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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 robust 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 quoting behaviour and market participation. 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 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 feature of the FX market is the predominance of trading in FX derivatives over spot transactions. FX swaps are widely used to hedge currency risk and to source short-term funding in a given currency. 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 trading in all the FX instruments globally (BIS, 2019).[1] 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 across currency pairs. Hence, in addition to assessing market liquidity on its own, we can examine the interaction between FX market liquidity and FX funding liquidity. To alleviate 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, and the main empirical analysis is based on intra-day quoting dynamics, leveraging information on prices with information on the number of active dealers, their quoting behaviour, and parent bank characteristics. The results are qualitatively similar for both currency pairs, but particularly significant across the board for JPY/USD, the currency pair where quarter-end funding liquidity shocks set-in earlier in the sample period compared to EUR/USD, for the reasons we discuss in subsequent sections.

Our main results are as follows. First, we find that bid-ask spreads in spot and FX swaps

[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.

are 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 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, as the framework for global systemically important banks (G-SIBs) was introduced and as banks started to shift to the Basel III reporting templates for their capital and liquidity ratios, even though the some regulatory requirements did not become fully bindings until 2018. Significant illiquidity spillovers from FX swaps to spot market also emerged during this period.

Fourth, we uncover 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 January 2015 and May 2017 than they were during the 2011-12 European debt crisis. Further, we document that it is the desks belonging to institutions classified as 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]

Fifth, we find that small dealers step-up their quoting activity in FX swaps when G-SIB dealers pull-back. However, since smaller dealers charge wider bid-ask spreads and a steeper forward discount compared to large dealers, liquidity in FX swaps remain 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"

[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.

forward rate.[3]

Finally, we link banks' liquidity provision in FX swap and spot markets with their balance sheet characteristics. Whether or not a dealer is classified as belonging to a G-SIB remains the most robust determinant of pull-back from posting FX swap quotes at quarter-ends. This is because FX swaps count toward the complexity score component, which can contribute to putting the bank into a higher G-SIB bucket subject to higher loss absorbency (HLA) requirements via additional capital charges. Therefore, G-SIBs have an incentive to cut back their FX swap business around regulatory reporting periods. In addition, we find evidence that capital and liquidity constraints of G-SIBs also appear to bind, suggesting that those manage down their consolidated balance sheet or operate closer to regulatory minimums also reduce liquidity provision in FX swaps by more. Furthermore, dealers with greater funding costs for their derivatives book - as gauged by higher funding value adjustment (FVA) costs - regardless of whether they belong to G-SIB or not, tend to decrease their FX swap liquidity provision in one of the currency pairs. Importantly, in contrast to the swap market, dealer quoting activity in the spot market appears largely unaffected by these balance sheet and funding cost metrics.

As in most empirical research, our findings are conditional on the representativeness of the data source(s). We source tick-level data from *Refinitiv* tick history database, which collects time-stamped electronic quotes covering a large segment of the FX market. The data mainly capture the dealer-to-client segment because the wholesale inter-dealer FX swap market is predominantly a brokered market. 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 presents summary statistics of liquidity measures and dealer activity. Section 5 contains the main empirical analysis of FX liquidity dynamics and combines data sourced at the tick-by-tick frequency with quarterly balance sheet information reported by banks. Section 6 concludes.

[3]Interestingly, our finding are echoed in the recent report published by the Bank of Japan in May 2021, which found that smaller banks that do not actively engage in currency swap trading in normal times entered the Tokyo swap market during the Covid-19 financial market turmoil in March 2020, while larger banks decreased their transaction volumes and diversified counterparties (see Maruyama and Washimi (2021)).

2 Related literature

This paper relates to several strands of the 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 considering liquidity conditions in the FX swap market as well as spot.[4]

This aforementioned extension allows us to explicitly account for the joint behavior of FX market liquidity and FX funding liquidity.[5] While Banti and Phylaktis (2015) do assess this 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) conduct an early assessment of the

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

[5]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 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.

effects of dealer competition on liquidity, but exclusively look at dynamics in the spot market segment. 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. Furthermore, we contribute 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) and assess the impact of large and small dealers on liquidity conditions in both spot and FX swaps.

In addition, 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 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 add 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 CIP deviations, particularly at quarter- and year-ends. We also show that both capital and liquidity ratios constitute bindings constraints for these dealers. 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.

Finally, our paper contributes to a broader literature on constraints on financial intermediation, particularly in OTC markets. From a theoretical perspective, Froot and Stein (1998) show that market distortions arising from credit risk or balance sheet compositions affect dealer's capacity of intermediation, risk management and hedging decisions. Andersen, Duffie, and Song (2019) illustrate how prices quoted by dealers in OTC markets are adjusted to account for intermediation costs and frictions. Specifically, they show that FX swap dealers incur FVA costs because hedging swap transactions in the inter-dealer market requires banks to post collateral, which needs to be financed at the expense of shareholders. On the empirical side, Munyan (2015) documents window-dressing activity of certain dealers in the repo market that can be linked to varying reporting requirements across jurisdictions in the post-2008 period. Also focusing on collateralised markets, Ranaldo, Schaffner, and Vasios (forthcoming) provide evidence of the impact of regulatory changes on both supply and demand side in European repo transactions. Cenedese, Ranaldo, and Michalis (2020) study interest rate swap markets, and find persistent OTC premia for contracts that are not centrally cleared. Given that none of the deliverable FX derivatives are centrally cleared, so that counterparties take direct bilateral risk exposures to each other, such premia are endemic in FX markets.

3 Data and Variable Definitions

We obtain tick-level data for JPY/USD and EUR/USD spot rates, 1-month swap points, and 1-month OIS rates from *Refinitiv's* Tick History data, distributed via 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. Table 1 shows the sample of tick history data for a two-second window for spot JPY/USD.[6]

[Table 1, about here]

We conduct our main analysis at the hourly frequency 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 and total number of unique banks actively posting quotes in each hour.

Next, while activity in 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 remove 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

[6]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 *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 *Refinitiv* 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.[7] In addition, we exclude flexible holidays, such as Good Friday, Easter Monday, Memorial Day, Labour Day, and Thanksgiving and the day after. The entire sample period comprises 44,088 hourly observations for each currency pair. In what follows, we describe the main price and quantity measures for our empirical analysis. An overview of these variables is provided in Table 2.

[Table 2, about here]

3.1 Price measures of market liquidity

We construct the measures of market liquidity, employing spot dealers' spot bid and spot ask prices and FX swap dealers' quoted bid and ask swap points. We define the 1-month forward rate implied by swap points as $F = S + SP * 10^{-2}$ for JPY/USD and $F = S + SP * 10^{-4}$ for EUR/USD, 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

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

at the pre-agreed forward exchange rate F.[8]

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

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

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 covered interest parity condition (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:[9]

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

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

The pricing of FX swaps thus contains information about both market and funding liquidity.[10] 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.

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

[9]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.

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

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 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.

3.4 Bank-level variables and regulatory considerations

Records of dealer identities actively posting quotes allows to construct variables that distinguish according to dealer characteristics. While Phylaktis and Chen (2010) relied on the ranking of the Annual *Euromoney Survey* to classify dealers by their FX business size, we consider as large dealers those whose parent bank has been designated as a G-SIBs according to the Financial Stability Board's (FSB) designation (BIS, 2011, 2013). Banks classified as G-SIBs are subject to higher loss absorbency (HLA) requirements via additional capital charges.[11] This categorization allows to investigate how regulatory frameworks and requirements specifically designed for G-SIBs may have an impact on the quoting activity of dealers in the FX markets. All other participants actively submitting FX swap quotes are referred to as small dealers.

Distinguishing between G-SIBs and other banks is important for our study because of the way FX swaps are treated in regulatory accounting and banks' capital requirements. Specifically, FX swaps book contributes to the G-SIB score via the so-called complexity

[11] Financial Stability Institute (2018) provides a concise summary of the G-SIB framework, including the following: during the Great Financial Crisis, the failure or impairment of a number of large, globally active financial institutions created enormous stress in the financial system and harmed the real economy. The public sector interventions to restore financial stability at the time demonstrated the need to put in place measures to reduce the likelihood and severity of the failure of a global systemically important financial institution (G-SIFI). To that effect, the official community developed new requirements for G-SIFIs, starting with global systemically important banks (G-SIBs). To reduce the probability of failure of G-SIBs, the Basel Committee on Banking Supervision (BCBS) increased the going-concern loss absorbency of G-SIBs through an assessment methodology and related higher loss absorbency (HLA) requirement.

component (BCBS (2013)), whereas only a tiny fraction of FX swaps business contributes to exposure under the leverage ratio reported by all banks (an often overlooked technicality in a number of previous studies).[12] Hence, the direct incentive to window-dress FX swaps exposure is much higher for 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.[13]

[Tables 3 and 4, about here]

Table 3 shows the timetable for operationalising the G-SIB framework. Note the lags in the timeline before a bank is subjected to new HLA requirements: the list of G-SIBs subject to HLA requirements in year t is published in year $t-2$ based on their financial data in year $t-3$ as compared to the scores calibrated to financial data of year $t-4$. As such, the first publication of the list of G-SIBs subject HLA requirement from 1 January 2016 took place in November 2014, based on the 2013 financial data comparison to the G-SIB bucket cutoff scores calibrated to the 2012 data. Table 4 shows all banks in our database that have been classified as G-SIBs at least during one year during the sample period.

In addition to G-SIB designation, we also account for the main balance sheet constrains that may affect FX swap liquidity provision by banks: leverage, capitalisation, liquidity, funding costs associated with derivatives business, and more general funding spreads related to banks' perceived credit risk. The specific metrics are leverage ratio (total equity % total assets, LR), Tier-1 capital ratio (% risk-weighted assets, $T1R$), liquidity coverage ratio (LCR), FVA (which we divide by the total size of the derivative trading assets to obtain a comparable ratio), and changes in banks' CDS spreads (ΔCDS). This data come at a quarterly frequency, from Q1 2010 to Q2 2017. The source is S&P Capital IQ.

[12] 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). For longer-dated instruments, i.e. cross-currency swaps, credit risk and market risk become relevant, and these are reflected in what is known as credit value adjustment (CVA) charge, see Borio, Iqbal, McCauley, McGuire, and Sushko (2016) for evidence.

[13] Derivatives, including FX swaps, are only one part of the total score (contributing to about 1/3 of one out of five components (the complexity component) of the total G-SIB score, BCBS (2013)).

Table 5 shows the timeline of the phase-in arrangements of Basel III standards for the leverage ratio, Tier-1 capital ratio, and the LCR. Note the gradual phasing-in for all three ratios between 2013 and 2019. Leverage ratio was on a parallel run with the old requirements from 1 January 2013 to 1 January 2017, with the disclosure of (but not the adherence to) the Basel III leverage ratio starting on 1 January 2015. Basel III leverage ratio finally became part of the Pillar 1 requirements on 1 January 2018. Concerning the minimum Tier-1 capital ratio, it was gradually raised from 3.5% to 4.5% during this period. Finally, the LCR was first introduced on 1 January 2015, and was gradually raised from 60% to 100% coverage by 1 January 2019.

[Table 5, about here]

4 Summary statistics

4.1 Liquidity at the 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.

The deterioration in liquidity conditions, reflected in all four series plotted in Figure 1, becomes apparent from 2014 onwards. As discussed in the previous section, 2014 was the year of the first publication of the G-SIB list, an increase in Tier-1 capital ratio from 3.5% to 4.0%; it was also the year based on which exposure under Basel III leverage ratio was calculated for the first-time disclosure on 1 Jan 2015 and the year prior to the first application of the LCR. There are also some differences between JPY/USD and EUR/USD. Most notably, while bid-ask spreads, forward discounts and CIP deviations widen for both currency pairs, the first quarter-end turn for EUR/USD only occurred in December 2015, right before the first round of HLA application to G-SIBs. By contrast, quarter-end balance sheet management by banks more active in JPY/USD intermediation exerted significant effects on prices since end-2014. This suggests some differences in the population of dealers between JPY/USD and EUR/USD, with banks more active in the former either exhibiting sensitivity to greater number of balance sheet constraints or simply approaching the disclosures and implementation of the new regulatory regimes with greater caution.

Table 6 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 the end of 2014. 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 in QE months, differences with the NQE monthly average, and p-values of a variance ratio test.

[Table 6, about here]

The table shows significant differences between quarter end and non-quarter end months, and that these differences grow stronger in the second half of our sample. Specifically, the table shows that FX funding liquidity, as measured by either $Fdiscount$ or $CIPdev$ (forward discount adjusted by the level of benchmark interest rates), 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 sub-sample period. In addition, spot market liquidity in JPY/USD has also began exhibiting significant deteriorations at quarter-ends in the latter half of our sample, 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.

Next, we provide preliminary evidence that the link between funding and market liquidity strengthened over time, is particularly apparent during quarter-end months, and is robust to several control factors. Table 7 reports standardized regression coefficients between funding liquidity, measured by the forward discount, and market liquidity in the spot market. We find that co-movement strengthens for JPY/USD (EUR/USD) from about -0.40 (0.26) to about -0.55 (-0.27) in the second sub-sample. Co-movement remains strongly significant and increases for both currency pairs, even after controlling for quoting intensity in spot markets (Q^S/N^S), volatility RV^S, and the strength of the U.S. dollar (DOL), as measured by the dollar portfolio, which is the cross-sectional average of G9 currency returns. Furthermore, we show that co-movement is particularly strong in the last month of each quarter. To this end, we construct a dummy variable that equals to one in quarter-end months, and zero otherwise, and interact it with our market liquidity measure ($BASpread^S_Q$). As shown, the coefficient is negative and significant at the 1% level in the second half of our sub-sample. For JPY/USD total co-movement accounts for -0.90, while it amounts to -0.71 for EUR/USD. Lastly, we note that the adjusted R^2 increases across all columns in the second half of our subsample, providing further evidence that co-movements between liquidity measures has become more important.

These quarter-end anomalies are a recent phenomenon that has emerged since about September 2014 for JPY/USD (March 2015 for EUR/USD).[14] 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).

[Table 7, about here]

4.2 G-SIB quoting activity compared to other FX dealers

The demarcation of the shift in FX swaps business runs along the G-SIB vs non G-SIB split, rather than being a common feature due to all banks. Large dealers have decreased the share of their activity in FX swaps in favour of spot. By contrast, small dealers have become increasingly important as liquidity providers in the FX swap markets.

The Venn diagrams in Figures 2a and 2b show the fraction of dealers quoting prices only for FX swaps, only for spot, or in both markets (overlapping areas), in the 2010-2014 versus

[14] More formally we repeat the univariate regression analysis in Table 7 and conduct a Wald test for a structural break at the end of 2014. The null hypotheses of no structural break is rejected for every specification. Results of the structural break test are reported in the appendix (Table A1).

the 2015-2017 period; for the two types of dealers: large dealers (G-SIBs) and small dealers.[15] The figures illustrate that the share of large dealers active in the JPY/USD FX swap market decreased from 55% in the 2010-2014 period to 49% in the 2015-2017 period (red circles, total areas). By contrast, the share of small dealers actively quoting in swap markets increased from 43% to 55%. At the same time, the proportion of smaller dealers active only in spot markets declined from 57% to 45%, pointing toward the growing importance of this dealer group for liquidity provision in more than one market segment.

Similar trends can be also observed in Figures 3a and 3b for the euro. Here, the share of large banks active in swap markets remains almost constant in both sub-periods (2010-2014: 61%; 2015-2017: 63%), while the activity of small dealers in swap increases significantly from 37% to 52%. Figure 2c and 3c further show 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. For both currency pairs, we observe spikes in the percentage of dealers active only in spot (blue) during quarter- and year-end periods.

[Figure 2 and 3, about here]

5 Empirical analysis

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 second 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 the end of 2014. Furthermore, it is only in the latest sub-sample period that FX funding liquidity droughts appear to spillover to market liquidity conditions.

5.1 Liquidity conditions in spot and FX swaps, and their interactions

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 esti-

[15] 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.

mate 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 model allows assessing the long- and short-run dynamics between various measures 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:

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

where $\mathbf{z_h^P} = (Spread_h^P, |Fdiscount|_h, Q_{LD,h}^P/N_{LD,h}^P, Q_{SD,h}^P/N_{SD,h}^P, Vol_h^P) = (Spread_h^P, \mathbf{x_h^P})'$ is a vector of endogenous variables. LD and SD denote large (G-SIB) and small (non G-SIB) dealers, for both spot and swap market quotes, $P = S, F$, respectively. The vector contains the 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 examine if the coefficient of the cointegrating relationship is smaller than 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 analyse 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 8 shows the coefficient estimates of the long-run equations, expressed in terms of economic magnitudes by scaling by the standard deviations of the regressors.[16] The reported

[16] Appendix Table A4 and Table A5 show the complete test results for the long-run relationship among the variables for JPY/USD and EUR/USD, respectively.

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 8, 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 32.8*bp* (8.8*bp*) wider bid-ask in JPY/USD (EUR/USD) swap, and a 19.3*bp* (9.0*bp*) wider bid-ask spread in JPY/USD (EUR/USD) spot. The link between funding and market liquidity strengthens in the second sub-sample period. For JPY/USD it increases to 38.7*bp* in the swap bid-ask spread equation, while we observe a substantial strengthening of the liquidity relationship from 8.8*bp* to 26.2*bp* for EUR/USD in the swap market. In the spot market, we also find a stronger relationship for the yen (30.0*bp*), while it remains on a comparable level for the euro (12.9*bp*).

Second, the marginal improving effect of dealer competition on market liquidity in FX swaps has declined significantly (JPY/USD) or even completely disappeared (EUR/USD). A one standard deviation increase in the quoting intensity by G-SIB dealers in the swap market, Q^F_{LD}/N^F_{LD} used to be associated with a 28.0*bp* (14.2*bp*) narrowing of bid-ask spreads on JPY/USD forward rate spread (EUR/USD forward rate spread) in the 2010 to 2014 period, but the effect becomes small or even insignificant in the second period. For the yen, the coefficient declines to -0.097 while it becomes statistically indistinguishable from zero for the euro (0.011). In contrast, the association between higher quoting intensity of small dealers (non G-SIB dealers), Q^F_{SD}/N^F_{SD}, and worse market liquidity in FX swaps has strengthened for both currency pairs. For JPY/USD the coefficient associated with small dealer quoting activity increases from 0.092 to 0.125, while it turns positive and significant for the euro (0.074). Thus, a one standard deviation increase in Q^F_{SD}/N^F_{SD} is associated with 12.5*bp* (7.4*bp*) wider bid-ask spreads in FX swap market for JPY/USD (EUR/USD). The change in magnitudes of these coefficients indicates the increasing relative importance of small dealers on liquidity dynamics in the FX swap market.

Third, in contrast to the swap market, competition amongst large dealers 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_{LD}/N^S_{LD}, is associated with 13.3bp (24.7bp) narrower bid-ask spreads in JPY/USD (EUR/USD) spot.

Fourth, a rise in non G-SIB dealer activity in swaps appears to have adverse 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 small dealers in swaps is associated with wider bid-ask spreads in the spot market (Table 8, last column). For example, 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 larger in magnitude and takes on a positive sign (15.4bp). Similar dynamics can be observed for the yen, where the coefficient associated with Q^F_{SD}/N^F_{SD} increases to 21.4bp, while the impact of small dealer quoting activity in spot markets is insignificant.[17]

5.2 The shift towards small dealers and illiquidity

What are the possible economic explanations 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 9, which shows averages of the median hourly bid-ask spreads and forward discounts computed from forward quotes by large and small dealers. Considering the full sample period, 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 dealers. For example, for JPY/USD (EUR/USD) the average spread quoted by small dealers in the forward market is 3.688bp (2.247bp), compared to 3.315bp (2.218bp) by large 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 liquidity providers 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 same degree as achievable by large dealers. The differences in quoted forward discounts between large and small dealers are also consistent across quarter-end and non-quarter-end months, as shown by the middle and bottom panel of Table 9. While the differences for EUR/USD are small, for JPY/USD we find that forward discounts and forward spreads of small dealers tend to be consistently larger than those of large dealers.

[17] The results are also robust to measuring FX funding liquidity using CIP deviations instead of the unadjusted forward discount (see Appendix Tables A6 and A7).

[Table 9, 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 rates via the intermediation of large dealers. Our logic is consistent with this literature. Large dealers intermediate the lion share of customer flow 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 examine this conjecture, we follow recent studies which assess the distribution of quote submissions. For example, Corsetti, Lafarguette, and Mehl (2017) use information on both 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 controls:

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

$\mathbf{z_h^F} = (Disp_h^F, Q_{j,h}^F/N_{j,h}^F, Vol_h^F) = (Disp_h^F, \mathbf{x_h^F})'$ and $j = LD, SD$, denotes large (G-SIB) and small dealer (non G-SIB) quoting intensity, respectively. Table 10 shows the results.

In the top panel, coefficients are scaled by the variables' standard deviation and we report results for both sample periods separately. In the first sub-sample (02/2010-12/2014) higher quoting intensity of all dealers leads to a decline in the dispersion of forward spreads. For JPY/USD, a one standard deviation increase in quoting intensity of large and small dealers decreases the dispersion of forward quotes by 5.2*bp* and 17.4*bp*, respectively. Similar observations can be made for EUR/USD, even though the impact of small dealers appears to be not significant. Consistent with the hypothesis outlined above, however, we find that these dynamics change in the period after 2014. Higher quoting intensity by G-SIB dealers continues to be associated with a significant decline in the dispersion of forward quotes of 8.8*bp* for JPY/USD and 7.1*bp* for EUR/USD. In contrast, quoting intensity by non G-SIB FX dealers continues to have a weaker effect on the price discovery process or even increases dispersion, suggesting that small dealers quote prices further away from the average mid-quote. For JPY/USD, higher small dealer quoting intensity increases the spread of quoted forward rates by 17.8*bp*. For EUR/USD, small dealer quoting activity continues to be negatively associated with quote dispersion in the period 2015-2917; yet the coefficient is smaller compared to the impact of large dealers and it is only weakly statistically significant at the 10% level. Taken together, these results suggest that banks with a smaller customer base and exposed to lower volumes of customer order flow contribute to a wider dispersion of forward quote submissions.

[Table 10, about here]

To summarise, the results reported in Tables 9 and 10 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.

5.3 Bank characteristics and quoting activity

The analysis in the previous sections showed that a relative decline in liquidity provision by dealers belonging to G-SIBs in recent years has been accompanied by wider spreads and higher price dispersion in both spot and FX swap markets. In this sub-section, we assess whether such demarcation along the G-SIB designation is robust to controlling for other balance sheet constraints and funding costs. We also assess whether some balance sheet constraints are more binding for G-SIB compared to non-G-SIB dealers, and whether the effects are different between spot and FX swap markets.

We construct a quarterly panel with (consolidated) information on dealer banks' leverage ratio, capital-to-risk weighted assets ratio, liquidity ratio, the cost of funding a derivatives book of dealer banks, and the broader funding costs measure. The specific metrics are leverage ratio (total equity % total assets, LR), capital-to-risk-weighted assets ratio (Tier-1 capital % risk-weighted assets, $T1R$), liquidity coverage ratio (LCR), funding value adjustment (FVA) costs normalised by the notional amount of derivatives trading assets reported by each bank, and changes in banks' CDS spread (ΔCDS). In order to examine the impact of these bank-level variables on dealer's quoting behaviour, for each bank we construct a quarter-end quoting-activity ratio (QER) equal to the average number of daily quote updates during quarter-end months divided by the same measures in non-quarter-end month. In line with Munyan (2015), who documents a change in quoting activity towards the end of the month, in the baseline specification we focus on the last two weeks (15 days) of the quarter-end periods to capture dealers' potential window dressing activity at the end of a quarter.[18]

We estimate different specifications of a panel regression model of the form:

$$QER_{it} = \alpha + \lambda LD_i + \boldsymbol{\beta} \boldsymbol{X_1} + \boldsymbol{\gamma} \boldsymbol{X_2} + \boldsymbol{\delta} \boldsymbol{X_3} + \phi_i + \varepsilon_{it} \quad (8)$$

with the quarter-end quoting activity ratio (QER) and a dummy variable (LD) that equals one if a bank is classified as G-SIB, and zero otherwise. Further, aforementioned bank characteristics serve as regressors, whereby the liquidity and capital ratios are grouped in $\boldsymbol{X_1}$, i.e. $\boldsymbol{X_1} \in \{T1R, LCR, LR\}$, $\boldsymbol{X_2}$ contains interaction terms between the ratios and the large bank dummy variable, i.e. $\boldsymbol{X_2} \in \{T1R \times LD, LCR \times LD, LR \times LD\}$ and $\boldsymbol{X_3}$ contains cost related measures, i.e. $\boldsymbol{X_3} \in \{FVA, \Delta CDS\}$. The interaction terms between the dummy variable and the balance sheet ratios capture any differences in the impact of regulatory reporting requirements between the two dealer groups. Table 11 report the main

[18]We document in the appendix that results are robust and qualitatively similar if other intra-month periods are used.

results for JPY/USD (top) and EUR/USD (bottom).

[Table 11, about here]

The four main take-aways are as follows. First, the negative relation between G-SIB designation and liquidity is very robust, and G-SIB quoting activity in FX swaps indeed began to decline during quarter-ends in the post-2014 period. The coefficient associated with the dummy variable LD (λ) is negative for both currency pairs and is significant across almost all model specifications for JPY/USD and in most cases for EUR/USD.[19]

Second, both capital and liquidity appear to be binding constraints for G-SIB dealers in FX swap markets. This suggests that G-SIBs that are engaged in consolidated balance sheet management around reporting periods, or operate close to capital or liquidity regulatory minima, reduce FX swap liquidity provision by more. At the same time, although the results are significant for capital-to-risk weighted assets ratio, they are not significant for the leverage ratio. Table 11 column 5 shows that the coefficient on the interaction term of $T1R$ with LD (γ_2) is significant at the 10% level for both JPY/USD and EUR/USD. Column 6 also shows significant positive coefficient on the interaction term of LCR with LD (γ_3) for JPY/USD, but not for EUR/USD. These results indicate that G-SIBs with higher levels of Tier-1 capital and, in the case of JPY/USD, also with higher levels of liquid assets, post relatively more quotes (i.e. window-dress less) compared to G-SIBs with lower ratios.[20] In contrast, coefficients associated with the leverage ratio (LR) are insignificant across all specifications and for both currency pairs (column 7). Hence, the results point at no discernible window-dressing in FX swaps for the purposes of minimising the exposures (total assets) of banks' calculation of the LR. That said, the total effects of leverage ratio reporting may have set-in in the period outside of our sample: as discussed in Section 3.4, while disclosed as of 1 January 2015, the Basel III LR did not become part of the Pillar 1 requirements until 1 January 2018 (see Table 5), whereas our sample period ends in May 2017.

Third, there is some evidence that dealers of all banks that incur higher FVA costs, relative to the size of their derivatives book, reduce their liquidity provision in FX swaps relatively more around quarter-ends. Table 11 column 8 shows that for EUR/USD the coefficient on FVA is negative and significant at the 1% level; however, it is not significant for JPY/USD. This suggests that, at least for EUR/USD, funding frictions lead to changing quoting pattern

[19] Table A8 in the Appendix shows that prior to 2015 large dealers did not exhibit window-dressing behavior in the FX market. In both spot and swap market segments, the coefficients are not significantly different from zero, adding further evidence of a structural change in FX markets post-2014.

[20] The number of observations drops significantly for some specifications, as balance sheet data coverage is sparse.

of dealers, in line with Andersen, Duffie, and Song (2019). As an alternative measure, we also consider the change in CDS spreads (ΔCDS) to capture changes in banks' funding costs due to their perceived credit risk; however, for both currencies the coefficients are not significantly different from zero.

[Table 12, about here]

Lastly, in contrast to the swap market, liquidity provision in the spot market was not affected by dealers' parent banks' capital and liquidity ratios. The results are reported in Table 12. Regression results also show that the coefficients associated with LD (λ) are not particularly robust, even change sign across model specifications, and we are unable to identify a clear evidence of window-dressing behavior by G-SIBs, in contrast to liquidity provision in FX swap markets.

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

As the regulatory requirements were gradually phased-in (see Tables 3 and 5) and their effects on FX market liquidity conditions became more apparent (see Figure 1), smaller dealers started periodically substituting for large dealers as liquidity providers in FX swaps. By December 2016 (the last year-end in our sample), smaller dealers were posting consistently tighter bid-ask spreads compared to G-SIB dealers, with particularly narrower spreads for JPY/USD.

Figure 4 shows the median hourly quotes of swap points of small and large dealers for each hour of the 24-hour trading day for JPY/USD (EUR/USD) on the left (right), for ask (top) and bid prices (bottom). Small dealers quoted comparably lower ask and higher bid prices in FX swap markets over most of the day, and in particular during the most liquid trading hours when European and North American markets are open. The comparison of pricing patterns across the two groups indicates small dealer quotes were more competitive and favorable compared to those of G-SIB dealers. This suggests that for the majority of hours of the trading days in December 2016, small dealers displaced G-SIB bank dealers as liquidity providers to clients in the FX swap market.[21] In the spot market, no such substitution took place for either currency pair, indicating that these dynamics are related to constraints on liquidity provision in derivatives (see appendix Figure A1).

[Figure 4, about here]

[21] See appendix Figure A2 for an illustration of how to infer a more competitive quote from bid and ask prices.

The results thus indicate that smaller dealers can play an important role in liquidity provision 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 liquidity providers. In this context, special periods, like quarter-ends, can be used for identification of funding liquidity effects on dealer competition and FX market activity.

5.4.1 Liquidity provision versus dollar funding

An alternative, plausible, hypothesis is that smaller dealers at times post more competitive quotes in FX swaps in order to source USD funding. However, as explained in detail below, Figure 4 does not support this conjecture. Because, if this were the case, the analysis of bid-ask spreads by dealer category would have shown skewed quotes posted by smaller dealers.

From a dealer's perspective, using passive quotes on a dealer-client platform to borrow USD via FX swaps would involve exchanging JPY or EUR for USD at the bid spot rate, S^{bid} (buy USD using JPY or EUR), with an agreement to repay (sell) the USD for JPY or EUR at the ask forward rate, $F^{ask} = S^{ask} + FP^{ask} \times 10^{-2}$. Note that swap points, FP, are negative when the USD is trading at a premium in the swap market (Figure 4). This ensures that USD borrower receives less units of JPY or EUR per USD in the forward leg than she pays to obtain the USD in the spot leg. In this way, USD borrower pays implicit interest, while the counterparty is compensated by the negative swap points.

If a small bank intended to source USD liquidity, it would want its ask forward quote to be hit (sell USD forward) and its bid spot quote to be hit (buy USD spot), but not its bid forward quote and not its ask spot quote. In other words, in order to purposefully swap into the USD, a small dealer would have to skew the quotes by posting lower ask swap point quotes, but not higher bid swap point quotes, compared to large dealers.

More formally, quote skew for USD funding purposes requires:

$$\text{Spot leg: } S^{ask}_{SD} > \overbrace{S^{ask}_{LD} > S^{bid}_{SD}}^{\text{Spot effective spread}} > S^{bid}_{LD}$$

$$\text{Forward leg: } F^{ask}_{LD} > \overbrace{F^{ask}_{SD} > F^{bid}_{LD}}^{\text{Foward effective spread}} > F^{bid}_{SD}$$

or, if SD and LD spot quotes approximately equal:

$$\text{Spot leg: } \overbrace{S_{SD}^{ask} \approx S_{LD}^{ask} > S_{SD}^{bid} \approx S_{LD}^{bid}}^{\text{Spot effective spread}}$$

$$\text{Forward leg: } 0 > FP_{LD}^{ask} > \overbrace{FP_{SD}^{ask} > FP_{LD}^{bid}}^{\text{Foward effective spread}} > FP_{SD}^{bid}$$

Given that, as highlighted above, we do not observe significant differences between large and small dealer quotes in the spot market (see appendix Figure A1), it is the latter condition that applies, making it sufficient to compare the quotes for FP. If small dealers use FX swaps for USD funding, we would expect FP effective bid-ask spreads to be determined by both types of dealers, and with small dealers quoting better ask prices and large dealers quoting favourable bid prices. Going back to Figure 4, the graph shows that, especially during London and New York open, small dealers are quoting better prices on both sides; and, when some skew can be observed during the less liquid Tokyo open (23:00-7:00 GMT), it runs in the opposite direction than what USD funding purposes would stipulate. Hence, the data on dealers quotes does not support USD funding motive behind the competitive quote placement by smaller dealers.

6 Conclusion

In this paper, we analyse the joint evolution of FX spot and swap market liquidity conditions in one of the main dealer-client electronic market segments. We also draw on the pricing dynamics of both types of instruments to study the relationship between FX market liquidity and FX funding liquidity.

The results for the two most traded currency pairs 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.

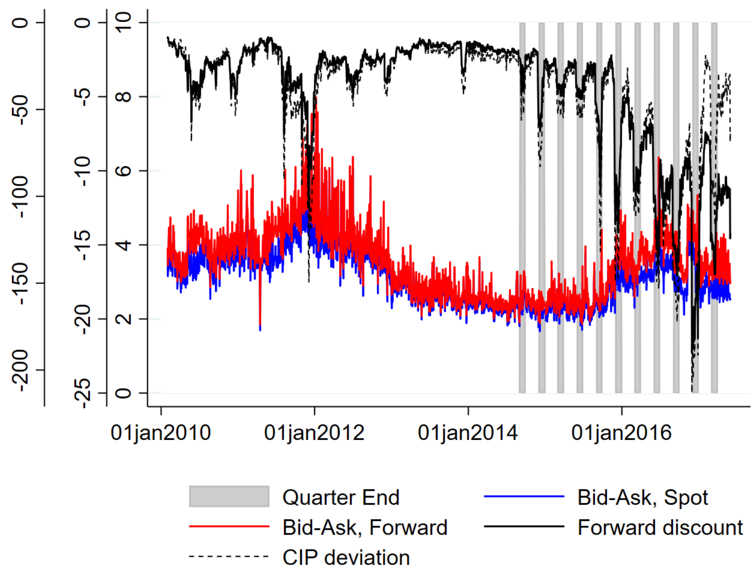
Competition by FX dealers plays an important role in these liquidity dynamics. The positive marginal impact of dealer competition on FX market liquidity has decreased over time. The structural break in the relationship between FX swap and spot market liquidity conditions, and with dealer activity, appears related to the quarter- and year-end window dressing behaviour of large FX swap dealers, particularly desks of banks classified as G-SIBs. While large dealers still dominate liquidity provision in the spot market 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. Even though smaller dealers step-in as marginal liquidity providers when spreads widen during such periods, they appear to be more expensive and less informed so that liquidity droughts persist as a result. Furthermore, spot market liquidity also appears to suffer due to pricing spillovers.

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.

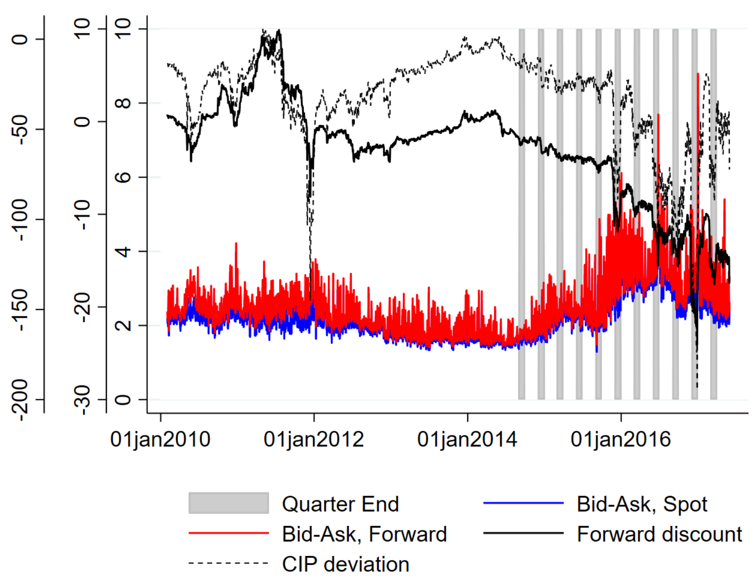
7 Figures

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

(a) JPY/USD



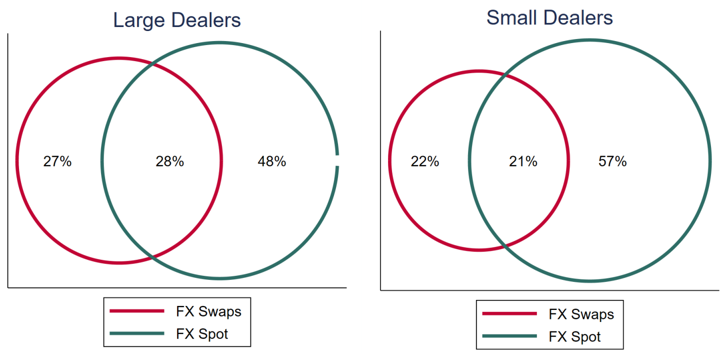
(b) EUR/USD



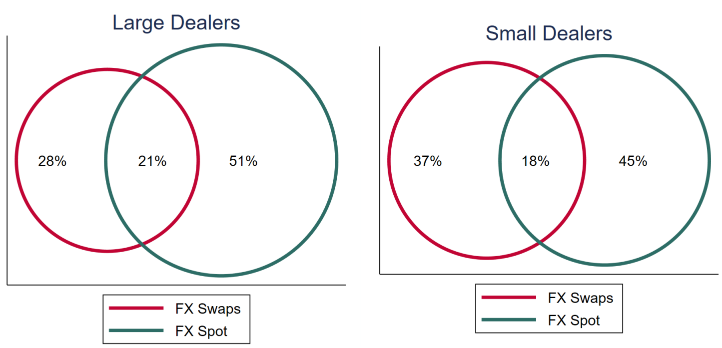
The outside y-axis shows OIS-based 1-month CIP deviations, in basis points; the middle y-axis shows 1-month forward discount, in basis points as a percentage of spot price; the inner y-axis shows bid-ask spreads, in basis points as a percentage of mid-price.

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 - Dec 2014



(b) Average share of dealers active in spot and derivative markets: Jan 2015 - May 2017



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

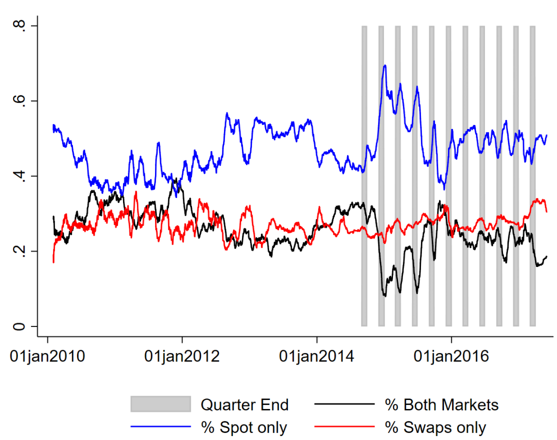
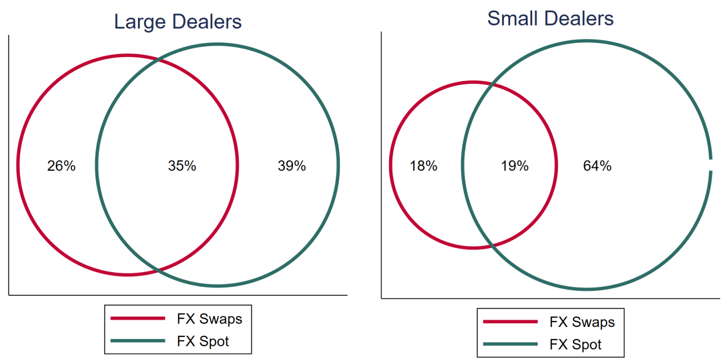


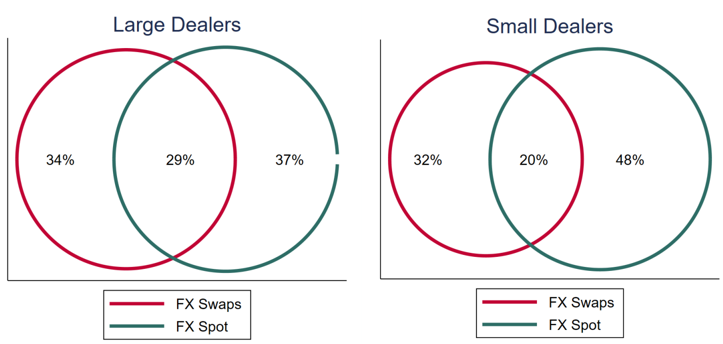
Figure 2a and 2b show the average share of dealers active in different market segments for the period February 2010 - December 2014 and January 2015 to May 2017, respectively. The red line refers to dealers that are only active in the swap market, the blue line refers to dealers active only in spot markets, and the intersection refers to dealers that are active in both markets. Figure 2c shows the 25-day moving average of G-SIBs (large 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 - Dec 2014



(b) Average share of dealers active in spot and derivative markets: Jan 2015 - May 2017



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

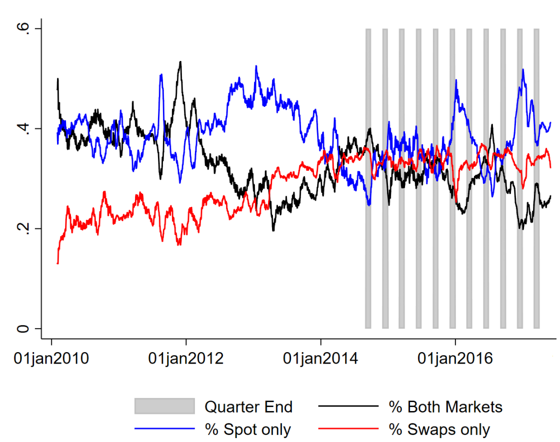
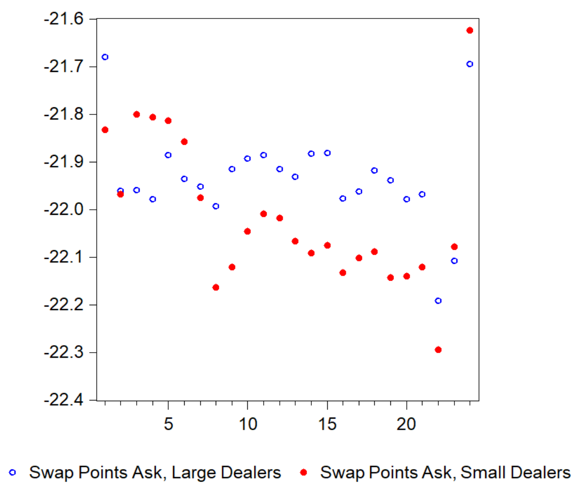
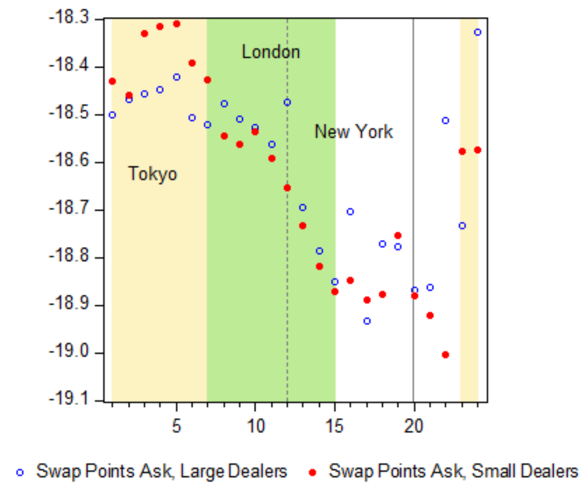


Figure 3a and 3b show the average share of dealers active in different market segments for the period February 2010 - December 2014 and January 2015 to May 2017, respectively. The red line refers to dealers that are only active in the swap market, the blue line refers to dealers active only in spot markets, and the intersection refers to dealers that are active in both markets. Figure 3c shows the 25-day moving average of G-SIBs (larges dealers) that are only active in spot markets, only in swap markets, and in both markets.

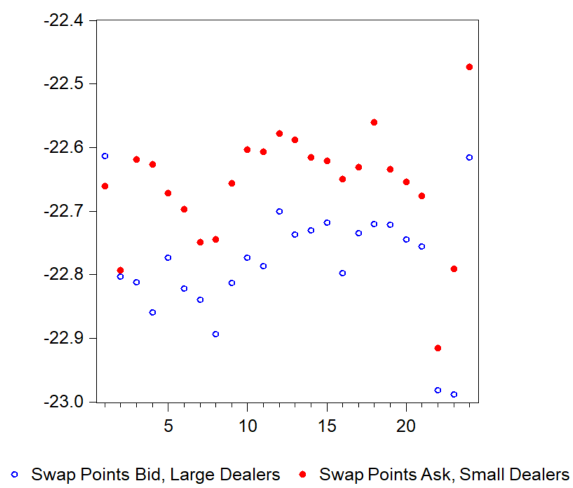
Figure 4: Median quote submissions of swap points quotes (December 2016)



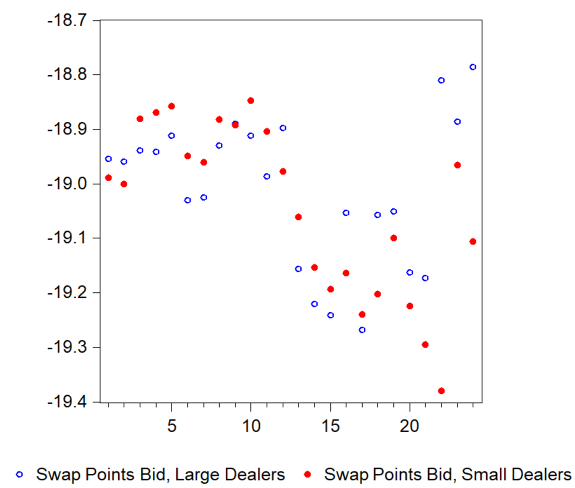
(a) JPY: swap points ASK



(b) EUR: swap points ASK



(c) JPY: Actual swap points BID



(d) EUR: swap points BID

This figure shows median swap point quotes of smaller dealers (non G-SIB banks) compared to forward quotes of large dealers (G-SIB banks) for JPY/USD (left) and EUR/USD (right)). Hourly frequency. GMT timestamps.

8 Tables

Table 1: **Data Snapshot**

This table provides a two-second window snapshot from the Refinitiv Tick History database for JPY/USD spot markets on 5th May 2017.

RIC	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: Refinitiv Tick History (RTH) data, available via Refinitiv Datascope.

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

This table provides an overview of the benchmark measures and outlines the definitions of variables used in the empirical analysis. The column 'Daily' indicates how hourly measures are transformed to the daily frequency.

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: **G-SIB framework – operational timetable**

The table shows the operational timetable for the G-SIB regime and the application of the higher loss absorbency (HLA) requirement for the period relevant to our study.

	Timetable for implementation	
	Mar:	Collection of end-2012 data
2013	Nov:	Collection of end-2012 data
		Publish cutoff scores, bucket sizes and denominators
	Jan:	Implementation of national reporting and disclosure requirements
2014	Mar:	Collection of end-2013 data
	Nov:	Publish updated list of G-SIBs to be subject to HLA requirement from 1 Jan 2016, and updated denominators
	Mar:	Collection of end-2014 data
2015	Nov:	Publish updated list of G-SIBs to be subject to HLA requirement from 1 Jan 2017, and updated denominators
	Jan:	HLA requirement applied to banks designated as G-SIBs published in Nov 2014
2016	Mar:	Collection of end-2015 data
	Nov:	Publish updated list of G-SIBs to be subject to HLA requirement from 1 Jan 2018, and updated denominators
	Jan:	HLA requirement applied to banks designated as G-SIBs published in Nov 2015
2017	Mar:	Collection of 2016 data
	Nov:	Complete first methodology review and announce changes
		Publish updated list of G-SIBs to be subject to HLA requirement from 1 Jan 2019 and updated denominators

Source: Basel Committee on Banking Supervision, Annex 3 in BIS (2013).

Table 4: **G-SIB classification 2016**

This table provides an overview of banks, which are classified in 2016 by the Financial Stability Board as global systemically important banks (G-SIBs).

Agricultural Bank of China	ING Bank
Bank of America Merrill Lynch	JP Morgan Chase
Bank of China	Mitsubishi UFJ FG
Bank of New York Mellon	Mizuho FG
Barclays	Morgan Stanley
BNP Paribas	Nordea
China Construction Bank	Royal Bank of Scotland
Citigroup	Santander
Credit Suisse	Societe Generale
Deutsche Bank	Standard Chartered
Goldman Sachs	State Street
Groupe BPCE	Sumitomo Mitsui FG
Groupe Credit Agricole	UBS
HSBC	Unicredit Group
ICBC	Wells Fargo

Table 5: **Basel III (select) phase-in arrangements**

This table shows the timeline of the phase-in arrangements of select Basel III capital and liquidity standards discussed in the paper. All dates are as of 1 January. For the full list of capital and liquidity standards see: `www.bis.org/bcbs/basel3/basel3_phase_in_arrangements.pdf`.

Phases	2013	2014	2015	2016	2017	2018	**2019**
Leverage ratio	Parallel run, disclosure 1 Jan 2015					Pillar 1	
Minimum Tier-1 Capital	3.5%	4.0%			4.5%		**4.5%**
Liquidity coverage ratio			60%	70%	80%	90%	**100%**

Source: Basel Committee on Banking Supervision

Table 6: **Summary Statistics: Liquidity dynamics at quarter ends**

This table reports the average (Panel A) and standard deviation (Panel B) of 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 for the sub-sample periods 02/2010 - 12/2014 and 01/2015 - 05/2017. The column 'QE' refers to quarter-end months (March, June, September, December), while 'NQE' refers to non-quarter-end months. In Panel A, the column 'p-val' reports the p-value of a one-sided t-test assessing the difference in means between QE- and NQE-months. In Panel B, the column 'p-val' refers to a ratio test assessing the difference in volatility between QE- and NQE-months.

Panel A: Average and t-test

	JPY/USD						EUR/USD					
	02/2010 - 12/2014			01/2015 - 05/2017			02/2010 - 12/2015			01/2015 - 05/2017		
	QE	NQE	p-val	QE	NQE	p-val	QE	NQE	p-val	QE	NQE	p-val
$Fdiscount$	-3.05	-2.37	0.00	-11.13	-7.09	0.00	-0.37	0.21	0.00	-10.38	-8.42	0.00
$CIPdev$	-31.64	-23.45	0.00	-101.12	-51.88	0.00	-25.36	-20.99	0.00	-65.96	-43.10	0.00
$Spread^S$	3.31	3.32	0.78	2.89	2.81	0.08	1.97	1.97	0.91	2.74	2.73	0.76
$Spread^F$	3.61	3.57	0.49	3.35	3.21	0.02	2.18	2.15	0.25	3.02	2.95	0.30

Panel B: Standard deviation and ratio test

	JPY/USD						EUR/USD					
	02/2010 - 12/2014			01/2015 - 05/2017			02/2010 - 12/2015			01/2015 - 05/2017		
	QE	NQE	p-val	QE	NQE	p-val	QE	NQE	p-val	QE	NQE	p-val
$Fdiscount$	1.80	1.06	0.00	4.95	3.74	0.00	2.89	2.97	0.48	5.37	4.19	0.00
$CIPdev$	21.88	12.56	0.00	43.12	29.30	0.00	21.86	13.42	0.00	39.21	24.40	0.00
$Spread^S$	0.81	0.85	0.23	0.58	0.51	0.02	0.39	0.37	0.23	0.69	0.71	0.65
$Spread^F$	0.93	0.97	0.31	0.77	0.66	0.00	0.65	0.45	0.17	0.84	0.77	0.15

Results are based on daily data.

Table 7: **Co-movement of liquidity measures**

This table reports standardized regression coefficients between funding liquidity (*Fdiscount*) and market liquidity in spot markets ($Spread^S$) for two-sample periods (02/2010 - 12/2014; 01/2015 - 05/2017), and controlling for quoting intensity in spot markets (Q^S/N^S), realized volatility (RV^S), the dollar portfolio (DOL), defined as the cross-sectional average of returns of G9 currencies, and $Spread^S_Q$ which is an interaction term between market liquidity in spot markets and a dummy variable equal to 1 in quarter-end months (March, June, September, December).

	JPY/USD					
	02/2010 - 12/2014			01/2015 - 05/2017		
BASpread^S	-0.41***	-0.43***	-0.40***	-0.55***	-0.60***	-0.52***
BASpread^S_Q			-0.23***			-0.38***
Q^S/N^S		-0.04	-0.05		-0.33***	-0.32***
DOL		-0.04*	-0.05*		0.03	0.01
VOL^S		0.01	0.01		0.13***	0.13***
adj-R2	0.17	0.17	0.22	0.31	0.40	0.54
Obs	1,489	1,489	1,489	735	735	735

	EUR/USD					
	02/2010 - 12/2014			01/2015 - 05/2017		
BASpread^S	0.26***	0.41***	0.43***	-0.27***	-0.56***	-0.52***
BASpread^S_Q			-0.11**			-0.19***
Q^S/N^S		0.34***	0.34***		-0.63***	-0.61***
DOL		-0.05*	-0.05*		0.01	-0.00
VOL^S		0.02	0.02		0.28***	0.30***
adj-R2	0.07	0.16	0.17	0.07	0.35	0.38
Obs	1,489	1,489	1,489	735	735	735

Results are based on daily data; Asterisks refer to the following level of significance assigned based on Newey-West adjusted standard errors: *** p<0.01, ** p<0.05, * p<0.1.

Table 8: **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. We estimate the following ARDL model 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, $P = S, F$:

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

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 $j = LD, SD$, denote quoting activity of large and small dealers, respectively. The coefficients are scaled by the standard deviation of the explanatory variables in each sub-sample.

	JPY/USD					
	02/2010 - 12/2014			01/2015 - 05/2017		
Variable	$Spread^F$	$Spread^S$	$Spread^S$	$Spread^F$	$Spread^S$	$Spread^S$
$\lvert Fdiscount\rvert$	0.328***	0.193***	0.182***	0.387***	0.300***	0.277***
Q^F_{LD}/N^F_{LD}	-0.280***			-0.097***		
Q^F_{SD}/N^F_{SD}	0.092***		0.025	0.125***		0.214***
Vol^F	0.152***			0.310***		
Q^S_{LD}/N^S_{LD}		-0.651***	-0.565***		-0.133***	-0.111***
Q^S_{SD}/N^S_{SD}		0.140***			0.004	
Vol^S		0.131***	0.131***		0.260***	0.275***
	EUR/USD					
	02/2010 - 12/2014			01/2015 - 05/2017		
Variable	$Spread^F$	$Spread^S$	$Spread^S$	$Spread^F$	$Spread^S$	$Spread^S$
$\lvert Fdiscount\rvert$	0.088***	0.090***	0.090***	0.262***	0.129***	0.091***
Q^F_{LD}/N^F_{LD}	-0.142***			0.011		
Q^F_{SD}/N^F_{SD}	0.000		-0.004	0.074***		0.154***
Vol^F	0.264***			0.224***		
Q^S_{LD}/N^S_{LD}		-0.158***	-0.166***		-0.247***	-0.286***
Q^S_{SD}/N^S_{SD}		-0.008			-0.022	
Vol^S		0.240***	0.240***		0.108***	0.109***

Hourly sample; GMT timestamps. ARDL lags chosen based on the Schwarz (Bayes) criterion (SC). Asterisks refer to the following level of significance assigned based on standard errors: *** p<0.01, ** p<0.05, * p<0.1.

Table 9: **Forward rate bid-ask spreads and forward discounts by dealer classification**

This table reports median bid-ask spreads of forward rates and quoted forward discount submitted by large and small dealers for the full sample, and for quarter- and non quarter-end months, separately. Large dealers refer to banks classified as global systemically important banks (G-SIBs). Small dealers are banks not classified as G-SIBs. The sample period is February 2010 to May 2017.

	JPY/USD		EUR/USD	
Full Sample:	$Spread^F$	$Fdiscount$	$Spread^F$	$Fdiscount$
Large dealers	3.315*bp*	-2.951*bp*	2.218*bp*	-2.021*bp*
Small dealers	3.688*bp*	-2.985*bp*	2.247*bp*	-2.022*bp*
Quarter-End:				
Large dealers	3.497*bp*	-3.649*bp*	2.270*bp*	-2.186*bp*
Small dealers	3.766*bp*	-3.799*bp*	2.211*bp*	-2.189*bp*
Non-Quarter-End:				
Large dealers	3.300*bp*	-2.580*bp*	2.182*bp*	-1.946*bp*
Small dealers	3.688*bp*	-2.826*bp*	2.250*bp*	-1.946*bp*

Hourly sample; GMT timestamps.

Table 10: **Forward quote dispersion of small and large dealers**

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 for two different sample periods: February 2010 to December 2014 and January 2015 to May 2017:

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

where the 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 $j = LD, SD$, denotes quoting intensity of large and small dealers, respectively. F-statistics refers to the results of the bound testing procedure for a long-run relationship. The estimated constant term and coefficients on short-run effects are omitted for brevity.

	JPY/USD		EUR/USD	
	02/2010 - 12/2014	01/2015 - 05/2017	02/2010 - 12/2014	01/2015 - 05/2017
Q_{LD}^F/N_{LD}^F	-0.052*	-0.088*	-0.226***	-0.071***
	(0.030)	(0.046)	(0.018)	(0.027)
Q_{SD}^F/N_{SD}^F	-0.174***	0.178***	-0.013	-0.056*
	(0.026)	(0.046)	(0.018)	(0.030)
Vol^F	2.997***	2.994***	2.433***	2.755***
	(0.044)	(0.071)	(0.026)	(0.040)
θ	-0.554***	-0.489***	-0.743***	-0.696***
	(0.009)	(0.012)	(0.008)	(0.012)
$F - Stat$	748.7	337.3	2076	703.2
Hour dummies	yes	yes	yes	yes
$Adj.\ R^2$	0.632	0.607	0.618	0.672
Obs	28,267	13,997	28,267	13,997

Hourly sample; GMT timestamps. *** p<0.01, ** p<0.05, * p<0.1.

Table 11: **Bank characteristics and quoting activity in swap markets**

This table reports regression coefficients of a random fixed effects panel model where the left hand-side variable is the ratio of the average number of daily quotes a bank posted in the last two-weeks (15 days) of quarter-end months over the average number of daily quotes in the last two-weeks of non-quarter-end months; explanatory variables include LD, an indicator for banks classified as globally systematically important (G-SIBs), $T1R$, Tier-1 capital (ratio to risk-weighted assets), LCR, liquidity coverage ratio, LR, leverage ratio (common equity over total assets), FVA, funding value adjustment costs (divided by total derivatives trading assets), and ΔCDS, quarterly change in CDS spreads. $T1R \times LD$, $LCR \times LD$, and $LR \times LD$ refer to the corresponding interaction terms. Standard errors are clustered at the dealer group level for multivariate regressions and are reported in parentheses. Observations are quarterly. The period is January 2015 to May 2017.

	JPY/USD								
α	1.71***	2.70***	1.99***	2.43***	3.34***	1.72***	1.55***	1.43***	1.79***
	(0.15)	(0.88)	(0.08)	(0.84)	(0.85)	(0.48)	(0.50)	(0.11)	(0.01)
LD	-0.44**	-0.32**	-0.29***	-0.27***	-2.51*	-2.57**	-0.57	-0.23***	-0.55***
	(0.18)	(0.12)	(0.02)	(0.05)	(1.33)	(1.14)	(1.08)	(0.06)	(0.01)
T1R		-0.07	-0.02**	-0.03	-0.11**				
		(0.06)	(0.01)	(0.03)	(0.06)				
T1R×LD					0.14*				
					(0.08)				
LCR			-0.00***	-0.00***		-0.00			
			(0.00)	(0.00)		(0.00)			
LCR×LD						0.02**			
						(0.01)			
LR				-0.04			0.02		
				(0.07)			(0.08)		
LR×LD							0.02		
							(0.17)		
FVA								0.04	
								(0.93)	
ΔCDS									0.00
									(0.01)
adj-R2	0.02	0.03	0.01	0.01	0.04	0.02	0.02	0.01	0.03
Obs	155	123	54	54	123	61	126	47	110
	EUR/USD								
α	3.82*	4.62	6.79	-4.36	15.81	7.47	1.57	1.65	4.75***
	(2.05)	(10.25)	(13.96)	(4.09)	(11.72)	(4.66)	(2.53)	(0.02)	(0.00)
LD	-2.19	-2.15***	-4.54***	-4.98***	-23.14*	-13.71	-3.35	-0.42***	-3.09***
	(2.08)	(0.49)	(0.84)	(0.23)	(13.14)	(9.96)	(4.18)	(0.01)	(0.00)
T1R		-0.05	-0.02	-0.42	-0.84				
		(0.72)	(0.95)	(1.03)	(0.68)				
T1R×LD					1.44*				
					(0.80)				
LCR			-0.00	-0.01		-0.01			
			(0.01)	(0.01)		(0.01)			
LCR×LD						0.07			
						(0.07)			
LR				3.12			0.38		
				(2.10)			(0.61)		
LR×LD							0.12		
							(0.85)		
FVA								-0.63***	
								(0.18)	
ΔCDS									0.00
									(0.00)
adj-R2	0.00	0.00	0.01	0.05	0.03	0.01	0.01	0.05	0.01
Obs	218	175	85	85	175	95	189	59	171

Quarterly data. *** p<0.01, ** p<0.05, * p<0.1.

Table 12: **bank characteristics and quoting activity in spot markets**

This table reports regression coefficients of a random fixed effects panel model where the left hand-side variable is the ratio of the average number of daily quotes a bank posted in the last two-weeks (15 days) of quarter-end months over the average number of daily quotes in the last two-weeks of non-quarter-end months; explanatory variables include LD, an indicator for banks classified as globally systematically important (G-SIBs), $T1R$, Tier-1 capital (ratio to risk-weighted assets), LCR, liquidity coverage ratio, LR, leverage ratio (common equity over total assets), FVA, funding value adjustment costs (divided by total derivatives trading assets), and ΔCDS, quarterly change in CDS spreads. $T1R \times LD$, $LCR \times LD$, and $LR \times LD$ refer to the corresponding interaction terms. Standard errors are clustered at the dealer group level for multivariate regressions and are reported in parentheses. Observations are quarterly. The period is January 2015 to May 2017.

	JPY/USD								
α	8.71	2.39***	-0.37	-1.94	2.96**	-175.85	-30.31	1.75***	2.13***
	(7.14)	(0.55)	(3.86)	(4.16)	(1.42)	(111.61)	(29.88)	(0.08)	(0.00)
LD	-7.64	-0.70***	-0.65**	-0.47	-1.80	176.76	31.25	-0.68***	-1.05***
	(7.14)	(0.01)	(0.32)	(0.36)	(1.43)	(111.61)	(29.88)	(0.04)	(0.00)
T1R		-0.04	-0.01	0.01	-0.08				
		(0.04)	(0.02)	(0.05)	(0.09)				
T1R×LD					0.08				
					(0.09)				
LCR			0.02	0.02		1.43*			
			(0.03)	(0.02)		(0.84)			
LCR×LD						-1.43*			
						(0.84)			
LR				0.12***			4.81		
				(0.04)			(4.46)		
LR×LD							-4.78		
							(4.46)		
FVA								-0.33	
								(0.34)	
ΔCDS									0.00
									(0.00)
adj-R2	0.00	0.02	0.06	0.06	0.02	0.22	0.04	0.06	0.02
Obs	193	137	66	66	137	80	186	40	139
	EUR/USD								
α	6.36*	19.81*	0.85	0.99	29.10	-10.88	10.87	1.22***	7.95***
	(3.72)	(10.83)	(0.66)	(0.76)	(28.01)	(17.12)	(20.29)	(0.08)	(0.00)
LD	-5.27	-5.34***	0.12***	0.13***	-27.77	11.99	-9.75	-0.17***	-6.86***
	(3.72)	(0.26)	(0.00)	(0.00)	(28.01)	(17.12)	(20.29)	(0.03)	(0.00)
T1R		-0.93	0.03	0.03	-1.60				
		(0.77)	(0.06)	(0.06)	(1.63)				
T1R×LD					1.58				
					(1.63)				
LCR			-0.00	-0.00***		0.15			
			(0.00)	(0.00)		(0.18)			
LCR×LD						-0.15			
						(0.18)			
LR				-0.01***			-0.45		
				(0.01)			(2.24)		
LR×LD							0.45		
							(2.24)		
FVA								0.05	
								(0.41)	
ΔCDS									0.00***
									(0.00)
adj-R2	0.00	0.01	0.02	0.02	0.01	0.04	0.00	0.04	0.01
Obs	284	198	101	101	198	128	259	50	190

Quarterly data. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

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A Appendix

Table A1: **Funding and Market Liquidity Co-movement: Structural Break Test**

This table reports statistics and corresponding p-values of a Wald test, assessing the null hypothesis of "no structural break in December 2014" in the co-movement between funding and market liquidity for JPY/USD and EUR/USD, respectively. Market liquidity in spot (S) and forward markets (F) is measured by the bid-ask spreads in the respective market segments. Funding liquidity is measured by the forward discount ($Fdiscount$) or deviations from CIP ($CIPdev$). The sample period is February 2010 to May 2017.

	JPY/USD				EUR/USD			
	$Fdiscount$		$CIPdev$		$Fdiscount$		$CIPdev$	
	χ^2	$pval$	χ^2	$pval$	χ^2	$pval$	χ^2	$pval$
$Spread^S$	69.68	0.00	43.81	0.00	68.92	0.00	6.84	0.03
$Spread^F$	70.63	0.00	45.83	0.00	73.11	0.00	5.83	0.05

Monthly sample.

Table A2: **Conditional co-movement of liquidity measures (CIP)**

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. We estimate the following ARDL model 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, $P = S, F$:

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

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

	JPY/USD					
	02/2010 - 12/2014			01/2015 - 05/2017		
Variable	$Spread^F$	$Spread^S$	$Spread^S$	$Spread^F$	$Spread^S$	$Spread^S$
$\|CIPdev\|$	0.282***	0.179***	0.169***	0.343***	0.244***	0.251***
Q_{LD}^F/N_{LD}^F	-0.295***			-0.121***		
Q_{SD}^F/N_{SD}^F	0.104***		0.027	0.225***		
Vol^F	0.161***			0.323***		0.135***
Q_{LD}^S/N_{LD}^S		-0.667***	-0.582***		-0.162***	-0.092***
Q_{SD}^S/N_{SD}^S		0.138***			0.129***	
Vol^S		0.127***	0.136***		0.258***	0.279***
	EUR/USD					
	02/2010 - 12/2014			01/2015 - 05/2017		
Variable	$Spread^F$	$Spread^S$	$Spread^S$	$Spread^F$	$Spread^S$	$Spread^S$
$\|CIPdev\|$	0.163***	0.094***	0.095***	0.280***	0.138***	0.122***
Q_{LD}^F/N_{LD}^F	-0.132***			0.021		
Q_{SD}^F/N_{SD}^F	-0.015		-0.016**	0.066***		0.069***
Vol^F	0.206***			0.198***		
Q_{LD}^S/N_{LD}^S		-0.122***	-0.122***		-0.251***	-0.275***
Q_{SD}^S/N_{SD}^S		0.005			0.001	
Vol^S		0.204***	0.204***		0.098***	0.100***

Hourly sample; GMT timestamps. ARDL lags chosen based on the Schwarz (Bayes) criterion (SC). Asterisks refer to the following level of significance assigned based on standard errors: *** p<0.01, ** p<0.05, * p<0.1.

Table A3: **Co-movement of liquidity measures: Individual impact of dealer quoting intensity**

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. We estimate the following ARDL model 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, $P = S, F$:

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

where a vector $\mathbf{z_h^S} = (Spread_h^P, |CIPdev|_t, Q_{j,h}^P/N_{j,h}^P, Vol_h^P) = (Spread_h^P, \mathbf{x_h^P})'$ and $j = LD, SD$, denote quoting activity of large and small dealers, respectively. The coefficients are scaled by the standard deviation of the explanatory variables in each sub-sample. In contrast to the main analysis, the results shown here only include either large (LD) or small (SD) dealer quoting intensity as explanatory variable.

	JPY/USD									
	Large Dealers					Small Dealers				
	02/2010 - 12/2014		01/2015 - 05/2017			02/2010 - 12/2014		01/2015 - 05/2017		
Variable	$Spread^F$	$Spread^S$	$Spread^S$	$Spread^F$	$Spread^S$	$Spread^S$	$Spread^F$	$Spread^S$	$Spread^S$	$Spread^F$
$\|Fdiscount\|$	0.341***	0.186***	0.381***	0.265***	0.291***	0.417***	0.299***	0.398***	0.315***	0.270***
Q_{LD}^F/N_{LD}^F	-0.279***	-0.566***				-0.111***				
Q_{SD}^F/N_{SD}^F			0.104***		0.067**			0.138***		0.084***
Vol^F	0.150***		0.181***			0.317***		0.316***		
Q_{LD}^S/N_{LD}^S							-0.105***			
Q_{SD}^S/N_{SD}^S				-0.211***					-0.050*	
Vol^S		0.131***		0.150***	0.149***		0.283***		0.253***	0.268***

	EUR/USD									
	Large Dealers					Small Dealers				
	02/2010 - 12/2014		01/2015 - 05/2017			02/2010 - 12/2014		01/2015 - 05/2017		
Variable	$Spread^F$	$Spread^S$	$Spread^S$	$Spread^F$	$Spread^S$	$Spread^S$	$Spread^F$	$Spread^S$	$Spread^S$	$Spread^F$
$\|Fdiscount\|$	0.088***	0.090***	0.089***	0.072***	0.057***	0.276***	0.109***	0.263***	0.251***	0.166***
Q_{LD}^F/N_{LD}^F	-0.141***					0.014				
Q_{SD}^F/N_{SD}^F			0.013		-0.014			0.070***		0.043**
Vol^F	0.244***		0.296***			0.223***		0.219***		
Q_{LD}^S/N_{LD}^S		-0.167***					-0.270***			
Q_{SD}^S/N_{SD}^S				-0.062***					-0.131***	
Vol^S		0.221***		0.204***	0.201***		0.108***		0.109***	0.133***

Hourly sample; GMT timestamps. ARDL lags chosen based on the Schwarz (Bayes) criterion (SC). Asterisks refer to the following level of significance assigned based on standard errors: *** p<0.01, ** p<0.05, * p<0.1.

Table A4: **Conditional co-movement of liquidity measures: Results (JPY)**

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. We estimate the following ARDL model 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, $P = S, F$:

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

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 $j = LD, SD$, denote quoting activity of large and small dealers, respectively. The coefficients are scaled by the standard deviation of the explanatory variables in each sub-sample.

	02/2010 - 12/2014			01/2015 - 05/2017		
Variable	$Spread^F$	$Spread^S$	$Spread^S$	$Spread^F$	$Spread^S$	$Spread^S$
$\|Fdiscount\|$	0.327***	0.193***	0.183***	0.387***	0.300***	0.278***
	(0.032)	(0.018)	(0.018)	(0.026)	(0.022)	(0.020)
Q_{LD}^F/N_{LD}^F	-0.280***			-0.097***		
	(0.032)			(0.025)		
Q_{SD}^F/N_{SD}^F	0.092***		0.025	0.124***		0.087***
	(0.032)		(0.018)	(0.032)		(0.020)
Vol^F	0.154***			0.315***		
	(0.031)			(0.039)		
Q_{LD}^S/N_{LD}^S		-0.650***	-0.565***		-0.133***	-0.110***
		(0.026)	(0.022)		(0.027)	(0.026)
Q_{SD}^S/N_{SD}^S		0.141***			0.004	
		(0.023)			(0.027)	
Vol^S		0.123***	0.132***		0.264***	0.280***
		(0.017)	(0.018)		(0.031)	(0.031)
θ	-0.081***	-0.142***	-0.140***	-0.116***	-0.142***	-0.142***
	(0.003)	(0.004)	(0.004)	(0.005)	(0.006)	(0.006)
N	28,421	28,421	28,421	14,115	14,115	14,115
R^2	0.238	0.255	0.254	0.248	0.264	0.252
F-test	137.4	241	234.8	123.3	126.5	140.2

Hourly sample; GMT timestamps. ARDL lags chosen based on the Schwarz (Bayes) criterion (SC). Asterisks refer to the following level of significance assigned based on standard errors: *** p<0.01, ** p<0.05, * p<0.1.

Table A5: **Conditional co-movement of liquidity measures: Results (EUR)**

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. We estimate the following ARDL model 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, $P = S, F$:

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

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 $j = LD, SD$, denote quoting activity of large and small dealers, respectively. The coefficients are scaled by the standard deviation of the explanatory variables in each sub-sample.

	02/2010 - 12/2014			01/2015 - 05/2017		
Variable	$Spread^F$	$Spread^S$	$Spread^S$	$Spread^F$	$Spread^S$	$Spread^S$
$\|Fdiscount\|$	0.088***	0.090***	0.090***	0.263***	0.129***	0.091***
	(0.011)	(0.009)	(0.009)	(0.023)	(0.031)	(0.021)
Q_{LD}^F/N_{LD}^F	-0.141***			0.011		
	(0.012)			(0.025)		
Q_{SD}^F/N_{SD}^F	0.000		-0.004	0.074***		0.078***
	(0.011)		(0.008)	(0.024)		(0.022)
Vol^F	0.244***			0.218***		
	(0.018)			(0.024)		
Q_{LD}^S/N_{LD}^S		-0.158***	-0.166***		-0.246***	-0.287***
		(0.013)	(0.012)		(0.039)	(0.037)
Q_{SD}^S/N_{SD}^S		-0.008			-0.022	
		(0.011)			(0.033)	
Vol^S		0.221***	0.221***		0.106***	0.106***
		(0.013)	(0.013)		(0.021)	(0.020)
θ	-0.124***	-0.163***	-0.164***	-0.117***	-0.131***	-0.134***
	(0.004)	(0.004)	(0.004)	(0.005)	(0.005)	(0.005)
N	28,421	28,421	28,421	14,115	14,115	14,115
R^2	0.241	0.245	0.244	0.335	0.361	0.345
F-test	185.8	247.9	251.7	109.8	111.1	115.5

Hourly sample; GMT timestamps. ARDL lags chosen based on the Schwarz (Bayes) criterion (SC). Asterisks refer to the following level of significance assigned based on standard errors: *** p<0.01, ** p<0.05, * p<0.1.

Table A6: **Conditional co-movement of liquidity measures: Results CIP (JPY)**

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. We estimate the following ARDL model 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, $P = S, F$:

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

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 $j = LD, SD$, denote quoting activity of large and small dealers, respectively. The coefficients are scaled by the standard deviation of the explanatory variables in each sub-sample.

	02/2010 - 12/2014			01/2015 - 05/2017		
Variable	$Spread^F$	$Spread^S$	$Spread^S$	$Spread^F$	$Spread^S$	$Spread^S$
$\|CIPdev\|$	0.282***	0.179***	0.169***	0.343***	0.244***	0.251***
	(0.033)	(0.018)	(0.018)	(0.027)	(0.020)	(0.020)
Q_{LD}^F/N_{LD}^F	-0.295***			-0.121***		
	(0.034)			(0.027)		
Q_{SD}^F/N_{SD}^F	0.104***		0.027	0.225***		0.135***
	(0.033)		(0.018)	(0.033)		(0.021)
Vol^F	0.161***			0.323***		
	(0.032)			(0.043)		
Q_{LD}^S/N_{LD}^S		-0.667***	-0.582***		-0.162***	-0.092***
		(0.026)	(0.022)		(0.027)	(0.027)
Q_{SD}^S/N_{SD}^S		0.138***			0.129***	
		(0.023)			(0.025)	
Vol^S		0.127***	0.136***		5.229	0.279***
		(0.017)	(0.018)		(0.032)	(0.032)
θ	-0.078***	-0.141***	-0.139***	-0.107***	-0.139***	-0.137***
	(0.003)	(0.004)	(0.004)	(0.005)	(0.006)	(0.006)
N	28,421	28,421	28,421	14,115	14,115	14,115
R^2	0.237	0.254	0.253	0.247	0.263	0.250
F-test	133.1	238.6	232.8	118.6	122	136.1

Hourly sample; GMT timestamps. ARDL lags chosen based on the Schwarz (Bayes) criterion (SC). Asterisks refer to the following level of significance assigned based on standard errors: *** p<0.01, ** p<0.05, * p<0.1.

Table A7: **Conditional co-movement of liquidity measures: Results CIP (EUR)**

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. We estimate the following ARDL model 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, $P = S, F$:

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

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 $j = LD, SD$, denote quoting activity of large and small dealers, respectively. The coefficients are scaled by the standard deviation of the explanatory variables in each sub-sample.

	02/2010 - 12/2014			01/2015 - 05/2017		
Variable	$Spread^F$	$Spread^S$	$Spread^S$	$Spread^F$	$Spread^S$	$Spread^S$
$\|CIPdev\|$	0.163***	0.094***	0.095***	0.280***	0.138***	0.122***
	(0.010)	(0.008)	(0.008)	(0.022)	(0.023)	(0.020)
Q_{LD}^F/N_{LD}^F	-0.132***			0.021		
	(0.010)			(0.024)		
Q_{SD}^F/N_{SD}^F	-0.015		-0.016**	0.066***		0.069***
	(0.010)		(0.008)	(0.023)		(0.021)
Vol^F	0.206***			0.198***		
	(0.015)			(0.023)		
Q_{LD}^S/N_{LD}^S		-0.122***	-0.122***		-0.251***	-0.275***
		(0.012)	(0.011)		(0.035)	(0.035)
Q_{SD}^S/N_{SD}^S		0.005			0.001	
		(0.010)			(0.025)	
Vol^S		0.204***	0.204***		0.098***	0.100***
		(0.013)	(0.013)		(0.020)	(0.020)
θ	-0.145***	-0.168***	-0.169***	-0.121***	-0.134***	-0.138***
	(0.004)	(0.004)	(0.004)	(0.005)	(0.005)	(0.005)
N	28,421	28,421	28,421	14,115	14,115	14,115
R^2	0.246	0.245	0.245	0.336	0.362	0.346
F-test	215.1	251.2	255.2	112.9	114	118.4

Hourly sample; GMT timestamps. ARDL lags chosen based on the Schwarz (Bayes) criterion (SC). Asterisks refer to the following level of significance assigned based on standard errors: *** p<0.01, ** p<0.05, * p<0.1.

Table A8: **Bank Characteristics and Quoting Activity in Swap Markets (pre-2015)**

This table reports regression coefficients to a random fixed effects panel model where the left hand-side variable is the ratio of the average quoting activity in the last 15 days of quarter-end months over the average quoting activity in the last 15 days of non-quarter-end months; as explanatory variables serve *LD*, which is an indicator for banks classified as global systematically important banks (G-SIBs). Estimates of the intercept are omitted to preserve space. Observations are quarterly, and the period is February 2010 to December 2014.

	JPY/USD		EUR/USD	
	Swap	Spot	Swap	Spot
LD	15.31	-1.06	0.50*	-1.20
	(14.42)	(1.02)	(0.26)	(3.20)
adj-R2	0.00	0.00	0.00	0.00
Obs	333	447	416	543

Quarterly data. *** p<0.01, ** p<0.05, * p<0.1.

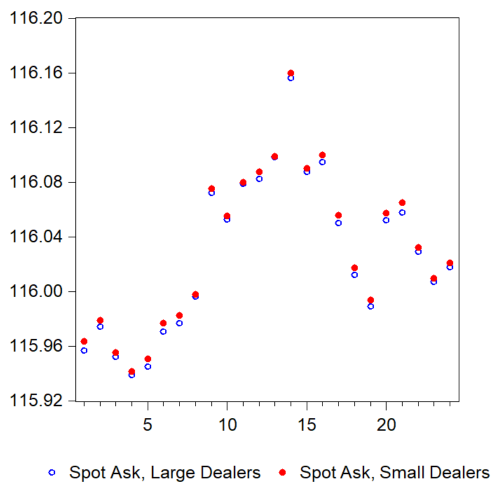
Table A9: **Bank Characteristics and Quoting Activity in Swap Markets (Last 10 Days)**

This table reports regression coefficients of a random fixed effects panel model where the left hand-side variable is the ratio of the average number of daily quotes a bank posted in the last two-weeks (10 days) of quarter-end months over the average number of daily quotes in the last two-weeks of non-quarter-end months; explanatory variables include LD, an indicator for banks classified as globally systematically important (G-SIBs), $T1R$, Tier-1 capital (ratio to risk-weighted assets), LCR, liquidity coverage ratio, LR, leverage ratio (common equity over total assets), FVA, funding value adjustment costs (divided by total derivatives trading assets), and ΔCDS, quarterly change in CDS spreads. $T1R \times LD$, $LCR \times LD$, and $LR \times LD$ refer to the corresponding interaction terms. Standard errors are clustered at the dealer group level for multivariate regressions and are reported in parentheses. Observations are quarterly. The period is January 2015 to May 2017.

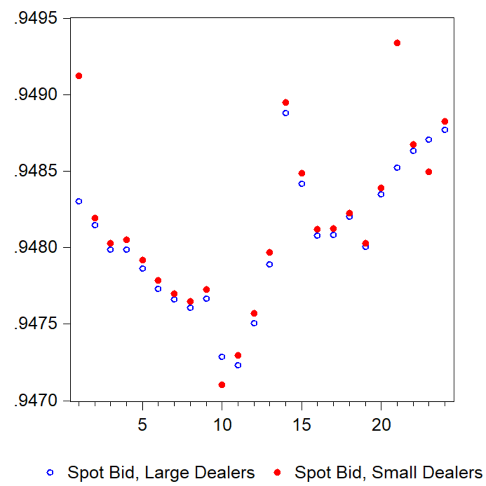
	JPY/USD								
α	1.79***	3.62***	3.29***	2.49***	4.60***	1.88***	0.42***	1.48***	1.95***
	(0.22)	(1.34)	(0.20)	(1.06)	(1.59)	(0.87)	(0.81)	(0.15)	(0.02)
LD	-0.52**	-0.35*	-0.13***	-0.17***	-3.68***	-1.84	0.66	-0.22**	-0.75***
	(0.24)	(0.19)	(0.03)	(0.05)	(1.94)	(1.30)	(1.28)	(0.09)	(0.02)
T1R		-0.12	-0.10***	-0.08***	-0.19*				
		(0.09)	(0.01)	(0.03)	(0.10)				
T1R×LD					0.21*				
					(0.12)				
LCR			-0.00***	-0.00***		-0.00			
			(0.00)	(0.00)		(0.00)			
LCR×LD						0.01			
						(0.01)			
LR				0.07			0.22		
				(0.11)			(0.15)		
LR×LD							-0.20		
							(0.21)		
FVA								0.09	
								(1.24)	
ΔCDS									0.01
									(0.02)
adj-R2	0.01	0.03	0.01	0.01	0.04	0.00	0.02	0.01	0.02
Obs	155	123	54	54	123	61	126	47	110
	EUR/USD								
α	2.91**	1.42	1.64	-5.71	11.08	5.28*	0.85	1.53***	3.47***
	(1.26)	(9.17)	(13.62)	(6.26)	(8.11)	(3.03)	(1.97)	(0.04)	(0.00)
LD	-1.12	-1.08**	-2.58***	-2.80***	-19.77*	-11.96	-1.91	-0.16***	-1.63***
	(1.34)	(0.42)	(0.67)	(0.21)	(10.86)	(10.56)	(3.39)	(0.02)	(0.00)
T1R		0.10	0.20	-0.05	-0.57				
		(0.64)	(0.91)	(0.88)	(0.48)				
T1R×LD					1.28*				
					(0.70)				
LCR			-0.00	-0.00		-0.01			
			(0.01)	(0.01)		(0.00)			
LCR×LD						0.07			
						(0.08)			
LR				2.04			0.35		
				(1.32)			(0.45)		
LR×LD							0.07		
							(0.68)		
FVA								-0.53	
								(0.34)	
ΔCDS									-0.00
									(0.00)
adj-R2	0.00	0.00	0.00	0.03	0.03	0.00	0.00	0.03	0.00
Obs	218	175	85	85	175	95	189	59	171

Quarterly data. *** p<0.01, ** p<0.05, * p<0.1.

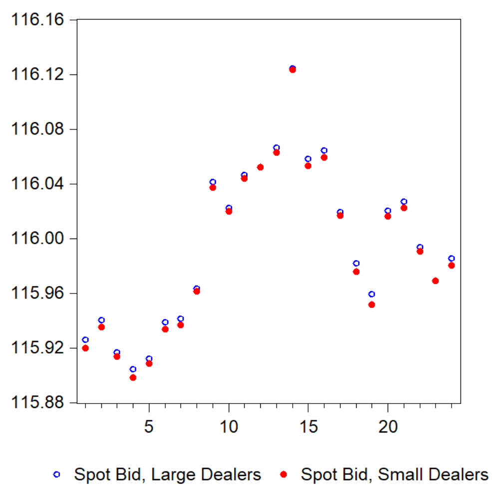
Figure A1: Median quote submissions of spot quotes (December 2016)



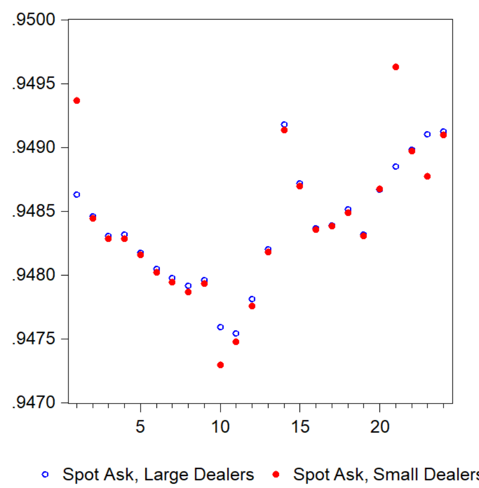
(a) JPY: Spot ASK



(b) EUR: Spot ASK^{-1}



(c) JPY: Spot BID

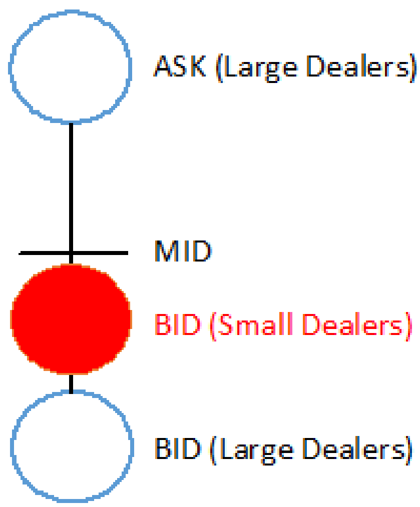


(d) EUR: Spot BID^{-1}

This figure shows median swap point quotes of smaller dealers (non G-SIB banks) compared to forward quotes of large dealers (G-SIB banks) for JPY/USD (left) and EUR/USD (right)). Note, since EUR/USD is shown as 1/ASK and 1/BID to keep consistent units with JPY/USD, while FX dealers actually post quotes in the units of USD per EUR, the inverse of the bid price appears higher than the inverse of the ask price in the graphs. Hourly frequency. GMT timestamps.

Figure A2: Example of small dealer quote submission impact in JPY/USD swap markets (December 2016)

(a) Hypothetical: Small Dealers Short USD forward



(b) Hypothetical: Small Dealers Long USD forward

This figure illustrates the pricing dynamics in FX swap markets in December 2016 when small dealers provided more competitive prices compared to swap point quotes of large dealers (G-SIB banks). As indicated, small dealers replaced G-SIB bank dealers as market-makers in FX swap markets as their quoted swap prices were closer to the mid-price. On the left, small dealer U.S. dollar are cheaper than those offered by large dealers on the ask side (ASK: SELL USD @ 116.160 - 0.221), and on the bid side, i.e. also when small dealers would take a long U.S. dollar forward position (BID: BUY USD @ 116.124 - 0.226).

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