + \theta_0 Spread_{h-1}^P + \boldsymbol{\theta x_{h-1}} + \sum_{i=1}^{p-1} \boldsymbol{\gamma_i \Delta z_{h-i}^P} + \boldsymbol{\beta \Delta x_h^P} + u_h$$

where a vector $\mathbf{z_h^S} = (Spread_h^P, |CIPdev|_h, Q_{LD,h}^P/N_{LD,h}^P, Q_{SD,h}^P/N_{SD,h}^P, Vol_h^P) = (Spread_h^P, \mathbf{x_h^P})'$ and LD, SD denotes large and small dealers. F-statistics based on the results of the bound testing procedure for long-run relationship, robust to variables being in between I(0) and I(1). Constant and coefficients on short-run effects omitted for brevity.

Sub-sample period:	2/01/2010 00:00-12/31/2014 23:00			01/01/2015 00:00-5/31/2017 23:00		
Variable:	$Spread^F$	$Spread^S$	$Spread^S$	$Spread^F$	$Spread^S$	$Spread^S$
$\|CIPDev\|$	0.009***	0.005***	0.006***	0.009***	0.003***	0.001***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Q_{LD}^F/N_{LD}^F	-0.003***			0.000		
	(0.00)			(0.00)		
Q_{SD}^F/N_{SD}^F	-0.001		-0.002***	0.003**		0.001***
	(0.00)		(0.00)	(0.00)		(0.00)
Vol^F	7.411***			3.484***		
	(0.78)			(0.60)		
Q_{LD}^S/N_{LD}^S		-0.001***	-0.001***		-0.004***	-0.004
		(0.00)	(0.00)		(0.00)	(0.00)
Q_{SD}^S/N_{SD}^S		0.000			0.001	
		(0.00)			(0.00)	
Vol^S		6.104***	6.022***		1.932***	1.908***
		(0.55)	(0.54)		(0.34)	(0.33)
θ	-0.12***	-0.12***	-0.13***	-0.09***	-0.11***	-0.11***
$F-Stat$	108.04	108.11	110.60	52.28	61.15	61.94
Hour dummies	yes	yes	yes	yes	yes	yes
Adj. R^2	0.279	0.276	0.276	0.348	0.355	0.349
Obs	29457	29457	29457	14619	14619	14619

Hourly sample; GMT time-stamps. ARDL lags chosen based on the Schwarz (Bayes) criterion (SC). HAC robust standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1. F-statistic based on the Pesaran et al (2001) bounds test: 1% critical values 3.29 for I(0) and 4.37 for I(1).

Table A9: **Long-run liquidity dynamics in JPY/USD (By Bank Tiers)**

This table reports coefficients from the long-run equation of a conditional error correction model (ECM) derived from an autoregressive distributed lag (ARDL) model specification. Specifically, for the two sub-sample periods and for spot and swap market liquidity, measured by spot rate $Spread^S$ and forward rate $Spread^F$ bid ask spreads, $P = S, F$, we estimate:

$$\Delta Spread_h^P = \alpha + \sum_{i=1}^{23} \delta_i H_i + \theta_0 Spread_{h-1}^P + \boldsymbol{\theta x_{t-1}} + \sum_{i=1}^{p-1} \boldsymbol{\gamma_i \Delta z_{h-i}^P} + \boldsymbol{\beta \Delta x_h^P} + u_t$$

where a vector $\mathbf{z_h^S} = (Spread_h^P, |Fdiscount|_t, Q_{j,h}^P/N_{j,h}^P, Vol_h^P) = (Spread_h^P, \mathbf{x_h^P})'$ and $j = T1, T2, T3$, denotes Tier-1, Tier-2, and Tier-3 dealer quoting intensity, respectively. F-statistics based on the results of the bound testing procedure for long-run relationship, robust to variables being in between I(0) and I(1). Constant and coefficients on short-run effects are omitted for brevity.

Sample:	2/01/2010 00:00-6/30/2014 23:00			7/01/2014 00:00-5/31/2017 23:00		
Variable:	$Spread^F$	$Spread^S$	$Spread^S$	$Spread^F$	$Spread^S$	$Spread^S$
$\|Fdiscount\|$	0.268***	0.141***	0.143***	0.057***	0.069***	0.041***
	(0.03)	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)
Q^F_{T1}/N^F_{T1}	-0.005***			-0.002***		
	(0.00)			(0.00)		
Q^F_{T2}/N^F_{T2}	0.017***		0.008***	-0.001		0.002**
	(0.00)		(0.00)	(0.00)		(0.00)
Q^F_{T3}/N^F_{T3}	0.037***		0.015***	0.024***		0.015***
	(0.00)		(0.00)	(0.00)		(0.00)
Vol^F	1.480***			2.113***		
	(0.51)			(0.23)		
Q^S_{T1}/N^S_{T1}		-0.006***	-0.006***		-0.002***	-0.002***
		(0.00)	(0.00)		(0.00)	(0.00)
Q^S_{T2}/N^S_{T2}		-0.002***			0.002***	
		(0.00)			(0.00)	
Q^S_{T3}/N^S_{T3}		0.002*			0.000	
		(0.00)			(0.00)	
Vol^S		1.316	1.367		1.893	1.987
		(0.40)	(0.40)		(0.26)	(0.26)
θ	-0.08***	-0.12***	-0.12***	-0.10***	-0.12***	-0.12***
$F-Stat$	83.57	113.65	113.58	125.71	109.87	93.74
Hour dummies	yes	yes	yes	yes	yes	yes
Adj. R^2	0.28	0.28	0.28	0.27	0.28	0.27
Obs	26484	26484	26484	17592	17592	17592

Hourly sample; GMT time-stamps. ARDL lags chosen based on the Schwarz (Bayes) criterion (SC). HAC robust standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1. F-statistic based on the Pesaran et al (2001) bounds test: 1% critical values 3.29 for I(0) and 4.37 for I(1).

Table A10: **Long-run liquidity dynamics in EUR/USD (By Bank Tiers)**

This table reports coefficients from the long-run equation of a conditional error correction model (ECM) derived from an autoregressive distributed lag (ARDL) model specification. Specifically, for the two sub-sample periods and for spot and swap market liquidity, measured by spot rate $Spread^S$ and forward rate $Spread^F$ bid ask spreads, $P = S, F$, we estimate:

$$\Delta Spread_h^P = \alpha + \sum_{i=1}^{23} \delta_i H_i + \theta_0 Spread_{h-1}^P + \boldsymbol{\theta x_{t-1}} + \sum_{i=1}^{p-1} \boldsymbol{\gamma_i \Delta z_{h-i}^P} + \boldsymbol{\beta \Delta x_h^P} + u_t$$

where a vector $\mathbf{z_h^S} = (Spread_h^P, |Fdiscount|_t, Q_{j,h}^P/N_{j,h}^P, Vol_h^P) = (Spread_h^P, \mathbf{x_h^P})'$ and $j = T1, T2, T3$, denotes Tier-1, Tier-2, and Tier-3 dealer quoting intensity, respectively. F-statistics based on the results of the bound testing procedure for long-run relationship, robust to variables being in between I(0) and I(1). Constant and coefficients on short-run effects omitted for brevity.

Sample:	2/01/2010 00:00-6/30/2014 23:00			7/01/2014 00:00-5/31/2017 23:00		
Variable:	$Spread^F$	$Spread^S$	$Spread^S$	$Spread^F$	$Spread^S$	$Spread^S$
$\|Fdiscount\|$	0.037***	0.037***	0.040***	0.059***	0.031***	0.021***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Q_{T1}^F/N_{T1}^F	-0.004***			0.000		
	(0.00)			(0.00)		
Q_{T2}^F/N_{T2}^F	0.001***		0.000	-0.001		-0.002
	(0.00)		(0.00)	(0.00)		(0.00)
Q_{T3}^F/N_{T3}^F	-0.002*		-0.001**	0.001**		0.001*
	(0.00)		(0.00)	(0.00)		(0.00)
Vol^F	8.780***			3.768***		
	(0.90)			(0.66)		
Q_{T1}^S/N_{T1}^S		-0.001***	-0.002***		-0.003***	-0.004***
		(0.00)	(0.00)		(0.00)	(0.00)
Q_{T2}^S/N_{T2}^S		-0.003***			0.004***	
		(0.00)			(.00)	
Q_{T3}^S/N_{T3}^S		0.000			-0.004***	
		(0.00)			(0.00)	
Vol^S		5.777***	7.739***		1.430***	1.985***
		(0.52)	(0.65)		(0.28)	(0.33)
θ	-0.10***	-0.14***	-0.13***	-0.09***	-0.14***	-0.11***
$F-Stat$	80.67	105.28	96.76	44.42	70.37	52.46
Hour dummies	yes	yes	yes	yes	yes	yes
Adj. R^2	0.28	0.28	0.28	0.35	0.38	0.35
Obs	26484	26484	26484	17592	17592	17592

Hourly sample; GMT time-stamps. ARDL lags chosen based on the Schwarz (Bayes) criterion (SC). HAC robust standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1. F-statistic based on the Pesaran et al (2001) bounds test: 1% critical values 3.29 for I(0) and 4.37 for I(1).

Table A11: **Long-run dynamics in JPY/USD incl. CIP Deviation by Bank Tiers**

This table reports coefficients from the long-run equation of a conditional error correction model (ECM) derived from an autoregressive distributed lag (ARDL) model specification. Specifically, for the two sub-sample periods and for spot and swap market liquidity, measured by spot rate $Spread^S$ and forward rate $Spread^F$ bid ask spreads, $P = S, F$, we estimate:

$$\Delta Spread_h^P = \alpha + \sum_{i=1}^{23} \delta_i H_i + \theta_0 Spread_{h-1}^P + \boldsymbol{\theta x_{h-1}} + \sum_{i=1}^{p-1} \boldsymbol{\gamma_i \Delta z_{h-i}^P} + \boldsymbol{\beta \Delta x_h^P} + u_h$$

where a vector $\mathbf{z_h^S} = (Spread_h^P, |CIPdev|_h, Q_{T1,h}^P/N_{T1,h}^P, Q_{T2,h}^P/N_{T2,h}^P, Q_{T3,h}^P/N_{T3,h}^P Vol_h^P) = (Spread_h^P, \mathbf{x_h^P})'$ and $T1$, $T2$, $T3$ denote the quoting intensity of Tier-1, Tier-2, and Tier-3 dealers, respectively. F-statistics based on the results of the bound testing procedure for long-run relationship, robust to variables being in between I(0) and I(1). Constant and coefficients on short-run effects omitted for brevity.

	2/01/2010 00:00 6/30/2014 23:00			7/01/2014 00:00 5/31/2017 23:00		
Variable:	$Spread^F$	$Spread^S$	$Spread^S$	$Spread^F$	$Spread^S$	$Spread^S$
$\|CIPDev\|$	0.023***	0.012***	0.012***	0.005***	0.006***	0.004***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Q_{T1}^F/N_{T1}^F	-0.005***			-0.002***		
	(0.00)			(0.00)		
Q_{T2}^F/N_{T2}^F	0.017***		0.008***	0.000		0.003***
	(0.00)		(0.00)	(0.00)		(0.00)
Q_{T3}^F/N_{T3}^F	0.043***		0.018***	0.030***		0.018***
	(0.00)		(0.00)	(0.00)		(0.00)
Vol^F	1.504***			2.146***		
	(0.51)			(0.24)		
Q_{T1}^S/N_{T1}^S		-0.006***	-0.006***		-0.003***	-0.002***
		(0.00)	(0.00)		(0.00)	(0.00)
Q_{T2}^S/N_{T2}^S		-0.003***			0.002***	
		(0.00)			(0.00)	
Q_{T3}^S/N_{T3}^S		0.002***			0.001***	
		(0.00)			(0.00)	
Vol^S		1.341***	1.369***		1.945***	1.998***
		(0.41)	(0.40)		(0.29)	(0.27)
θ	-0.08***	-0.12***	-0.12***	-0.10***	-0.11***	-0.12***
$F-Stat$	83.53	114.17	114.61	126.34	105.31	94.65
Hour dummies	yes	yes	yes	yes	yes	yes
Adj. R^2	0.28	0.282	0.28	0.27	0.28	0.28
Obs	26484	26484	26484	17592	17592	17592

Hourly sample; GMT time-stamps. ARDL lags chosen based on the Schwarz (Bayes) criterion (SC). HAC robust standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1. F-statistic based on the Pesaran et al (2001) bounds test: 1% critical values 3.29 for I(0) and 4.37 for I(1).

Table A12: **Long-run dynamics in EUR/USD incl. CIP Deviation**

This table reports coefficients from the long-run equation of a conditional error correction model (ECM) derived from an autoregressive distributed lag (ARDL) model specification. Specifically, for the two sub-sample periods and for spot and swap market liquidity, measured by spot rate $Spread^S$ and forward rate $Spread^F$ bid ask spreads, $P = S, F$, we estimate:

$$\Delta Spread_h^P = \alpha + \sum_{i=1}^{23} \delta_i H_i + \theta_0 Spread_{h-1}^P + \boldsymbol{\theta x_{h-1}} + \sum_{i=1}^{p-1} \boldsymbol{\gamma_i \Delta z_{h-i}^P} + \boldsymbol{\beta \Delta x_h^P} + u_h$$

where a vector $\mathbf{z_h^S} = (Spread_h^P, |CIPdev|_h, Q_{T1,h}^P/N_{T1,h}^P, Q_{T2,h}^P/N_{T2,h}^P, Q_{T3,h}^P/N_{T3,h}^P Vol_h^P) = (Spread_h^P, \mathbf{x_h^P})'$ and $T1$, $T2$, $T3$ denote the quoting intensity of Tier-1, Tier-2, and Tier-3 dealers, respectively. F-statistics based on the results of the bound testing procedure for long-run relationship, robust to variables being in between I(0) and I(1). Constant and coefficients on short-run effects omitted for brevity.

Sub-sample period:	2/01/2010 00:00-12/31/2014 23:00			01/01/2015 00:00-5/31/2017 23:00		
Variable:	$Spread^F$	$Spread^S$	$Spread^S$	$Spread^F$	$Spread^S$	$Spread^S$
$\|CIPDev\|$	0.009***	0.004***	0.006***	0.009***	0.003***	0.004***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Q_{T1}^F/N_{T1}^F	-0.003***			0.000		
	(0.00)			(0.00)		
Q_{T2}^F/N_{T2}^F	0.000		-0.002	0.000		-0.002
	(0.00)		(0.00)	(0.00)		(0.00)
Q_{T3}^F/N_{T3}^F	-0.001***		0.000	0.001*		0.001*
	(0.00)		(0.00)	(0.00)		(0.00)
Vol^F	7.450***			3.482***		
	(0.78)			(0.61)		
Q_{T1}^S/N_{T1}^S		-0.001**	-0.001***		-0.003***	-0.004***
		(0.00)	(0.00)		(0.00)	(0.00)
Q_{T2}^S/N_{T2}^S		-0.002***			0.004***	
		(0.00)			(0.00)	
Q_{T3}^S/N_{T3}^S		0.000			-0.003***	
		(0.00)			(0.00)	
Vol^S		5.643***	5.992***		1.386***	1.887***
		(0.53)	(0.54)		(0.28)	(0.32)
θ	-0.12***	-0.13***	-0.13***	-0.09***	-0.14***	-0.11***
$F-Stat$	93.32	100.49	95.28	44.65	69.87	53.36
Hour dummies	yes	yes	yes	yes	yes	yes
$Adj.\ R^2$	0.279	0.278	0.276	0.348	0.377	0.350
Obs	26484	26484	26484	17592	17592	17592

Hourly sample; GMT time-stamps. ARDL lags chosen based on the Schwarz (Bayes) criterion (SC). HAC robust standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1. F-statistic based on the Pesaran et al (2001) bounds test: 1% critical values 3.29 for I(0) and 4.37 for I(1).

Table A13: **Contagion from FX funding to market liquidity in JPY/USD**, incl. CIP Deviations

The table shows tests for contagion from FX funding liquidity to FX market liquidity in spot and swaps. We follow Forbes and Rigobon (2002), and conduct a t-test of whether the correlations between $\Delta CIPDev$ and $\Delta Spread^P$ is significantly more negative at quarter-ends, where $P = S, F$. The correlation coefficients are estimated using a 200-hour rolling window bi-variate VAR, and adjusted for heteroskedastic levels of volatility, thus allowing to make statements about contagions rather than a simple co-movement.

To spot market:	$\Delta CIPDev \rightarrow \Delta Spread^S$					
	Q-end month		Prior 2 months		Contagion	
QEs:	ρ_{QE}	σ_{QE}	ρ_{NQE}	σ_{NQE}	t-stat	Reject H_0
09/14	0.007	0.012	-0.006	0.011	-17	
12/14	0.019	0.021	-0.02	0.024	-24.53	
03/15	0.035	0.045	0.024	0.059	-3.16	
06/15	-0.01	0.054	0	0.058	2.63	Yes
09/15	0.005	0.008	-0.009	0.02	-17.2	
12/15	0.029	0.042	0.027	0.054	-0.55	
03/16	0.027	0.05	-0.008	0.097	-7.8	
06/16	-0.075	0.087	-0.008	0.021	13.74	Yes
09/16	0.005	0.052	-0.081	0.081	-20.75	
12/16	-0.077	0.047	0.004	0.049	24.97	Yes
03/17	-0.015	0.08	-0.051	0.068	-7.3	
Avg. contagion	**-0.054**	**0.063**			**13.78**	**3/11 QEs**

To forward market:	$\Delta CIPDev \rightarrow \Delta Spread^F$					
	Q-end month		Prior 2 months		Contagion	
QEs:	ρ_{QE}	σ_{QE}	ρ_{NQE}	σ_{NQE}	t-stat	Reject H_0
09/14	0.005	0.011	-0.007	0.011	-16.37	
12/14	0.015	0.02	-0.023	0.022	-25.04	
03/15	0.037	0.044	0.03	0.06	-2.04	
06/15	-0.015	0.056	0.002	0.055	4.39	Yes
09/15	0.014	0.014	-0.011	0.02	-23.29	
12/15	0.004	0.02	0.044	0.052	17.92	
03/16	0.029	0.064	-0.012	0.093	-8.24	
06/16	-0.059	0.099	-0.01	0.03	8.71	Yes
09/16	0.035	0.081	-0.029	0.086	-11.64	
12/16	-0.088	0.045	-0.013	0.059	22.45	Yes
03/17	-0.021	0.075	-0.054	0.065	-7.18	
Avg. contagion	**-0.054**	**0.067**			**11.85**	**3/11 QEs**

Hourly samples. Bivariate VAR, $\Delta y_h = \phi(L)\Delta y_{h-1} + \eta_h$ with $\Delta y_h = \left[\Delta CIPDev_h, \Delta Spread_h^P\right]$, where $P = F, S$ and all endogenous variables de-seasonalised of hourly effects.

Table A14: **Contagion from FX funding to market liquidity in EUR/USD**, incl. CIP Deviations

The table shows tests for contagion from FX funding liquidity to FX market liquidity in spot and swaps. We follow Forbes and Rigobon (2002), and conduct a t-test of whether the correlations between $\Delta CIPDev$ and $\Delta Spread^P$ is significantly more negative at quarter-ends, where $P = S, F$. The correlation coefficients are estimated using a 200-hour rolling window bi-variate VAR, and adjusted for heteroskedastic levels of volatility, thus allowing to make statements about contagions rather than a simple co-movement.

To spot market:	$\Delta CIPDev \rightarrow \Delta Spread^S$					
	Q-end month		Prior 2 months		Contagion	
QEs:	ρ_{QE}	σ_{QE}	ρ_{NQE}	σ_{NQE}	t-stat	Reject H_0
03/15	0.015	0.034	-0.064	0.108	-18.150	
06/15	0.112	0.051	0.043	0.123	-12.910	
09/15	0.021	0.043	-0.003	0.053	-7.860	
12/15	-0.033	0.044	-0.005	0.067	7.810	Yes
03/16	0.126	0.053	0.054	0.046	-21.090	
06/16	0.011	0.007	-0.002	0.023	-14.040	
09/16	0.044	0.037	-0.080	0.065	-40.060	
12/16	-0.123	0.072	0.040	0.058	35.020	
03/17	-0.039	0.041	-0.074	0.150	-6.120	Yes
Avg. contagion	**-0.078**	**0.058**			**21.42**	**2/9 QEs**

To forward market:	$\Delta CIPDev \rightarrow \Delta Spread^F$					
	Q-end month		Prior 2 months		Contagion	
QEs:	ρ_{QE}	σ_{QE}	ρ_{NQE}	σ_{NQE}	t-stat	Reject H_0
03/15	0.019	0.034	-0.073	0.11	-20.89	
06/15	0.101	0.049	0.009	0.114	-18.58	
09/15	0.021	0.042	-0.027	0.062	-15.2	
12/15	-0.04	0.04	-0.021	0.064	5.46	Yes
03/16	0.153	0.058	0.053	0.043	-27.12	
06/16	-0.01	0.029	-0.003	0.025	3.64	Yes
09/16	0.057	0.036	-0.07	0.063	-42.09	
12/16	-0.11	0.071	0.029	0.057	30.59	Yes
03/17	-0.043	0.039	-0.074	0.159	-5.14	
Avg. contagion	**-0.053**	**0.047**			**13.23**	**3/9 QEs**

Hourly samples. Bivariate VAR, $\Delta y_h = \phi(L)\Delta y_{h-1} + \eta_h$ with $\Delta y_h = \left[\Delta CIPDev_h, \Delta Spread_h^P\right]$, where $P = F, S$ and all endogenous variables de-seasonalised of hourly effects.

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