Working Paper Series

Faculty of Finance

No. 25

FX Market Liquidity, Funding Constraints and Capital Flows

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Abstract

We study various aspects of the impact of funding liquidity constraints and capital flows, which proxy for supply and demand considerations of liquidity respectively, on two measures of the common component of FX market liquidity across developed and emerging market currencies, transaction costs and market depth. Funding liquidity constraints reduce FX market liquidity, after controlling for global volatility, and have a stronger impact when the amount outstanding of repos is associated with an increase in the costs of funding and a shortening of their maturity. Increasing capital flows at the global level increase liquidity. Demand and supply determinants of liquidity have also a stronger impact during the recent financial crisis, when liquidity dry-ups were severe. The analysis on individual currencies with diverse riskiness confirms that a shock to speculator capital would lead to a reduction in market liquidity through a spiral effect that is stronger for more volatile currencies. Furthermore, more volatile currencies have a stronger exposure to the liquidity effect of capital flows.

Keywords: foreign exchange; liquidity; funding liquidity constraints; capital flows; microstructure.

JEL Classification: F31; G15.

1 Introduction

Trading volume in the foreign exchange (FX) market is particularly high compared to other financial markets. Whether the large trading volume corresponds to a highly liquid FX market depends on the definition of liquidity adopted and the proxy employed to measure it. With respect to trading volume and the bid-ask spread, there are significant differences across currencies both in the level of liquidity and its time-variation. Furthermore, measuring liquidity as the temporary price impact of transactions, recent studies have found that there is a common component in FX market liquidity across currencies. This common component often

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referred to as commonality in FX market liquidity can arise from variations in the determinants of dealer inventory levels, which is one of the two channels that microstructure has identified of how dealers operations affect market liquidity (Stoll, 1978; Ho and Stoll, 1981).[1] For example, variations in market interest rates are likely to induce co-movements in inventory carrying costs, and optimal inventory levels which lead in turn to co-movements in bid-ask spreads of individual assets, a proxy for liquidity. Studies have found that this common component in FX market liquidity exhibits a strong variation through time (Banti, Phylaktis, and Sarno, 2012; Mancini, Ranaldo, and Wrampelmeyer, 2013).

Recently, a literature on the interaction of market liquidity and funding liquidity has emerged in order to provide an explanation to the severity of the liquidity drop observed during the recent financial crisis (Brunnermeier and Pedersen, 2009; Hameed, Kang, and Viswanathan, 2010; Acharya and Skeie, 2011; Acharya and Viswanathan, 2011). That is, traders' financial constraints influence the liquidity of financial markets (Shleifer and Vishny, 1997; Gromb and Vayanos, 2002). It is important to underline the systematic nature of such an effect: funding liquidity constraints affect all the operations of traders, creating a systematic source of variation in liquidity across financial assets.

Furthermore, recent theoretical studies have proposed an effect of institutional investors' behavior and correlated trading as a source of commonality across assets and markets (Kamara, Lou, and Sadka, 2008; Koch, Ruenzi, and Starks, 2012). In an empirical investigation of the stock market, Karolyi, Lee, and van Dijk (2012) show that these demand-side factors are more relevant as determinants of liquidity commonality across stocks than the supply-side factors related to the funding constraints story.

Building on the recent theoretical literature on the interaction of funding liquidity and market liquidity, we examine whether the time-variation in FX market liquidity is due to changes in the funding liquidity of the principal traders in FX, namely the financial intermediaries. Indeed, bearing in mind that the ease with which financial intermediaries are able to finance their operations has an impact on traders' operations in the cross-section of the financial assets they trade, we expect to find a positive relationship between changes in funding constraints and market illiquidity. In line with the literature on the role of the demand of liquidity, we extend our analysis to the investigation of correlated trading across investors into the FX market by considering the capital flows between the US and the relevant countries. Furthermore, we take into account a variable related to the inventory control risk and market uncertainty, namely global FX implied volatility (Copeland and Galai, 1983). Our approach is empirical in line with Chordia, Roll, and Subrahmanyam (2001) investigation of the determinants of market liquidity in the stock market.

Our paper is related to a recent paper by Mancini et al. (2013) which identifies a negative relationship

[1]The other channel is the asymmetric information channel (Copeland and Galai, 1983; Kyle, 1985; Glosten and Milgrom, 1985).

between the VIX, a proxy for financial uncertainty, and the TED spread, an indicator of funding liquidity constraints, and FX market liquidity for the most traded currencies during the recent financial crisis. However, our paper investigates the impact of not only supply but also demand side factors of FX market illiquidity. Our broad data set of 20 currencies from both developed and emerging markets over 14 years allows us to explore various aspects of the impact of funding liquidity constraints and capital flows, a proxy for demand considerations of liquidity. These include (i) whether funding liquidity dry-ups are worse during the recent financial crisis when funding became a serious issue as stressed by Brunnermeier and Pedersen (2009); (ii) whether when extending the analysis to individual currencies the impact of funding liquidity constraints is stronger for illiquid currencies as a shock to speculator capital would lead to a reduction in market liquidity through a spiral effect that is stronger for more volatile, less liquid currencies, as again proposed by Brunnermeier and Pedersen (2009); and (iii) whether correlated trading in the FX market affect the time variation of FX market liquidity as confirmed for the stock market by Karolyi et al. (2012).

Liquidity is a broad concept and no unique definition exists. Several proxies have been developed to measure it, each referring to some specific aspects. Using a broad data set for 20 daily exchange rates of both developed and emerging markets' currencies over 14 years, we employ the daily percentage bid-ask spreads as our measure of individual currency illiquidity. Averaging across individual currencies, we construct a measure of illiquidity in the FX market. Thus, our main proxy for FX market illiquidity measures the level of transaction costs. Investigating the determinants of liquidity commonality across currencies, we find that the commonality is stronger for more volatile currencies and when the market uncertainty is high.

In order to proxy for funding liquidity, we consider the conditions on the secured interbank market in New York and London, which host over 75% of global FX turnover (BIS, 2013). We show that a lowering in the availability of repurchase agreements for financial intermediaries is associated with a decrease in transaction costs, that is an increase in the liquidity of the FX market. Moreover, we consider the impact of increasing the cost of funding and shortening of repos maturities on this relationship. Furthermore, we take into account the conditions of the liquidity demand and show that as investors buy or sell the currencies vs USD to enter or exit the foreign markets, they exert a pressure on the liquidity of the currency markets. In more detail, we show that increasing capital flows at the global level reduce the illiquidity in the FX market. Overall, our explanatory variables capture an appreciable fraction of the monthly time series variation in market wide liquidity of around 20%.

The length of our sample period allows us to explore whether liquidity dry-ups are worse during the recent financial crisis, when liquidity funding became a serious issue and capital flows experienced a severe drop. We show that both factors of demand and supply of liquidity have a stronger impact on market illiquidity during the crisis.

Our findings are robust to controlling for global FX volatility. Global FX volatility is found to increase transactions costs, consistent with previous studies at the individual currency level. However, while global FX volatility is able to explain a share of the changes in market liquidity, it does not drive out the effect of our explanatory variables on market liquidity. Even though our supply and demand side proxies and volatility are intertwined, their effect on market liquidity can be individually measured. Extending the market level analysis and building on the role of volatility to determine the commonality in liquidity across currencies, we investigate the impact of funding liquidity and capital flows in the analysis of individual currencies. In our sample we have currencies with diverse riskiness. We take that into account in our panel estimation and confirm that a shock to speculator capital would lead to a reduction in market liquidity through a spiral effect that is stronger for more volatile currencies and during crisis periods (Brunnermeier and Pedersen, 2009). Furthermore, we find that capital flows exert a stronger impact on the liquidity of more volatile currencies, especially in normal market conditions.

Our results are robust to another measure of liquidity that has recently received significant attention, namely the temporary return reversal inspired by Pastor and Stambaugh (2003), which relates to the depth of the market.

The paper is structured as follows. In the next section the methodology for the construction of our liquidity measures and proposed determinants is presented. Section 3 reports some preliminary analysis of the data and the results of the regression analysis. Robustness tests, which include the extension of our analysis to the measurement of liquidity at another time period, when liquidity in the market is lower, and filtering for the extreme behavior of the Turkish lira during the 2000-2001 crisis and seasonality, are conducted in section 4. Finally, section 5 concludes.

2 Methodology and data

2.1 Estimation of FX market liquidity

No unique definition of liquidity exists. According to Kyle (1985), liquidity is a "slippery and elusive concept" because of its broadness. In fact, the concept of market liquidity encompasses the properties of "tightness", "depth", and "resiliency". These attributes describe the characteristics of transactions and their price impact. In particular, a market is liquid if the cost of quickly turning around a position is small, the price impact of a transaction is small, and the speed at which prices recover from a random, uninformative shock is high. In our analysis, we are employing the percentage bid-ask spreads as a proxy for transaction costs. The bid-ask spread is the most widely used measure of liquidity in the FX market e.g. Bessembinder (1994), Bollerslev and Melvin (1994), Lee (1994), and Hsieh and Kleidon (1996).

However, the bid-ask spread suffers from some limitations as a measure for liquidity. For example, Grossman and Miller (1988) highlight that the bid-ask spread gives the cost of providing immediacy of the market maker in the case of a contemporaneous presence of buy and sell transactions. Furthermore, because the spread is valid only for transactions up to a certain size, it provides no information on the prices at which larger transactions might take place, or how the market might respond to a long sequence of transactions in the same direction, which could be generated when a trader breaks a large trade into many smaller ones, that could span several days. In contrast, measures such as those proxying for price impact capture that aspect better than the bid-ask spread Vayanos and Wang (2013). As a result of these possible limitations, we extend our analysis to another liquidity measure, which proxies for the price impact to obtain a more complete picture, a modified version of Pastor and Stambaugh (2003) measure in section (4.4) .

We build the daily series of percentage bid-ask spreads of the USD against other currencies following the American system and we employ the percentage spread to increase comparability across currencies, as follows:

$$PSPR_{i,d} = \frac{(ask_{i,d} - bid_{i,d})}{mid_{i,d}}, \tag{1}$$

where $ask_{i,d}$, $bid_{i,d}$ and $mid_{i,d}$ are the daily series of the ask, bid and mid prices of the USD against currency i. We obtain the monthly series, $PSPR_{i,t}$, by taking the end of the month observations of the daily series. The percentage bid-ask spread measures transaction costs. Hence, the larger the spread, the larger transaction costs and the lower the liquidity level. It is important to note that the percentage spread measure is thus a measure of illiquidity.

In order to build these illiquidity measures, we employ daily data for 20 bid, ask and mid exchange rates of the USD versus 20 currencies for a time period of 14 years, from January 01, 1999 to December 31, 2012. Of the 20 currencies in the data set, 10 are of developed economies (Australian dollar, Canadian dollar, Danish krone, euro, Great Britain pound, Japanese yen, New Zealand dollar, Norwegian kroner, Swedish krona, and Swiss franc) and 10 are of emerging markets (Brazilian real, Chilean peso, Czech koruna, Hungarian forint, Korean won, Mexican peso, Polish zloty, Singaporean dollar, South African rand, and Turkish lira).[2] The selection of the currencies reflected the importance of the currencies in FX trading according to BIS (2010) and the availability of data.[3]

We obtained the daily series from Datastream (WM/REUTERS). The quotes provided by WM/Reuters are collected at 16 GMT, which is the time of highest liquidity in the FX market.[4] For a large sample of the

[2]The classification in developed and emerging countries above does not correspond to the IMF classification, but follows instead common practice in the FX market.

[3]The Turkish lira experienced substantial distress during the Turkish crisis of 2000/2001. For robustness, we run the main analysis excluding this currency from the sample to confirm that our results are not driven by its extreme behavior during those years.

[4]As a robustness, we employ an alternative measures of illiquidity by taking the observations of the bid, ask and mid quotes

currencies in our data set (AUD, CAD, CHF, CZK, DKK, EUR, GBP, HUF, JPY, MXN, NOK, NZD, PLN, SGD, SEK, TRY, ZAR)[5] the ask and bid rates are from actual trades and they are calculated independently as the median of actual trades during a fixing period (one minute). If actual trade rates are not available, quoted rates are reported. For the other currencies (BRL, CLP, KRW), the bid and ask rates are quotes from Reuters.[6]

Next, we calculate market illiquidity by averaging across currencies the individual percentage spread series (e.g. Chordia, Roll, and Subrahmanyam (2000a); Pastor and Stambaugh (2003)), as follows:

$$pspr_t = \frac{1}{N}\sum_{i=1}^{N} PSPR_{i,t}. \tag{2}$$

Since we are interested in the changes of market illiquidity and we are not able to reject the hypothesis that *pspr* is non-stationary, we take the first difference of the logs of the market illiquidity measure just calculated:

$$\Delta illiq_t = \log(pspr_t) - \log(pspr_{t-1}). \tag{3}$$

Running a regression of individual currency illiquidity on market illiquidity, we find that market illiquidity can explain a substantial proportion of the movements in individual currencies illiquidity (Table 1A in Appendix A). Furthermore, in accord with Mancini et al. (2013), we find that more liquid FX rates, such as the EUR/USD and GBP/USD tend to have lower liquidity sensitivity to market wide FX liquidity. The opposite is true for less liquid FX rates, such as the Brazilian Real /USD, the Korean won/USD, Turkish Lira/USD and the Hungarian forint/USD.

2.2 Funding liquidity constraints

Building on the recent theoretical literature on the interaction of funding and market liquidity, we examine whether changes in the availability of funding to traders determine the time-variation in FX market liquidity.

Funding liquidity is defined as the ease with which traders can obtain funding. During the recent financial crisis, funding markets have experienced severe distress. Interestingly, different sources of funding responded differently to these events. While unsecured interbank financing halted after Lehman Brothers bankruptcy and returned to be available only to the most credit-worthy counterparties after AIG bailout, severe uncertainty in the future value of collateral led to a near collapse of the repo market in the US (Krishnamurthy, 2010; Afonso, Kovner, and Schoar, 2011; Gorton and Metrick, 2012). These events on the

at 21.50 GMT, which is a time of lower liquidity in the FX market but that is relevant as it corresponds to the closing of the main US stock exchanges. These data is provided by Thomson Reuters.

[5]For the abbreviations of currencies see notes in Table 1A in Appendix A.

[6]It should be noted that Phylaktis and Chen (2009) find using various information measures that the matched tick by tick indicative data bear no qualitative difference from the transaction data and have higher information content.

major funding markets were deeply intertwined with the dynamics of trading in the financial markets. In fact, the presence of constraints to the ability of traders to finance their operations may affect negatively market liquidity (Gromb and Vayanos, 2002; Brunnermeier and Pedersen, 2009; Acharya and Skeie, 2011; Acharya and Viswanathan, 2011). Moreover, Brunnermeier and Pedersen (2009) and Acharya and Viswanathan (2011) provided theoretical evidence of illiquidity spirals precipitated by the interaction of declining asset prices and low availability of financing.

In the theoretical literature, financial constraints are defined as margin requirements (Gromb and Vayanos, 2002; Brunnermeier and Pedersen, 2009; Acharya, Gale, and Yorulmazer, 2011; Garleanu and Pedersen, 2011), as limits to the availability of external capital financing (Shleifer and Vishny, 1997) or as short-term debt that needs to be rolled over (Acharya and Skeie, 2011; Acharya and Viswanathan, 2011; Huang and Ratnovski, 2011). The largely short-term nature of financing arises mainly from borrowers inability to commit to a specified maturity structure in the presence of a number of lenders (Brunnermeier and Oehmke, 2013). Moreover, Acharya and Skeie (2011) looks at lenders' own rollover-risk that provide an incentive to short term financing as opposed to longer term one. These funding characteristics are generally measured in empirical studies by the volume or cost of the different sources of funding that is more frequently found on the liability side of the balance sheets of financial institutions.

Empirically different proxies are used to measure the conditions with which financial intermediaries can access financing. These measures reflect the different sources of wholesale financing available to financial intermediaries that are found on the liability side of their balance sheet.

Some studies focus on unsecured short-time funding and employ measures based on the interest rates. The Fed Funds interest rate, the TED spread, the LIBOR-OIS spread, and financial commercial paper interest rates are measures of the cost of unsecured funding (Coffey and Hrung, 2009; Acharya and Skeie, 2011; Cornett, McNutt, Strahan, and Tehranian, 2011; Garleanu and Pedersen, 2011; Chiu, Chung, Ho, and Wang, 2012). Given the unsecured nature of these sources of financing, it is restricted to more credit-worthy financial institutions and it is more volatile in times of distress.

Given the presence of collateral, secured short term financing is a less costly and more stable source of funding. In fact, collateralized borrowing is at the heart of financial intermediaries' operations. Adrian and Shin (2010) show that financial intermediaries adjust their leverage in a procyclical manner, that is increasing leverage during booms and reducing it during busts, and the margin of adjustment in the expansion and contraction of their balance sheets is through repurchase agreements and reverse repurchase agreements. Indeed, several studies focus on the amount outstanding and interest rates of repurchase agreements (repos) (Brunnermeier and Pedersen, 2009; Coffey and Hrung, 2009; Adrian, Etula, and Shin, 2010; Adrian and Shin, 2010; Acharya and Viswanathan, 2011; Griffoli and Ranaldo, 2011) as proxies for financing conditions. In addition, other studies look at another measure of collateralized borrowing, such as asset-backed commercial papers (ABCP) (Acharya and Skeie, 2011; Acharya and Viswanathan, 2011; Chiu et al., 2012).

Specifically to the FX market and funding conditions, Mancini et al. (2013) use the TED spread to document the impact of changing funding constraints on FX market liquidity during the crisis. Looking at exchange rates and funding conditions, Adrian et al. (2010) analyze the funding liquidity ability of US financial intermediaries by considering the amount outstanding of commercial papers and repos, and find that changes in funding liquidity affect exchange rate variation of some currencies versus the US dollar. Moreover, Coffey and Hrung (2009) and Griffoli and Ranaldo (2011) investigate the impact of funding conditions on deviations from the covered interest parity conditions and look at the repo rates on MBS collateral and general collateral, respectively.

Finally, financial institutions can access funding via discount windows at their central banks. However, they do so only when other sources are unavailable because of the relative higher cost and bad signaling.

2.2.1 The repo market

While the unsecured interbank market is generally more volatile, costlier and restricted to higher quality counterparties, short-term secured funding is the preferred source of wholesale financing for financial institutions (Adrian and Shin, 2010; Afonso et al., 2011; Gorton and Metrick, 2012). Financial institutions generally enter repo contracts to finance their purchases of securities. In a standard repo contract, the initiating party sells a security at a discount, determined by the haircut or margin, with the agreement to buy it back at a later date at an agreed price plus a premium, the repo rate. The most common collateral in the US and UK markets are sovereign securities, either Treasuries or Gilts, which enjoy relatively low credit risk and high liquidity. The trading activity of financial institutions is largely conducted via collateralized borrowing on these markets, with a preference for short maturities to reduce risk and lower the cost of borrowing IMF (2013). If longer term positions or activities need to be funded, traders generally proceed to roll over their positions and enter into new contracts to terminate the old one. The preference for short-term maturities is stronger in times of uncertainty. In fact, the term sectors of both secured and unsecured interbank markets have experienced the largest drop during the recent financial crisis.

Financing constraints may be tightening in several respects. First of all, if the amount of repos available is low, funding is scarce and financial institutions are likely to experience funding constraints. Second, funding constraints may be binding when the cost of funding increases. In this case, higher repo rates may be related to more stringent funding constraints. Finally, the lower availability of term repo contracts may be indicative of constraints in obtaining funding. In fact, when the level of uncertainty in the market increases, funding is generally tighter at longer horizons. Overall, we consider the volume of repos issued as the more informative of the general conditions of funding. In fact, low amount outstanding of repos may be due to a low demand, which in turn may be caused by high repo rates, high haircuts, or strict collateral requirements, or by rationing from the suppliers of funds. While representative of some source of constraints, repo rates may be low but funding may be generally rationed and only available to more creditworthy parties. Furthermore, low rates can be accompanied by stricter collateral requirements and higher haircuts.

Hence, in order to investigate the implications of funding conditions on FX market liquidity, we employ the amount outstanding of repos as a measure of funding availability. We consider the repo markets in the US and UK because New York and London are the two main financial centers for FX trading.[7]

The data of the outstanding amount of US repos is collected by the Federal Reserve Bank of New York on a weekly basis. It comprises the opened positions of primary dealers, serving as trading counterparties of the New York Fed in its implementation of monetary policy. We construct the monthly series of the overnight amount outstanding by taking the last observation of the month available. The data of outstanding amount of UK repos is collected by the Bank of England at the end of the month and it includes the amount outstanding of all sterling repos of monetary financial institutions versus the private sector.

Since we are interested in the tightening of funding liquidity and we cannot reject the null of non-stationarity, we take the first difference of the logs of the amount outstanding of US and UK repos, as follows:

$$\Delta repo_t^c = \log(REPO_t^c) - \log(REPO_{t-1}^c) \quad c = [US, UK] \tag{4}$$

where $REPO$ is the monthly series of the amount outstanding of repos in the US and UK respectively. We expect to find a negative relationship between changes in funding liquidity and changes in FX market illiquidity. In fact, a decrease in repos amount outstanding is associated with a decrease in the volume of funding available to traders. As a result, traders are expected to decrease their operations leading to an increase in FX market illiquidity.

Funding liquidity constraints may materialize also as an increase in the cost of funding or a decrease in the maturity of the contracts. To account for these considerations, we build proxies for the cost of funding and the shortening of the maturities in the repo market.

We proxy for the cost of funding in the US repo market with the 3-month US LIBOR-OIS spread that has been found to be highly correlated with the repo rate with Treasuries as collateral in the US (Gorton and Metrick, 2012).[8] The data is available from Bloomberg starting in the 2001. For the UK repo market, we obtain the series of the end of month 3-month Gilt repo rates from the Bank of England. We take the

[7] According to BIS (2013), London and New York together account for 75% of the overall trading volume in FX

[8] Applying the LIBOR-OIS spread decomposition of Schwarz (2014) in its liquidity and counterparty risk components, Gorton and Metrick (2012) showed that the counterparty risk component is the only significant.

first difference of the two variables because they exhibit non-stationarity:

$$\Delta rates_t^c = RATES_t^c - RATES_{t-1}^c \quad c = [US, UK] \tag{5}$$

where $RATES$ is the monthly series of the repo rates proxied by the US LIBOR-OIS for the US and the Gilt repo rate for the UK.

Finally, we construct a measure of the maturity structure of repos outstanding. We build the measure only for the US repo market because the breakdown of amount outstanding depending on the maturity, overnight vs term, is not available for the UK. We build a ratio of the overnight amount outstanding over the total amount outstanding, as follows:

$$mat_t^c = \frac{REPO_t^{short}}{REPO_t^{short+term}}. \tag{6}$$

We interpret mat as an indicator of the shortening of the maturities of the funding available.

2.2.2 Financial firms stock returns

We include in our analysis another indicator of tightness of capital in the market, which relates to the quality of institutions. Financial constraints are likely to be binding when the quality of financial institutions declines. In fact, an increase in counterparty risk may lead suppliers of funds to ration credit. Moreover, funding conditions may be related to the quality of financial institutions that provide funds. In fact, less funding may be available due to the inability of funding suppliers to lend as they experience distress (Acharya et al., 2011). Hence, we include the stock returns of financial institutions in the US as a proxy for their overall credit quality.

Following Hameed et al. (2010), we obtain daily data on the stock returns of investment banks and securities brokers and dealers listed in the NYSE from the CRSP database.[9] We begin by calculating excess returns by regressing individual stock returns on the value-weighted NYSE market return provided by CRSP:

$$ret_{i,d} = \alpha_i + \beta_i mkt_d + \epsilon_{i,d} \tag{7}$$
$$excret_{i,d} = \epsilon_{i,d}$$

where $excret$ are the daily series of returns for each stock i in excess of the market return mkt.

The common component across the stocks is then obtained by taking the cross-sectional weighted-average of the individual series, where the weights are the market capitalization of the stocks at the end of the previous

[9] We include the stocks identified by the SIC code 6211.

year over the total market capitalization of the stocks in the sample, as follows:

$$excret_d = \sum_{i=1}^{N} w_{i,d} excret_{i,d} \quad for \quad d = 1, .., T. \tag{8}$$

Finally, we obtain the monthly series $excret_t$ by taking the last observation of the series in the month.

We expect the quality of the financial institutions to be negatively related to FX market illiquidity. However, stock returns of financial institutions are affected by several other factors unrelated to funding conditions. As such, we expect to find the linkage to be stronger when the financial system is under distress (Chordia, Subrahmanyam, and Anshuman, 2000b; Hameed et al., 2010).

2.3 Aggregated capital flows

In addition to funding considerations, we extend the analysis to the implications of changes in the demand for liquidity.

Most recently, Karolyi et al. (2012) find that conditions on the demand side affect the commonality in liquidity across stocks. They measure demand-side determinants with a series of proxies derived for the stock markets of a variety of countries. Following their insights and focusing on the FX market, we investigate whether international capital flows exert pressure on the FX market and affect its liquidity over time, as investors require liquidity on the currency markets to enter/exit foreign stock and bond markets.

We measure capital flows as the aggregated flow of international capital between the US and foreign countries. The monthly data on bilateral flows is from the U.S. Department of Treasury. We take the inflows and outflows of equity and bond investments between the US and the 20 countries whose currencies are included in our sample. We aggregate the capital flows across countries and we measure the investment pressure on the FX market as the sum of inflows and outflows. Indeed, we are interested in the demand of the currency pair. So, irrespective of whether investors purchase or sell the foreign currency for the US dollar, their demand of the currency pair is still positive. Hence, we build the common measure across currencies as follows:

$$\begin{gathered} flows_{i,t} = equity_{i,t}^{in} + equity_{i,t}^{out} + bond_{i,t}^{in} + bond_{i,t}^{out}, \\ flow_t = \sum_{i=1}^{20} flows_{i,t} \quad for \quad t = 1, .., T \end{gathered} \tag{9}$$

where *equity* and *bond* are the equity and bond investment series between the US and country i, and the superscripts ^{in} and ^{out} indicate inflows and outflows.

Finally, we log-difference the series because it exhibits non-stationarity in levels:

$$\Delta flow_t = \log(flow_t) - \log(flow_{t-1}). \tag{10}$$

2.4 Global FX volatility

We include global FX volatility in our analysis to control for the level of uncertainty in the FX market (Menkhoff, Sarno, Schmeling, and Schrimpf, 2012). Following the inventory control theoretical models, an increase in the volatility affects the riskiness associated with holding inventory in the currencies involved. The increase in the uncertainty will thus result in a decrease in liquidity. While this relationship is found for individual currency liquidity (Bollerslev and Melvin, 1994; Bessembinder, 1994; Ding, 1999), it should also be in place once market-wide liquidity is considered. An observed increase in FX market volatility will impact the riskiness of holding any inventories in FX, thus leading to a decrease in the liquidity of the FX market as a whole.

We employ the JP Morgan VXY volatility index that captures the implied volatility from currency options of G7 countries and we take the last observation in the month to build our monthly series. Since the series exhibits non stationarity, we take the first difference of the logs of the measure, as follows:

$$vol_t = \log(vxy_t) - \log(vxy_{t-1}). \tag{11}$$

3 Empirical analysis

3.1 Preliminary analysis of the data

3.1.1 Description of the data

Table 1 reports the descriptive statistics of the variables in levels (panel a) and differences (panel b). The average percentage bid-ask spread in the FX market in our period is 0.09% with a relatively small standard deviation of 0.03%. In contrast, the proxy of changes in FX market illiquidity exhibits a strong variability, with a relatively high standard deviation over the mean. Turning to the amount outstanding of repos, the US market is the largest, with an average monthly amount of over USD 1.5 trillion as opposed to GBP 65 billions in the UK repo market. Moreover, the aggregated flows have averaged USD 3 trillions during our sample period with some degree of variation, reaching the peak of over USD 8 trillion in August 2007. Overall, all our measures, except financial firms' excess returns, present a high serial correlation. Generally, the serial correlation are lower for the differenced variables. Furthermore, the differenced variables have a significantly higher variability as opposed to the levels.

Figure 1 presents the level and change of FX market illiquidity. The series exhibit strong variation through time. Indeed, both the level and changes in transaction costs exhibit a high variation during the first part of the sample period. In particular, there are spikes in illiquidity during 2000, when Turkish lira were hit by a severe financial crisis. Figure 2 plots the patterns of the common component in liquidity across currencies when the TRY is removed from the sample. The impact of the Turkish lira distress on the analysis is evaluated in section 4.2, where the Turkish lira is excluded by the sample of currencies and the results of the main analysis are confirmed.

The graphical analysis of the supply-side explanatory variables present common patterns of sharp increases in funding constraints during the recent financial crisis (Figures 3 and 4). As an exception, the level of UK repo amount outstanding were rather unaffected by the financial crisis and their drop is registered later, with the start of the European sovereign debt crisis. In contrast, financial firms' excess returns present a sharp drop prior to the failure of Lehman Brothers, that coincides with the first signs of financial distress in the system as in August 2007 BNP Paribas announced its inability to evaluate its subprime collateralized investments (Figure 5). In Figure 6, aggregated capital flows share a common pattern with the US repo amount outstanding, as they increased steadily during the sample period to drop sharply during the crisis. They however quickly recovered and started rising again. Global FX volatility is plotted in Figure 7. It shows a strong variation through time and significant spikes during the recent financial crisis.

The correlation matrix is reported in Table 2. While the correlation coefficients between the levels need to be interpreted with caution due to the presence of a time trend in the variables, it is possible to note some relationships. There is a strong negative correlation between FX market illiquidity and the amount outstanding of repos, at around -50%. Moreover, the two measures of repos are highly correlated, with a coefficient of 56%. Turning the attention to the rates, UK repo rates are positively correlated with FX market illiquidity, with a coefficient of 51%. In contrast, the proxy for US repo rates has a relatively low and negative correlation with illiquidity. There is no evidence of correlation between the two proxies for repo rates. The last variable for funding conditions is positively correlated with FX market illiquidity, even if the coefficient is smaller at 14%. The demand-side variable, aggregated flows, has a strong negative correlation with FX market illiquidity, at around 56%. Overall, the coefficients decline when the changes in the variables are considered, suggesting that indeed the time trend is an important component of the large coefficients between the levels of the variables. Nonetheless, the direction of the relationship is largely unchanged. We account for this in the analysis and focus on the differenced variables.

3.1.2 Commonality in liquidity

Before turning to the analysis at market level, we study our market illiquidity proxy more in detail and focus on the determinants of the commonality in liquidity across the currencies. In more detail, we investigate the interaction between currencies' liquidity and its demand and supply, through the effect of changing funding conditions, capital flows and market uncertainty on the liquidity commonality across the currencies.

Following Karolyi et al. (2012), we measure the commonality between currency and market illiquidity by the explanatory power, or R-squared, of a regression of the daily changes in the currency percentage bid-ask spreads on the changes in the common component across all the currencies, as follows:

$$\Delta illiq_{i,d} = \alpha_i + \beta_i \Delta illiq_d + \varepsilon_{i,d}. \tag{12}$$

To obtain the monthly series of commonality for each currency, we run the above regression with daily data for each month independently and store the R^2. Following Karolyi et al. (2012), we employ the logistic-transformation of the R-squared, $rsq = \log[R^2/(1-R^2)]$, and end up with a monthly series for each of the 20 currencies in our sample, $rsq_{i,t}$.

We investigate the determinants of the commonality via a panel regression with fixed effects of the R-squared measures on the liquidity supply and demand factors identified in section 2. With respect to the capital flow measure, we do not employ the aggregated measure across countries because we are able to use each measure of capital flows between the US and each of the countries, thus capturing more precisely the effect of the pressure of the investment flows, to and from each country, on their currencies against the USD. Moreover, we include the realized volatility in each currency, measured by the standard deviation of daily currency returns in the month ($V_{i,t}$), in addition to our measure for FX market uncertainty, the implied global FX volatility (vol_t).

In more detail, we run the following regression:

$$rsq_{i,t} = \alpha + \beta \Delta X_t + \delta rsq_{i,t-1} + \varepsilon_t \tag{13}$$

where the matrix with the explanatory variable is $\Delta X_t = [\Delta repos_t^{US}, \Delta repos_t^{UK}, \Delta rates_t^{US}, \Delta rates_t^{UK}, excret_t, \Delta flows_{i,t}, V_{i,t}, vol_t]$.

Confirming the findings of Karolyi et al. (2012) for the stock market, the demand-side factor does offer some insights, while funding conditions are not significant (Table 3).[10] In fact, the positive and significant coefficient associated with aggregated flows suggests that currencies affected by larger capital flows experience

[10] We only report the regressions with the explanatory variables, which are statistically significant.

stronger commonality. Furthermore, as in Brunnermeier and Pedersen (2009) commonality is stronger for more volatile currencies and when market uncertainty is higher.

3.1.3 VAR analysis

In this section we start the analysis of the determinants of FX market illiquidity by investigating the dynamics of the relation between market liquidity and its demand and supply.[11] Hence, we include the variables into a VAR to conduct some structural analysis.

In more detail, we run the following VAR with 1 and 3 lags according to the Swartz and Akaike criteria respectively:

$$\Delta X_t = \alpha + \sum_{l=1}^{L} \beta \Delta X_{t-l} + \varepsilon_t \quad for \quad L = [1, 3] \tag{14}$$

where ΔX is a matrix with the changes in the endogenous variables: FX market illiquidity and the main demand and supply factors. The demand is measured by aggregated capital flows and we restrict the funding conditions in the two markets to the amount outstanding of repos in the US and UK for parsimony.[12]

The results in Table 4 show little evidence of dynamics. The correlation coefficients of the VAR innovations are generally significant, but not high, providing evidence of some commonality in shocks across the variables. There is evidence of causality from UK repos to FX market illiquidity, but there is generally weak reverse causality. The reverse causality is present in the VAR with 3 lags from FX market illiquidity to UK repos and aggregated flows. The IRFs do not show evidence of significant reactions to shocks in the system.[13] It is important to note that data availability allows us to study the dynamics only at low frequency and the system may be more dynamic at higher frequencies.[14] Nonetheless, in our analysis we concentrate on the contemporaneous impact of these factors on illiquidity and exclude the presence of significant dynamics.

3.2 Regression analysis

3.2.1 Market illiquidity, funding constraints and capital flows

We conduct a regression analysis to test whether movements in the proposed variables explain a sizable share of variation in FX market illiquidity.

[11] As noted by Brunnermeier and Pedersen (2009) and Acharya and Viswanathan (2011), although funding liquidity constraints affect all operations of traders creating a systemic source of variation in liquidity across financial assets, the effect may work also in the other direction. Changes in market liquidity can have a significant impact on the conditions at which funding is available to traders. Thus, by estimating a VAR we hope to pick up these possible dynamics.

[12] We do not include the repo rates and financial firms' returns to allow the VAR to clearly identify the interaction between market illiquidity and its supply and demand factors, and avoid the noise from the interaction between the repo market variables.

[13] The IRFs are not reported, but available from the authors upon request.

[14] Also, the monthly frequency prevents us from investigating the VAR during the crisis due to the limited number of observations.

Hence, we run the following regression of the changes in market illiquidity on the proposed determinants:

$$\Delta illiq_t = \alpha + \beta \Delta X_t + \sigma vol_t + \varphi \Delta illiq_{t-1} + \varepsilon_t, \tag{15}$$

where $\Delta X_t = [\Delta repos_t^{US}, \Delta repos_t^{UK}, \Delta rates_t^{US}, \Delta rates_t^{UK}, excret_t, \Delta flow_t]$. $\Delta repos^{US}$ and $\Delta repos^{UK}$ are the log-differenced repos amount outstanding in the US and UK, $\Delta rates^{US}$ and $\Delta rates^{UK}$ are the differenced repo rates in the US and UK, $excret$ are the financial firms' excess returns, $\Delta flow$ are the aggregated capital flows between the US and foreign countries. We include the global FX implied volatility, vol, as a control variable for market uncertainty. Finally, one lag of the dependent variable accounts for the serial correlation in the residuals.

Table 5 reports the results. Looking at funding liquidity constraints, changes in the amount outstanding of repos in both markets are significant in explaining changes in the transaction costs. In detail, the negative coefficients tell us that tightening funding liquidity constraints result in an increase in transaction costs. Proxies of repo rates are not significant, confirming their inferior ability to capture the conditions of funding markets in comparison to volume-related measures. Financial firms' excess returns are also insignificant in this analysis. Turning to the demand-side factor, increases in capital flows are associated with declines in FX market illiquidity. Thus, as global investments in equity and bonds increase, the liquidity of the FX market improves. Finally, global FX volatility is significant in explaining the movements in FX market illiquidity, consistently with previous studies at the individual currency level (Bollerslev and Melvin, 1994; Bessembinder, 1994; Ding, 1999). The coefficient is positive as expected, since an increase in uncertainty is associated with an increase in transaction costs. The regressions have a relatively high explanatory power, with adjusted R-squared around 20%. As expected given the negative serial correlation of our illiquidity measure, the lagged dependent variable is statistically significant.

To summarize, we find that FX market illiquidity is affected by both conditions of the supply and demand. Indeed, as funding liquidity and aggregated capital flows increase, FX market liquidity improves. Interestingly, we find evidence that international investment flows do not subtract liquidity on the currency markets, but rather contribute to make those markets.

3.2.2 The effect of funding cost and maturity

Funding constraints are not only binding when funds available decline, but also when their cost increases and their maturity shortens. Having documented a significant impact of changes in funding aggregates on FX market illiquidity, in this section we consider the implications of funding costs and shortening of the maturity on this liquidity effect.

While repo rates do not affect FX market illiquidity directly, they may have an impact when the costs are associated with changes in volume. To capture these indirect effects, we interact our proxies of amount outstanding of repos with dummies for decreases ($dummy^-$) and increases ($dummy^+$) in the repo rates. Moreover, we investigate the maturity effect and we interact the amount outstanding in repos with dummies for shortening ($dummy^-$) and lengthening ($dummy^+$) of the maturities of repos.[15]

In more detail, we run the following regression:

$$\begin{aligned}\Delta illiq_t = \alpha &+ \beta^{US,+}(dummy^+ * \Delta repos_t^{US}) + \beta^{US,-}(dummy^- * \Delta repos_t^{US}) \\ &+ \beta^{UK,+}(dummy^+ * \Delta repos_t^{UK}) + \beta^{UK,-}(dummy^- * \Delta repos_t^{UK}) + \sigma vol_t + \varphi \Delta illiq_{t-1} + \varepsilon_t,\end{aligned} \quad (16)$$

where $dummy^+$ and $dummy^-$ are dummies for increases and decreases in repo rates or maturities.

Table 6 reports the results. For the UK repo market, the cost effect is significant. In fact, the interaction term of increases in repo rates and the amount outstanding of repos is negative and statistically significant. Hence, in the UK repo markets the liquidity effect of tightening funding conditions is also related to increases in the cost of funding. The same effect is not found in the US repo market.[16] The interaction of the liquidity effect with the maturity of repo contracts shows that maturity plays a role in the impact of funding constraints on FX market illiquidity. In particular, the liquidity effect is stronger when the change in the amount outstanding of repos is associated with a shortening of their maturity.

To summarize, this section documents a significant interaction of the impact of funding on FX market illiquidity with the cost and maturity of the funding available. Hence, we can conclude that changes to the volume of funding available have a stronger impact on liquidity when they are associated with an increase in the cost and a decline in the maturity of the funding available.

3.2.3 The recent financial crisis

Given that market declines are indicative of funding liquidity constraints, we explore whether funding liquidity dry-ups are worse during the recent financial crisis (Brunnermeier and Pedersen, 2009).[17] Furthermore, capital flows declined sharply during the crisis, expanding the demand for liquidity in the currency markets.

We use a dummy, which takes the value of 1 during the period from Lehman Brothers collapse on September 2008 to July 2009, when the US recession ended, and 0 otherwise. We interact this indicator of the recent crisis with our measures of changes in funding conditions and aggregated flows. We control for

[15] As noted in section 2.2.1, we restrict the analysis of the maturity effect to the US repo market due to limitations in availability of UK data.

[16] The lack of significance for the US repo market may depend on the less precise US measure that is a proxy for repo rates, while the UK measure is the actual repo rates for gilts.

[17] Our data set enables us to study several important crisis episodes. However, we restrict the analysis to the latest crisis when funding liquidity became a real constraint for financial intermediaries.

the non-crisis period with an interactive term of the variables with a dummy that takes the value of 0 for the crisis episode, and 1 otherwise. In detail, we run the following regression:

$$\Delta illiq_t = \alpha + \beta(dummy_t^{crisis} * \Delta X_t) + \gamma(dummy_t^{nocrisis} * \Delta X_t) + \delta vol_t + \varphi \Delta illiq_{t-1} + \varepsilon_t \quad (17)$$

where $\Delta X_t = [\Delta repos_t^{US}, \Delta repos_t^{UK}, \Delta rates_t^{US}, \Delta rates_t^{UK}, excret_t, \Delta flow_t]$. $\Delta repos^{US}$ and $\Delta repos^{UK}$ are the log-differenced repo amount outstanding in the US and UK, $\Delta rates^{US}$ and $\Delta rates^{UK}$ are the differenced repo rates in the US and UK, $excret$ are the financial firms' excess returns, $\Delta flow$ are the aggregated capital flows between foreign countries and the US, and vol is the global FX implied volatility. Finally, one lag of the dependent variable accounts for the serial correlation in the residuals.

Table 7 shows the results of the analysis and present a rather clear effect. As expected, during the crisis the effects of funding constraints and aggregated flows are stronger. In fact, the coefficients associated with he crisis dummy are generally double the non-crisis ones.

3.2.4 The impact of funding liquidity and capital flows across currencies

To complete the analysis of the impact of demand and supply factors on illiquidity, we turn our attention to the level of the individual currencies. In this section, we investigate whether currencies that exhibit higher volatility also present the largest impact of changes in funding liquidity constraints on illiquidity, in accord with proposition 6(iv) of Brunnermeier and Pedersen (2009). Furthermore, we extend the investigation to the demand-side of liquidity and analyze the interaction between the liquidity impact of aggregated capital flows and volatility.

We employ measures of changes in illiquidity of individual currencies, by taking the first difference of the logs of all series and build a matrix of changes in monthly transaction cost over time for each currency. Next, we include the measures in a panel regression with fixed effects and we estimate the impact on the changes in individual currency illiquidity, $\Delta illiq_{i,t}$, of changes in the explanatory variables interacted with individual currency volatility:[18]

$$\Delta illiq_{i,t} = \alpha + \beta(\Delta X_t * V_{i,t}) + \varphi illiq_{i,t-1} + \varepsilon_t \quad (18)$$

where $\Delta X_t = [\Delta repos_t^{US}, \Delta repos_t^{UK}, \Delta rates_t^{US}, \Delta rates_t^{UK}, excret_t, \Delta flow_t]$ and V_i are the series of each currency realized volatility. $\Delta repos^{US}$ and $\Delta repos^{UK}$ are the log-differenced repo amount outstanding in the US and UK, $\Delta rates^{US}$ and $\Delta rates^{UK}$ are the differenced repo rates in the US and UK, $excret$ are the financial firms' excess returns, and $\Delta flow$ are the aggregated capital flow between foreign countries and the

[18] We measure the volatility for each currency as the monthly standard deviation of daily currency returns.

US. Finally, we include in the regression one lag of the dependent variable to account for the serial correlation in the residuals.

Table 8 presents the results of the regression in panel a. Confirmation of the relationship between currency illiquidity and volatility is reported in model (1), as more volatile currencies are associated with higher illiquidity. Interacting the volatility of currencies with funding constraints, we find that more volatile currencies suffer the stronger effects on illiquidity of US repos and UK repo rates. Moreover, the volatility effect is present also with respect to the demand-side factor. In fact, the interactive term of volatility with aggregated flows is negative and statistically significant. Hence, we can conclude that more volatile currencies are also more strongly affected by changes in capital flows.

Finally, we investigate whether the volatility effect is related to the crisis episode. Using the crisis and no-crisis dummies described above in equation (17), we interact them with our explanatory variables in this context, as follows:

$$\Delta illiq_{i,t} = \alpha + \beta(\Delta X_t * V_{i,t} * dummy_t^{crisis}) + \gamma(\Delta X_t * V_{i,t} * dummy_t^{nocrisis}) + \varphi illiq_{i,t-1} + \varepsilon_t. \quad (19)$$

Table 9 confirms the presence of an asymmetric effect of volatility depending on the conditions of the market. As expected from the theoretical predictions of Brunnermeier and Pedersen (2009), the impact of repos in the US on the more volatile currencies is significant during the crisis, when funding constraints are generally tighter. This confirms the evidence found in our main analysis in relation to the crisis. Interestingly, the demand-side factor reacts differently, and more volatile currencies present stronger impact of aggregated flow on their illiquidity during normal times.

In summary, we find that demand and supply factors' impact on market illiquidity is related to the volatility of the currencies. Indeed, funding liquidity conditions are mostly relevant for volatile currencies during the crisis. In contrast, aggregated flows are significantly associated with volatile currencies in normal times.

4 Robustness tests

4.1 FX market liquidity at New York markets close

In this section, we conduct the main analysis with an alternative measure of liquidity estimated at a different time during the day, when the FX market liquidity is generally lower. This time corresponds to the close of New York stock exchanges. In more detail, we take the bid, ask and mid prices collected at 21.50 GMT, or 16.50 EST, by Thomson Reuters and available from Datastream. We employ the data to build a new measure of FX market illiquidity following the procedure described in section (2.1). We then run the main regression analysis (15) with this new measure.

The results presented in Table 10 confirm the main findings. Tightening funding liquidity constraints in the US and UK repo markets have strong positive effects on FX market illiquidity. In addition, the illiquidity effect of aggregated flows is still significant. Interestingly, the coefficients associated with the explanatory variables are higher than in the main analysis, as it is the explanatory power of the regressions. Hence, the liquidity demand and supply factors are stronger when the level of liquidity in the FX market is scarce.

4.2 Filtering the FX market liquidity measure

The graphical analysis in Figures 1 and 2 shows a sharp rise in the level and variation of market illiquidity during the Turkish crisis in 2000-2001. To exclude that our main results are driven by the extreme behavior of the Turkish lira, we remove the TRY from the sample of the currencies and estimate the common component in illiquidity across the remaining 19 currencies.[19] Next, we estimate the main regression analysis (15) with this new measure. The results in Table 11 (panel a) confirm the robustness of the main analysis to the behavior of the Turkish lira.

Moreover, we evaluate whether the results of the main analysis are robust to the filtering for seasonality of our illiquidity variable. This is to account for the effects documented in Bessembinder (1994) and Ding (1999) of increases in FX spreads before weekends.

We filter the daily measures of transaction costs for each currency, $PSPR_i$ from equation (1), for the day-of-the-week effect by running the following regression:

$$PSPR_{i,d} = \alpha + \beta Dummy_d + \varepsilon_d \tag{20}$$

where $Dummy = [dummy^{Monday}, dummy^{Tuesday}, dummy^{Wednesday}, dummy^{Thursday}]$.[20] The residuals from this regression are the filtered illiquidity measures. We take the last observation of each month from the daily series. The common component across the currencies is then obtained from equations (2) and (3). Finally, we run the main regression analysis (15) with this new measure.

The results in Table 11 (panel b) confirm the robustness of the main results to the filtering for seasonality.

4.3 Unexpected changes in FX market illiquidity

In the analysis of the determinants of the time-variation in FX market illiquidity, we looked at changes in common illiquidity. As a robustness check, we now investigate whether unexpected changes, or shocks, to FX market illiquidity have the same determinants identified so far.

[19]The systemic effect of the crisis on the illiquidity of other currencies is still present, even after excluding the TRY.
[20]The dummies take the value of 1 for the days of the week, and 0 otherwise. The effect of Fridays is captured by the constant.

In order to identify the unexpected component of changes in FX market illiquidity, we take the residuals of an AR(1) model of the common illiquidity measure as our proxy.[21] In detail, we run the following regression:

$$\Delta illiq_t = \alpha + \beta \Delta illiq_{t-i} + \varepsilon_t \tag{21}$$

and we take ε_t to be our measure of shocks in FX market illiquidity, $\Delta illiq_t^{UNEXP}$. Next, we run the main regression analysis (15) (excluding the lagged dependent variable) with this measure of shocks in FX market as the dependent variable.

We report the results in Table 12. Indeed, the analysis of shocks does confirm the determinants found to be significant in explaining changes in FX market illiquidity.

4.4 FX market depth

In our main analysis above we analyzed changes in transaction costs as a measure of changes in the illiquidity of the FX market. Here, we extend our analysis to a different proxy for FX market liquidity. We employ the Pastor and Stambaugh (2003)'s measure and estimate liquidity as the expected temporary return reversal accompanying order flow. The Pastor-Stambaugh measure of liquidity captures the return reversal due to the behavior of risk-averse market makers, thus identifying market depth. Indeed, a market is deep if large trades are executed without a substantial price impact. We employ the measure of FX market liquidity developed in Banti et al. (2012). This measure is available from January 1999 to July 2008.[22]

We run the main regression analysis (15) with this alternative liquidity measure. Table 13 shows the results. Extending our analysis of the relationship to another measure of liquidity, we find the availability of funding liquidity to traders to be still an important determinant of FX market liquidity. Only the variable for the US repo market is significant and this is reasonable since this measure of market liquidity captures the trading activity of financial institutions based in the US. However, the demand factor is not significant in this context.

5 Conclusions

The recent financial crisis brought attention to the effects of variations in funding liquidity. In this paper, we, provide a systematic analysis of the impact of funding liquidity constraints on FX market illiquidity.

[21]We take an AR(1) model because it allows us to eliminate serial correlation from the residuals so that we take as our measure for shocks the unexpected component of changes in FX market illiquidity.

[22]The FX transaction data is obtained from State Street Corporation, one of the major custodian institutions with about 10,000 institutional investor clients and about 12 trillion US dollars under custody. The data provided by SSC is the daily order flow for our 20 currencies, defined as the overall buying pressure on the currency in millions of transactions. However, the transaction data provided by SSC is not exactly the raw net number of transactions, but is the net flow filtered through a 'normalization' to increase comparability through time and across currencies and to ensure SSC commitment to client confidentiality.

Our broad data set of 20 currencies from both developed and emerging markets over 14 years allows us to explore various aspects of the impact of funding liquidity constraints. Our results confirm the prediction of Brunnermeier and Pedersen (2009) that funding liquidity is a driving state variable of commonality in liquidity, as well as of individual currencies.

Furthermore, recent studies have highlighted the importance of institutional investors behavior and their correlated trading strategies as a source of commonality in liquidity across stocks (Karolyi et al., 2012). Extending the analysis to the FX market, we identify correlated trading that demands liquidity on the FX market by the buying and selling pressure triggered by capital flows between the US and a set of countries. We find changes in these flows to determine the time-variation in FX market illiquidity. Interestingly, these flows do not seem to use liquidity, but rather to have an aggregate effect, which reduces the bid-ask spreads.

Our empirical investigation also documents a strong relationship between market illiquidity and FX market uncertainty, measured as the implied volatility in currency options. In addition to the market level effect, currency volatility affects the illiquidity impact of funding and flows variables.

Our explanatory variables capture an appreciable fraction of the monthly time series variation in market wide liquidity, around 20% of transaction costs for funding and flows variables. The results are robust to controlling for measurement of liquidity at another time of the day and filtering for seasonality and the extreme behavior of the Turkish lira during the 2000-2001 crisis. These explanatory variables are found to explain unexpected changes in FX market illiquidity as well. Our results with respect to funding constraints are robust to an alternative liquidity measure, such as the Pastor-Stambaugh.

In conclusion, our study finds that funding liquidity constraints and capital flows are important determinants of FX market illiquidity and supports the impact of liquidity dry-ups on financial markets (Brunnermeier and Pedersen, 2009; Acharya and Viswanathan, 2011).

Appendix A. Regression of currencies' illiquidity on market illiquidity

Table 1A: Regression of currencies' illiquidity on market illiquidity

	AUD	**BRL**	**CAD**	**CHF**	**CLP**	**CZK**	**DKK**	**EUR**	**GBP**	**HUF**
Constant	-0.0050	-0.0167	-0.0025	-0.0005	0.0048	0.0014	0.0000	-0.0031	-0.0073	0.0079
	-0.1685	*-0.4311*	*-0.0748*	*-0.0229*	*0.1529*	*0.0547*	*0.0016*	*-0.1161*	*-0.2326*	*0.3266*
$\Delta illiq_t$	-0.1070	**0.6363**	0.0920	**0.3751**	**0.6309**	**0.3820**	0.2795	0.2753	0.0933	**0.7943**
	-0.6377	*2.8801*	*0.4893*	*3.1784*	*3.5065*	*2.6392*	*1.8413*	*1.7965*	*0.5198*	*5.7590*
R_{bar}	-0.00	0.04	-0.01	0.05	0.06	0.04	0.01	0.01	-0.00	0.16

	JPY	**KRW**	**MXN**	**NOK**	**NZD**	**PLN**	**SEK**	**SGD**	**TRY**	**ZAR**
Constant	-0.0053	-0.0073	-0.0137	-0.0010	-0.0029	0.0044	-0.0048	-0.0018	0.0057	0.0002
	-0.1925	*-0.0882*	*-0.3217*	*-0.0354*	*-0.0900*	*0.1648*	*-0.2291*	*-0.0614*	*0.1500*	*0.0059*
$\Delta illiq_t$	0.2132	**1.2333**	**0.9239**	**0.5632**	**0.6061**	**0.5891**	**0.2805**	0.3037	**2.0278**	**0.7581**
	1.3555	*2.6211*	*3.7912*	*3.4346*	*3.3464*	*3.9076*	*2.3518*	*1.8168*	*9.36.84*	*4.1489*
R_{bar}	0.01	0.03	0.07	0.06	0.06	0.08	0.03	0.01	0.34	0.09

Notes: The table reports the results of the regression of changes in each individual currencies' illiquidity on changes in common market illiquidity:

$$\Delta illiq_{i,t} = \alpha_i + \beta_i \Delta illiq_t + \varepsilon_{i,t} \tag{22}$$

The coefficients are reported in bold when the variable is statistically significant at 5%. t-statistics are adjusted via Newey-West (1987) and reported under the coefficients. The sample period is from January 1999 to December 2012. The currencies are against the USD and the abbreviation used are the following: AUD: Australian dollar, BRL: Brazilian real, CAD: Canadian dollar, CHF: Swiss franc, CLP: Chilean peso, CZK: Czech koruna, DKK: Danish krone, EUR: euro, GBP: Great British pound, HUF: Hungarian forint, JPY: Japanese yen, KRW: Korean won, MXN: Mexican peso, NOK: Norwegian kroner, NZD: New Zealand dollar, PLN: Polish zloty, SEK: Swedish krona, SGD: Singapore dollar, TRY: Turkish lira, ZAR: South African rand.

Acknowledgments

We are grateful to Tarun Chordia, Paul Gao, Joel Hasbrouck, Erik Hjalmarsson, Michael Melvin, Lukas Menkhoff, Michael Moore, Lucio Sarno and the participants of the EMG-ECRC Microstructure workshop at Cass Business School, City University, London, 2012, the Empirical Modelling of Financial Markets workshop at Brunel University, London, 2012, the Liquidity Risk Management conference at Fordham University, New York, 2012, the 8th Annual Central Bank Workshop on the Microstructure of Financial Markets in Ottawa, Canada, 2012, the 10th International Paris Finance Meeting, 2012, the World Finance Conference, 2013, and the 14th Infiniti Conference on International Finance in Prato, Italy, 2014.

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Table 1: Descriptive statistics

	a. Levels							
	FX illiq	US repos	UK repos	US rates	UK rates	flow	vol	excret
mean	0.0009	1,579,444	65,090	28.7114	3.5111	3,913,828	10.6655	0.0000
median	0.0008	1,706,992	53153	14.1000	4.4200	3,641,565	10.3150	0.0079
st dev	0.0003	585,774	44,043	37.7056	2.0227	1,726,367	2.5500	0.0890
min	0.0004	572,920	16,898	3.7100	0.4150	1,435,517	5.9500	-0.7126
max	0.0029	2,861,966	166,957	238.730	6.0350	8,395,932	23.0300	0.1499
skew	2.1914	0.0351	0.6976	3.4058	-0.6131	0.4145	1.5867	-4.3993
kurt	8.9237	-0.7765	-0.8766	14.1017	-1.2766	-0.8345	5.0053	30.6176
AC(1)	0.8099	0.9845	0.9814	0.8744	0.9948	0.9210	0.8899	0.0961
	b. Differences							
	FX illiq	US repos	UK repos	US rates	UK rates	flow	vol	
mean	-0.0057	0.0061	0.0097	0.0008	-0.0300	0.0069	-0.0022	
median	-0.0089	0.0083	0.0210	-0.0248	0.0000	0.0225	-0.0116	
st dev	0.1752	0.0631	0.1154	0.3408	0.2055	0.1398	0.0948	
min	-0.5554	-0.2100	-0.3507	-0.8761	-1.7750	-0.4638	-0.2099	
max	0.9957	0.1870	0.3205	1.8187	0.3900	0.34468	0.4640	
skew	0.9129	-0.0950	-0.2547	1.6873	-4.8839	-0.2156	1.1324	
kurt	6.8187	0.7837	0.6519	7.0092	36.4545	0.3038	3.7649	
AC(1)	-0.3939	-0.1645	0.3157	-0.0304	0.6352	-0.3954	-0.0493	

Notes: Descriptive statistics are reported for the illiquidity measure and the explanatory variables. Panel a shows the descriptive statistics for the FX market illiquidity, US repo amount outstanding (in millions of USD), UK repo amount outstanding (in millions of GBP), US 3-month LIBOR-OIS spread (in differences of percentage points), UK 3-month Gilt repo rates (in percentage points), aggregated capital flows between the US and relevant countries (in millions of USD), global FX implied volatility (in percentage points) and value-weighted average excess returns of US financial firms. Panel b shows the descriptive statistics for the differences of the variables: the log-differenced FX market illiquidity, log-differenced US repo amount outstanding, log-differenced UK repo amount outstanding, log-differenced US LIBOR-OIS spread, differenced UK repo rate, log-differenced aggregated flows and log-differenced global FX implied volatility. AC(1) refers to the first order autocorrelation of the series.

Table 2: Correlation matrix

	US repos	UK repos	US rates	UK rates	flow	vol	excret
			a. Levels				
FX illiq	-0.46	-0.58	-0.09	0.51	-0.56	-0.03	0.14
US repos	1	0.56	0.45	-0.19	0.86	-0.09	-0.19
UK repos		1	0.35	-0.80	0.67	0.44	-0.14
US rates			1	-0.02	0.36	0.64	-0.11
UK rates				1	-0.39	-0.37	0.07
flow					1	-0.01	-0.24
vol						1	-0.05
			b. Differences				
	US repos	UK repos	US rates	UK rates	flow	vol	excret (level)
FX illiq	-0.23	-0.24	-0.11	0.01	-0.13	0.18	-0.01
US repos	1	0.26	0.06	0.15	0.13	0.00	0.05
UK repos		1	-0.12	-0.13	0.03	0.00	0.02
US rates			1	0.06	0.07	0.26	0.03
UK rates				1	0.23	-0.11	0.03
flow					1	0.12	0.04
vol						1	-0.12

Notes: The correlation matrix reports the correlation coefficients between the variables. Panel a shows the correlation coefficients among FX market illiquidity, US repo amount outstanding, UK repo amount outstanding, US 3-month LIBOR-OIS spread, UK 3-month Gilt repo rates, aggregated capital flows between the US and relevant countries, global FX implied volatility and value-weighted average excess returns of US financial firms. Panel b shows the correlation coefficients among the differences of the variables: log-differenced FX market illiquidity, log-differenced US repo amount outstanding, log-differenced UK repo amount outstanding, log-differenced US LIBOR-OIS spread, differenced UK repo rate, log-differenced aggregated flows, log-differenced global FX implied volatility. Value-weighted average excess returns of US financial firms are in levels.

Table 3: Commonality

	1	2	3
$\Delta flows_i$	0.00000078		
	2.6216		
vol		1.1084	
		2.6388	
V_i			19.4375
			1.9311
$rsq_{i,t-1}$	0.0367	0.0591	0.0583
	1.9671	*3.4291*	*3.3821*
$constant$	-3.2673	-3.1662	-3.3048
	-37.8860	*-44.9244*	*-33.0415*
R_{bar}	0.05	0.04	0.04
DW	2.00	2.01	2.01

Notes: The table reports the results of the panel regression (13) with fixed effects estimated via OLS:

$$rsq_{i,t} = \alpha + \beta \Delta X_t + \delta rsq_{i,t-1} + \varepsilon_t$$

where rsq_i is the monthly series of the logistic-transformation of the R^2 of the regressions of the illiquidity of currency i on the common component of illiquidity across currencies, and $\Delta X_t = [\Delta repos_t^{US}, \Delta repos_t^{UK}, \Delta rates_t^{US}, \Delta rates_t^{UK}, excret_t, \Delta flows_{i,t}, V_{i,t}, vol_t]$. $\Delta repos^{US}$ and $\Delta repos^{UK}$ are the US and UK repos amount outstanding. $\Delta rates^{US}$ and $\Delta rates^{UK}$ are the US and UK repo rates. $excret$ are the value-weighted average excess returns of US financial firms. $\Delta flows_i$ are the series of aggregated capital flows between each country and the US. V_i are the series of currency realized volatility, calculated as the monthly standard deviations of daily currency returns. vol is the global FX implied volatility. We run the regression for each explanatory variable, but we only report them if significant for brevity. t-statistics are reported under the coefficients. The sample period is from January 1999 to December 2012, except for the US repo rates for which the sample period starts in 2001.

Table 4: VAR analysis

	a. VAR(1)			
	Innovation correlation matrix			
	US repos	UK repos	flow	
FX illiq	-0.15	-0.18	-0.13	
US repos	1	0.24	0.13	
UK repos		1	0.08	
	Granger causality			
	FX illiq	US repos	UK repos	flow
FX illiq	-	0.3975	0.0069	0.6207
US repos	0.2969	-	0.0287	0.1847
UK repos	0.6456	0.1977	-	0.1002
flow	0.8908	0.0001	0.5261	-
	b. VAR(3)			
	Innovation correlation matrix			
	US repos	UK repos	flow	
FX illiq	-0.09	-0.10	-0.16	
US repos	1	0.18	0.21	
UK repos		1	0.09	
	Granger causality			
	FX illiq	US repos	UK repos	flow
FX illiq	-	0.3376	0.0345	0.0886
US repos	0.2134	-	0.0097	0.9509
UK repos	0.0436	0.4835	-	0.0031
flow	0.0432	0.0074	0.3533	-

Notes: The table reports the results of the structural tests of the VAR estimation (14):

$$\Delta X_t = \alpha + \sum_{l=1}^{L} \beta \Delta X_{t-l} + \varepsilon_t \quad for \quad L = [1, 3]$$

where ΔX is the matrix with the changes in the endogenous variables: FX market illiquidity, the amount outstanding of repos in the US and UK and aggregated capital flows. In panel a, the number of lags is 1 according to the Swartz criterion. In panel b, the number of lags is 3 according to the Akaike criterion. The innovation correlation matrix reports the correlation coefficients of the innovations from the VAR estimation. The results of the Granger causality tests are the p-values of the column variable Granger causing the row variable. The sample period is from January 1999 to December 2012.

Table 5: Determinants of FX market illiquidity

	1	2	3	4	5	6
$\Delta repos^{US}$	-0.4719					
	-2.4796					
$\Delta repos^{UK}$		-0.3277				
		-2.7986				
$\Delta rates^{US}$			-0.0529			
			-1.5801			
$\Delta rates^{UK}$				0.0009		
				0.0198		
$excret$					0.0022	
					0.0228	
$\Delta flow$						-0.1852
						-2.4790
vol	0.2952	0.2951	0.2710	0.2932	0.2932	0.3275
	2.2354	*2.2598*	*2.2049*	*2.2994*	*2.2511*	*2.6359*
$\Delta illiq_{t-1}$	-0.3586	-0.3683	-0.4416	-0.3855	-0.3855	-0.3824
	-3.4365	*-3.5369*	*-6.3563*	*-3.5596*	*-3.5767*	*-3.5384*
$constant$	-0.0048	-0.0046	-0.0093	-0.0079	-0.0079	-0.0065
	-0.4124	*-0.4004*	*-0.9071*	*0.6670*	*-0.6566*	*-0.5454*
R_{bar}	0.19	0.21	0.24	0.16	0.16	0.19
$LMtest$	0.48	0.70	0.22	0.44	0.44	0.36

Notes: The table reports the results of the different specifications of regression (15) estimated via OLS:

$$\Delta illiq_t = \alpha + \beta \Delta X_t + \sigma vol_t + \varphi \Delta illiq_{t-1} + \varepsilon_t,$$

where $\Delta X_t = [\Delta repos_t^{US}, \Delta repos_t^{UK}, \Delta rates_t^{US}, \Delta rates_t^{UK}, excret_t, \Delta flow_t]$. $\Delta repos^{US}$ and $\Delta repos^{UK}$ are the log-differenced repos amount outstanding in the US and UK respectively, $\Delta rates^{US}$ and $\Delta rates^{UK}$ are the differenced repo rates in the US and UK respectively, $excret$ are the financial firms' excess returns, $\Delta flow$ are the aggregated capital flows between foreign countries and the US. We include the global FX implied volatility, vol, as a control variable for uncertainty in the market. t-statistics are adjusted via Newey-West (1987) and reported under the coefficients. Adjusted R^2 and LM test p-values for the null of first-order serial correlation in the residuals are reported in the last two rows. The sample period is from January 1999 to December 2012, except for the $\Delta rates^{US}$ for which the sample period starts in 2001.

Table 6: Cost and maturity of repos and the liquidity effect of funding constraints

	1	2	3
$dummy^{+}_{rates} * \Delta repos^{US}$	-0.6746		
	-1.8251		
$dummy^{-}_{rates} * \Delta repos^{US}$	-0.3939		
	-1.8345		
$dummy^{+}_{rates} * \Delta repos^{UK}$		-0.3747	
		-3.3719	
$dummy^{-}_{rates} * \Delta repos^{UK}$		-0.2898	
		-1.5607	
$dummy^{-}_{mat} * \Delta repos^{US}$			-0.5643
			-2.2971
$dummy^{+}_{mat} * \Delta repos^{US}$			-0.3334
			-1.3649
vol	0.2967	0.2859	0.2850
	2.2501	*2.1315*	*2.1921*
$\Delta illiq_{t-1}$	-0.3561	-0.3704	-0.3562
	-3.4204	*-3.4898*	*-3.4081*
$constant$	-0.0044	-0.0054	-0.0022
	-0.3776	*-0.4718*	*-0.1592*
R_{bar}	0.19	0.21	0.19
$LMtest$	0.49	0.74	0.50

Notes: The table reports the results of the different specifications of regression (16) estimated via OLS:

$$\Delta illiq_t = \alpha + \beta^{+}(dummy^{+} * \Delta X_t) + \beta^{-}(dummy^{-} * \Delta X_t) + \sigma vol_t + \varphi \Delta illiq_{t-1} + \varepsilon_t$$

where $\Delta X_t = [\Delta repos^{US}_t, \Delta repos^{UK}_t]$. $\Delta repos^{US}$ and $\Delta repos^{UK}$ are the first difference of the amount outstanding of repos in the US and UK. $dummy^{+}$ and $dummy^{-}$ are dummies for increases and decreases in repo rates or maturities. For rates, $dummy^{+}$ and $dummy^{-}$ take the value of 1 when the rates increase and decrease respectively, and 0 otherwise. They are calculated for the US and UK and interacted with their repo amount outstanding respective measure. For the maturity, $dummy^{-}$ and $dummy^{+}$ take the value of 1 for shortening and lengthening respectively of the maturities of the repos in the US market, and 0 otherwise. We include the global FX implied volatility, vol, as a control variable for uncertainty in the market. t-statistics are adjusted via Newey-West (1987) and reported under the coefficients. Adjusted R^2 and LM test p-values for the null of first-order serial correlation in the residuals are reported in the last two rows. The sample period is from January 1999 to December 2012, except for the US repo rate interaction for which the sample period starts in 2001.

Table 7: The recent financial crisis

	1	2	3	4	5	6
$dummy^{crisis} * \Delta repos^{US}$	-0.7470					
	-2.8796					
$dummy^{nocrisis} * \Delta repos^{US}$	-0.4207					
	-1.9649					
$dummy^{crisis} * \Delta repos^{UK}$		-0.4600				
		-1.8208				
$dummy^{nocrisis} * \Delta repos^{UK}$		-0.3080				
		-2.4271				
$dummy^{crisis} * \Delta rates^{US}$			-0.1394			
			-1.3469			
$dummy^{nocrisis} * \Delta rates^{US}$			-0.0414			
			-1.3407			
$dummy^{crisis} * \Delta rates^{UK}$				-0.0192		
				-0.6475		
$dummy^{nocrisis} * \Delta rates^{UK}$				0.0514		
				0.3899		
$dummy^{crisis} * excret$					-0.8853	
					-2.1413	
$dummy^{nocrisis} * excret$					0.0545	
					0.5669	
$dummy^{crisis} * \Delta flow$						-0.3459
						-1.9834
$dummy^{nocrisis} * \Delta flow$						-0.1567
						-1.9270
vol	0.2960	0.3107	0.2913	0.2900	0.3107	0.3346
	2.2329	*2.3888*	*2.2854*	*2.2477*	*2.4049*	*2.7983*
$\Delta illiq_{t-1}$	-0.3591	-0.3677	-0.4501	-0.3845	-0.3970	-0.3891
	-3.4259	*-3.5398*	*-6.410*	*-3.5273*	*-3.5937*	*-3.5598*
$constant$	-0.0059	-0.0044	-0.0101	-0.0083	-0.0070	-0.0071
	-0.4971	*-0.3800*	*-0.9824*	*0.6835*	*-0.5877*	*-0.5821*
R_{bar}	0.19	0.21	0.24	0.16	0.17	0.18
$LMtest$	0.48	0.67	0.31	0.45	0.48	0.41

Notes: The table reports the results of the different specifications of regression (17) estimated via OLS:

$$\Delta illiq_t = \alpha + \beta(dummy_t^{crisis} * \Delta X_t) + \gamma(dummy_t^{nocrisis} * \Delta X_t) + \delta vol_t + \varphi \Delta illiq_{t-1} + \varepsilon_t$$

where $\Delta X_t = [\Delta repos_t^{US}, \Delta repos_t^{UK}, \Delta rates_t^{US}, \Delta rates_t^{UK}, excret_t, \Delta flow_t]$. $\Delta repos^{US}$ and $\Delta repos^{UK}$ are the log-differenced repo amount outstanding in the US and UK, $\Delta rates^{US}$ and $\Delta rates^{UK}$ are the differenced repo rates in the US and UK, $excret$ are financial firms' excess returns, $\Delta flow$ are the aggregated capital flows between foreign countries and the US, and vol is the global FX implied volatility. $dummy^{crisis}$ takes the value of 1 during the period from Lehman Brothers collapse in September 2008 to July 2009, when the US recession ended, and 0 otherwise. $dummy^{nocrisis}$ takes the value of 0 for the crisis episode, and 1 otherwise. t-statistics are adjusted via Newey-West (1987) and reported under the coefficients. Adjusted R^2 and LM test p-values for the null of first-order serial correlation in the residuals are reported in the last two rows. The sample period is from January 1999 to December 2012, except for the $\Delta rates^{US}$ for which the sample period starts in 2001 due to data availability.

Table 8: Panel analysis

	1	2	3	4	5	6	7
V_i	9.0072						
	4.8873						
$V_i * \Delta repos^{US}$		-22.7146					
		-1.7968					
$V_i * \Delta repos^{UK}$			-4.3081				
			-0.6701				
$V_i * \Delta rates^{US}$				-1.8225			
				-0.7180			
$V_i * \Delta rates^{UK}$					-4.3298		
					-2.2170		
$V_i * excret$						4.1207	
						0.4200	
$V_i * \Delta flow$							-15.6897
							-2.8559
$illiq_{i,t-1}$	-0.4347	-0.4322	-0.4334	-0.4548	-0.4345	-0.4334	-0.4329
	-27.7670	*-27.5062*	*-27.5889*	*-26.1806*	*-27.6694*	*-27.5943*	*-27.5878*
$constant$	-0.0703	-0.0079	-0.0079	-0.0074	-0.0107	-0.0083	-0.0083
	-4.8109	*-1.0887*	*-1.0844*	*-0.9338*	*-1.4506*	*1.1337*	*-1.1423*
R_{bar}	0.19	0.18	0.18	0.20	0.18	0.18	0.18
DW	2.25	2.24	2.24	2.27	2.24	2.24	2.25

Notes: The table reports the results of the specifications of the panel regression (18) with fixed effects:

$$\Delta illiq_{i,t} = \alpha + \beta(\Delta X_t * V_{i,t}) + \varphi illiq_{i,t-1} + \varepsilon_t$$

where $\Delta X_t = [\Delta repos_t^{US}, \Delta repos_t^{UK}, \Delta rates_t^{US}, \Delta rates_t^{UK}, excret_t, \Delta flow_t]$ and V_i are the series of monthly standard deviation of daily currency returns. $\Delta repos^{US}$ and $\Delta repos^{UK}$ are the log-differenced repo amount outstanding in the US and UK, $\Delta rates^{US}$ and $\Delta rates^{UK}$ are the differenced repo rates in the US and UK, $excret$ are the financial firms' excess returns, and $\Delta flow$ are the aggregated capital flows between foreign countries and the US. t-statistics are reported under the coefficients. Adjusted R^2 and Durbin-Watson test for the null of first-order serial correlation in the residuals are reported in the last two rows. The sample period is from January 1999 to December 2012, except for the $\Delta rates^{US}$ for which the sample period starts in 2001 due to data availability.

Table 9: Panel analysis and the financial crisis

	1	2	3	4	5	6
$dummy^{crisis} * V_i * \Delta repos^{US}$	-41.8072					
	-2.2562					
$dummy^{nocrisis} * V_i * \Delta repos^{US}$	-5.6848					
	-0.3251					
$dummy^{crisis} * V_i * \Delta repos^{UK}$		2.4703				
		0.2746				
$dummy^{nocrisis} * V_i * \Delta repos^{UK}$		-11.3332				
		-1.2376				
$dummy^{crisis} * V_i * \Delta rates^{US}$			-1.3739			
			-0.2773			
$dummy^{nocrisis} * V_i * \Delta rates^{US}$			-1.9837			
			-0.6694			
$dummy^{crisis} * V_i * \Delta rates^{UK}$				-3.7102		
				-1.8621		
$dummy^{nocrisis} * V_i * \Delta rates^{UK}$				-18.8232		
				-1.9844		
$dummy^{crisis} * V_i * excret$					-27.7655	
					-1.1764	
$dummy^{nocrisis} * V_i * excret$					10.8170	
					1.0020	
$dummy^{crisis} * V_i * \Delta flow$						-13.5729
						-1.6636
$dummy^{nocrisis} * V_i * \Delta flow$						-17.4627
						-2.3397
$illiq_{i,t-1}$	-0.4328	-0.4335	-0.4548	-0.4355	-0.4344	-0.4325
	-27.5374	*-27.5971*	*-26.1629*	*-27.7153*	*-27.6365*	*-27.5143*
$constant$	-0.0096	-0.0080	-0.0073	-0.0108	-0.0077	-0.0081
	-1.2972	*-1.0944*	*-0.9226*	*-1.4661*	*1.0603*	*-1.1130*
R_{bar}	0.18	0.18	0.20	0.18	0.15	0.18
DW	2.25	2.24	2.27	2.25	2.24	2.25

Notes: The table reports the results of the specifications of the panel regression (19) with fixed effects:

$$\Delta illiq_{i,t} = \alpha + \beta(\Delta X_t * V_{i,t} * dummy_t^{crisis}) + \gamma(\Delta X_t * V_{i,t} * dummy_t^{nocrisis}) + \varphi illiq_{i,t-1} + \varepsilon_t$$

where $\Delta X_t = [\Delta repos_t^{US}, \Delta repos_t^{UK}, \Delta rates_t^{US}, \Delta rates_t^{UK}, excret_t, \Delta flow_t]$ and V_i are the series of monthly standard deviation of daily currency returns. $dummy^{crisis}$ takes the value of 1 during the recent financial crisis from September 2008 to June 2009, and 0 otherwise; $dummy^{nocrisis}$ takes the value of 0 during the crisis, and 1 otherwise. $\Delta repos^{US}$ and $\Delta repos^{UK}$ are the log-differenced repo amount outstanding in the US and UK, $\Delta rates^{US}$ and $\Delta rates^{UK}$ are the differenced repo rates in the US and UK, $excret$ are financial firms' excess returns, and $\Delta flow$ are the aggregated capital flows between foreign countries and the US. t-statistics are reported under the coefficients. Adjusted R^2 and Durbin-Watson test for the null of first-order serial correlation in the residuals are reported in the last two rows. The sample period is from January 1999 to December 2012, except for the $\Delta rates^{US}$ for which the sample period starts in 2001 due to data availability.

Table 10: Determinants of FX market illiquidity, at a less liquid time

	1	2	3	4	5	6
$\Delta repos^{US}$	-1.0886					
	-2.8522					
$\Delta repos^{UK}$		-0.5819				
		-3.1188				
$\Delta rates^{US}$			-0.1064			
			-1.5973			
$\Delta rates^{UK}$				-0.1263		
				-1.3119		
$excret$					0.0682	
					0.3176	
$\Delta flow$						-0.3546
						-2.5647
vol	0.6749	0.6771	0.7831	0.6461	0.6842	0.7421
	2.9684	*3.0937*	*3.3262*	*2.8204*	*3.0699*	*3.3965*
$\Delta illiq_{t-1}$	-0.4044	-0.4168	-0.5079	-0.4335	-0.4269	-0.4242
	-4.7329	*-5.0295*	*-6.5651*	*-5.1332*	*-4.9805*	*-5.0161*
$constant$	0.0059	0.0049	-0.0009	-0.0046	-0.0007	0.0019
	0.2891	*0.2480*	*-0.0476*	*-0.2341*	*-0.0361*	*-0.0919*
R_{bar}	0.25	0.25	0.32	0.22	0.21	0.23
$LMtest$	0.09	0.11	0.01	0.04	0.05	0.05

Notes: The table reports the results of the different specifications of regression (15) estimated via OLS with an alternative dependent variable, constructed with data observed at the 21.50 GMT:

$$\Delta illiq_t^{NYtime} = \alpha + \beta \Delta X_t + \sigma vol_t + \varphi \Delta illiq_{t-1}^{NYtime} + \varepsilon_t,$$

where $\Delta X_t = [\Delta repos_t^{US}, \Delta repos_t^{UK}, \Delta rates_t^{US}, \Delta rates_t^{UK}, excret_t, \Delta flow_t]$. $\Delta repos^{US}$ and $\Delta repos^{UK}$ are the log-differenced repo amount outstanding in the US and UK, $\Delta rates^{US}$ and $\Delta rates^{UK}$ are the differenced repo rates in the US and UK, $excret$ are financial firms' excess returns, $\Delta flow$ are the aggregated capital flows between foreign countries and the US. We include the global FX implied volatility, vol, as a control variable for uncertainty in the market. t-statistics are adjusted via Newey-West (1987) and reported under the coefficients. Adjusted R^2 and LM test p-values for the null of first-order serial correlation in the residuals are reported in the last two rows. The sample period is from January 1999 to December 2012, except for the $\Delta rates^{US}$ for which the sample period starts in 2001 due to data availability.

Table 11: Determinants of FX market illiquidity, filtering for seasonality and excluding the Turkish lira

	1	2	3	4	5	6
	a. Excluding the TRY					
$\Delta repos^{US}$	-0.3919					
	-2.2967					
$\Delta repos^{UK}$		-0.3563				
		-3.4300				
$\Delta rates^{US}$			-0.0498			
			-1.4698			
$\Delta rates^{UK}$				-0.0453		
				-1.1427		
$excret$					0.0065	
					0.0666	
$\Delta flow$						-0.1848
						-2.8152
vol	0.3253	0.3256	0.3531	0.3118	0.3242	0.3594
	2.8420	*2.5515*	*2.8338*	*2.8820*	*2.8410*	*3.7150*
$\Delta illiq_{t-1}$	-0.4441	-0.4513	-0.4661	-0.4815	-0.4732	-0.4536
	-6.3673	*-6.4968*	*-5.7108*	*-6.8549*	*-6.8138*	*-6.8653*
$constant$	-0.0058	-0.0048	-0.0061	-0.0099	-0.0084	-0.0069
	-0.6188	*-0.5133*	*-0.6098*	*-0.9882*	*-0.8592*	*-0.7303*
R_{bar}	0.28	0.32	0.28	0.26	0.26	0.28
$LMtest$	0.10	0.15	0.06	0.14	0.14	0.04
	b. Filtering for seasonality					
$\Delta repos^{US}$	-0.0003					
	-2.1747					
$\Delta repos^{UK}$		-0.0003				
		-3.5189				
$\Delta rates^{US}$			0.0000			
			-1.7682			
$\Delta rates^{UK}$				0.0000		
				-0.7015		
$excret$					0.0000	
					-0.3199	
$\Delta flow$						-0.0001
						-2.2842
vol	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003
	2.7099	*2.5055*	*2.9009*	*2.7411*	*2.7076*	*2.9729*
$\Delta illiq_{t-1}$	-0.4487	-0.4465	-0.4808	-0.4812	-0.4776	-0.4587
	-6.3273	*-6.2657*	*-5.6843*	*-6.7410*	*-6.8258*	*-6.8590*
$constant$	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	-0.6586	*-0.5134*	*-0.5531*	*-0.9607*	*-0.8872*	*-0.7732*
R_{bar}	0.28	0.33	0.30	0.26	0.26	0.28
$LMtest$	0.12	0.15	0.03	0.15	0.15	0.06

Notes: The table reports the results of the different specifications of regression (15) estimated via OLS with two alternative dependent variables, excluding the TRY from the sample of currencies in panel a and filtering the transaction cost measures for seasonality in panel b:

$$\Delta illiq_t = \alpha + \beta \Delta X_t + \sigma vol_t + \varphi \Delta illiq_{t-1} + \varepsilon_t,$$

where $\Delta X_t = [\Delta repos_t^{US}, \Delta repos_t^{UK}, \Delta rates_t^{US}, \Delta rates_t^{UK}, excret_t, \Delta flow_t]$. $\Delta repos^{US}$ and $\Delta repos^{UK}$ are the log-differenced repo amount outstanding in the US and UK, $\Delta rates^{US}$ and $\Delta rates^{UK}$ are the differenced repo rates in the US and UK, $excret$ are financial firms' excess returns, $\Delta flow$ are the aggregated capital flows between foreign countries and the US. We include the global FX implied volatility, vol, to account for uncertainty in the market. t-statistics are adjusted via Newey-West (1987) and reported under the coefficients. Adjusted R^2 and LM test p-values for the null of first-order serial correlation in the residuals are reported in the last two rows. The sample period is from January 1999 to December 2012, except for the $\Delta rates^{US}$ for which the sample period starts in 2001 due to data availability.

Table 12: Determinants of shocks to FX market illiquidity

	1	2	3	4	5	6
$\Delta repos^{US}$	-0.4562					
	-2.6147					
$\Delta repos^{UK}$		-0.3245				
		-2.8283				
$\Delta rates^{US}$			-0.0.0553			
			-1.6474			
$\Delta rates^{UK}$				0.0002		
				0.0045		
$excret$					0.0018	
					0.0180	
$\Delta flow$						-0.1849
						-2.4504
vol	0.2906	0.2917	0.2806	0.2918	0.2919	0.3258
	2.2684	*2.3022*	*2.2522*	*2.3616*	*2.3066*	*2.6970*
$constant$	-0.0052	-0.0048	-0.0089	-0.0080	-0.0080	-0.0066
	-0.4392	*0.4163*	*-0.8870*	*-0.6798*	*-0.6654*	*-0.6798*
R_{bar}	0.05	0.07	0.04	0.02	0.02	0.04
$LMtest$	0.75	0.92	0.09	0.50	0.50	0.43

Notes: The table reports the results of the different specifications of regression (15) (excluding the lagged dependent variable) estimated via OLS with the shocks in FX market illiquidity as the dependent variable:

$$\Delta illiq_t^{UNEXP} = \alpha + \beta \Delta X_t + \sigma vol_t + \varepsilon_t,$$

where $\Delta X_t = [\Delta repos_t^{US}, \Delta repos_t^{UK}, \Delta rates_t^{US}, \Delta rates_t^{UK}, excret_t, \Delta flow_t]$ and $\Delta illiq^{UNEXP}$ are the residuals from the regression of FX market illiquidity on its lag. $\Delta repos^{US}$ and $\Delta repos^{UK}$ are the log-differenced repo amount outstanding in the US and UK, $\Delta rates^{US}$ and $\Delta rates^{UK}$ are the differenced repo rates in the US and UK, $excret$ are financial firms' excess returns, $\Delta flow$ are the aggregated capital flows between foreign countries and the US. We include the global FX implied volatility, vol, to account for uncertainty in the market. t-statistics are adjusted via Newey-West (1987) and reported under the coefficients. Adjusted R^2 and LM test p-values for the null of first-order serial correlation in the residuals are reported in the last two rows. The sample period is from January 1999 to December 2012, except for the $\Delta rates^{US}$ for which the sample period starts in 2001 due to data availability.

Table 13: Determinants of FX market liquidity, measured as market depth

	1	2	3	4	5	6
$\Delta repos^{US}$	0.0043					
	2.0893					
$\Delta repos^{UK}$		0.0000				
		-0.0206				
$\Delta rates^{US}$			0.0004			
			0.6381			
$\Delta rates^{UK}$				0.0011		
				0.6893		
$excret$					-0.0021	
					-0.9526	
$\Delta flow$						-0.0009
						-0.5028
vol	-0.0046	-0.0039	-0.0049	-0.0039	0-0.0045	-0.0037
	-1.6190	*-1.3776*	*-1.3936*	*-1.3638*	*-1.5268*	*-1.2397*
$\Delta illiq_{t-1}$	-0.5177	-0.4874	-0.4585	-0.4978	-0.4952	-0.4844
	-7.8736	*-7.3925*	*-5.3605*	*-7.1860*	*-7.5886*	*-7.6807*
$constant$	-0.0001	0.0000	-0.0001	0.0000	0.0000	0.0000
	-0.3009	*-0.1588*	*-0.4265*	*-0.1520*	*-0.1188*	*-0.0966*
R_{bar}	0.28	0.24	0.22	0.24	0.24	0.24
$LMtest$	0.06	0.06	0.20	0.05	0.05	0.06

Notes: The table reports the results of the different specifications of regression (15) estimated via OLS with the Pastor-Stambaugh measure as the dependent variable:

$$\Delta liq_t = \alpha + \beta \Delta X_t + \sigma vol_t + \varphi \Delta liq_{t-1} + \varepsilon_t,$$

where $\Delta X_t = [\Delta repos_t^{US}, \Delta repos_t^{UK}, \Delta rates_t^{US}, \Delta rates_t^{UK}, excret_t, \Delta flow_t]$ and Δliq is the Pastor-Stambaugh liquidity measure. $\Delta repos^{US}$ and $\Delta repos^{UK}$ are the log-differenced repo amount outstanding in the US and UK, $\Delta rates^{US}$ and $\Delta rates^{UK}$ are the differenced repo rates in the US and UK, $excret$ are financial firms' excess returns, $\Delta flow$ are the aggregated capital flows between foreign countries and the US. We include the global FX implied volatility, vol, to account for uncertainty in the market. t-statistics are adjusted via Newey-West (1987) and reported under the coefficients. Adjusted R^2 and LM test p-values for the null of first-order serial correlation in the residuals are reported in the last two rows. The sample period is from January 1999 to July 2008, except for the $\Delta rates^{US}$ for which the sample period starts in 2001 due to data availability.

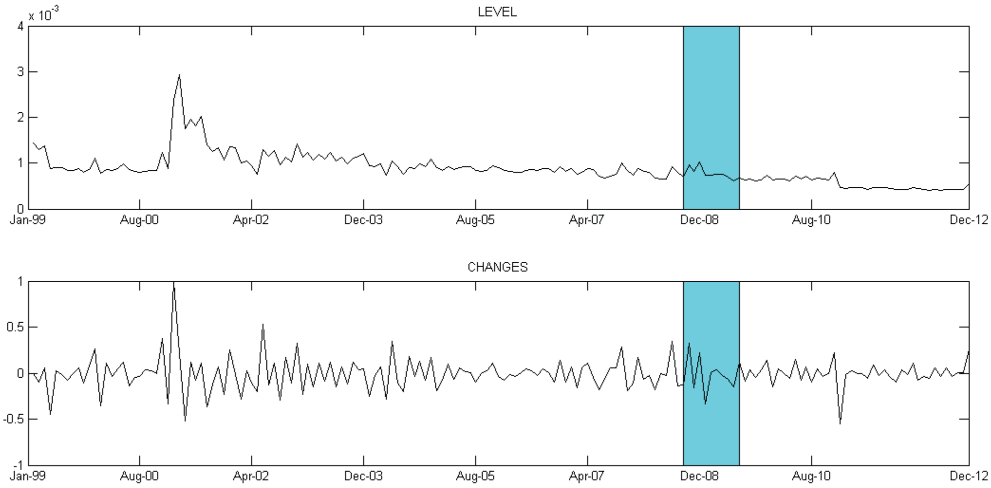


Figure 1: **FX market illiquidity** The FX market illiquidity is calculated as the cross-sectional average of percentage bid-ask spreads across the 20 currencies in the sample against the USD. The shaded area indicates the recent financial crisis from September 2008 to June 2009.

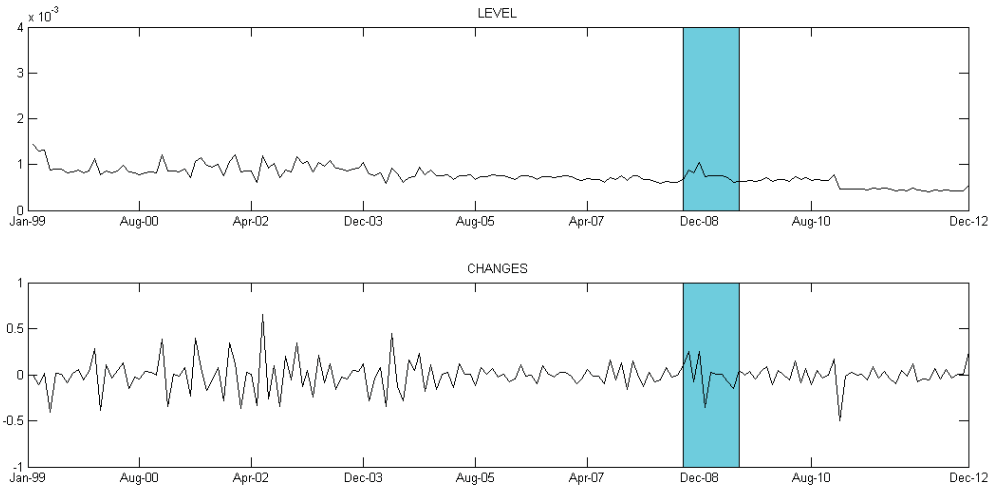
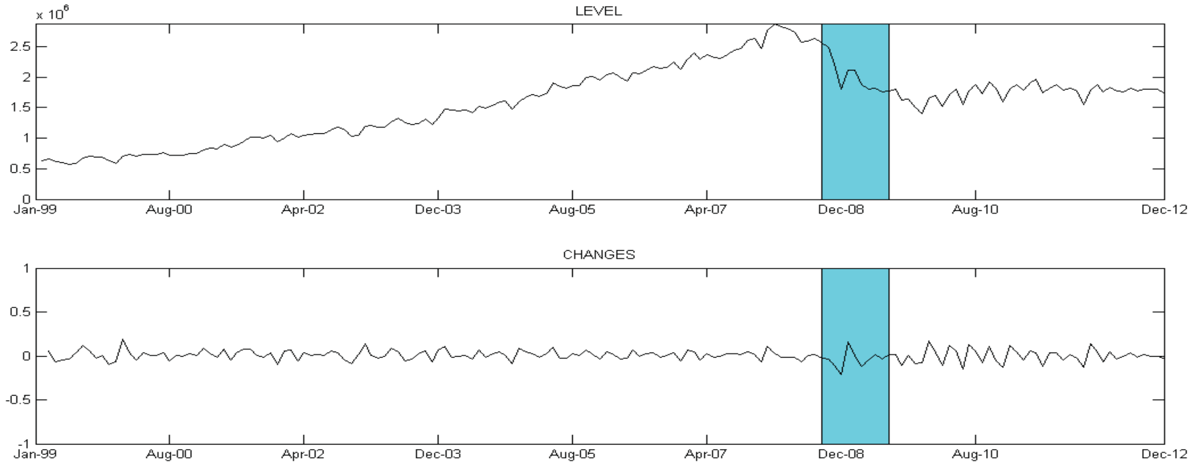
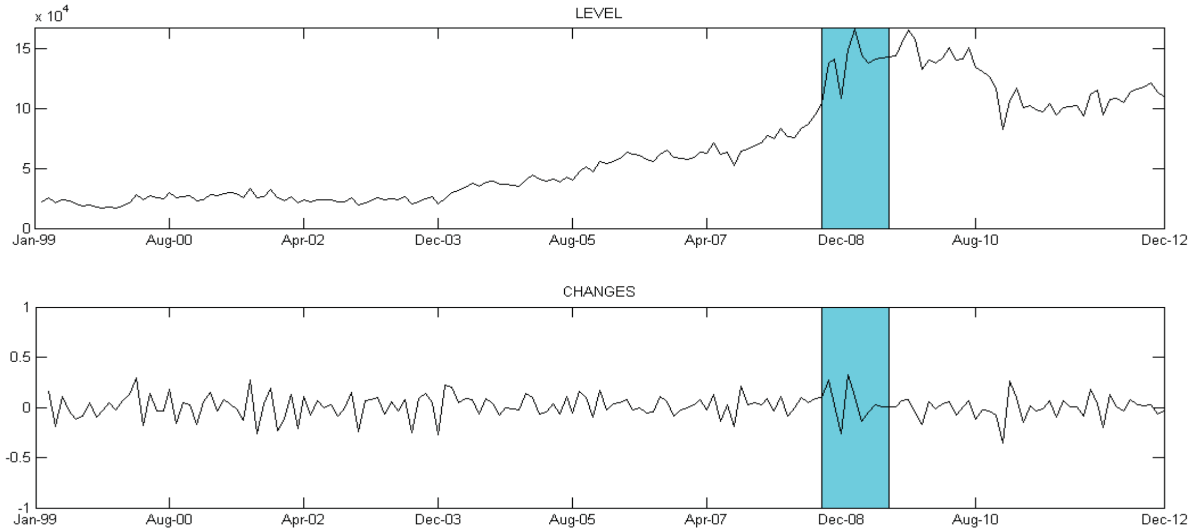


Figure 2: **FX market illiquidity excluding the TRY** The FX market illiquidity is calculated as the cross-sectional average of percentage bid-ask spreads across the 19 currencies in the sample against the USD. The shaded area indicates the recent financial crisis from September 2008 to June 2009.

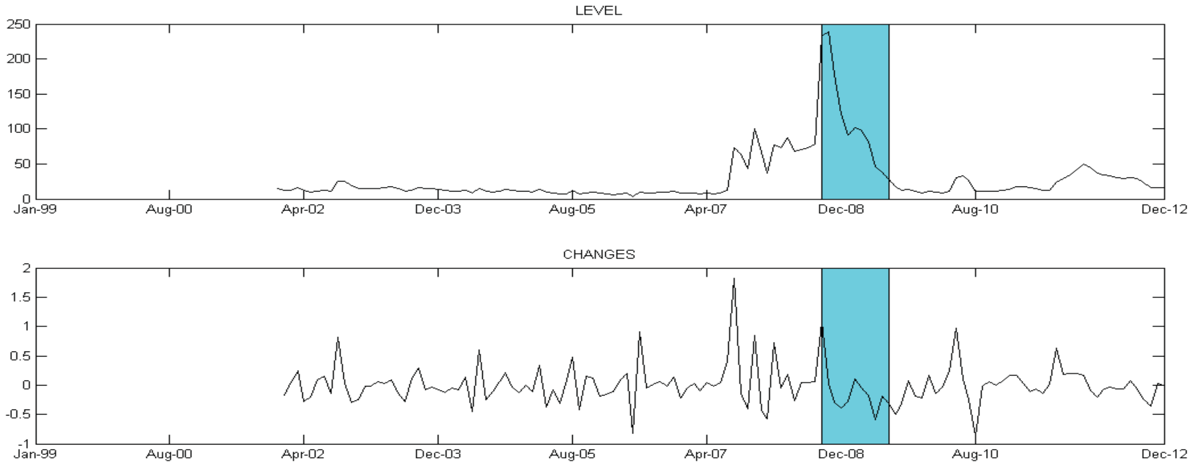


(a) US

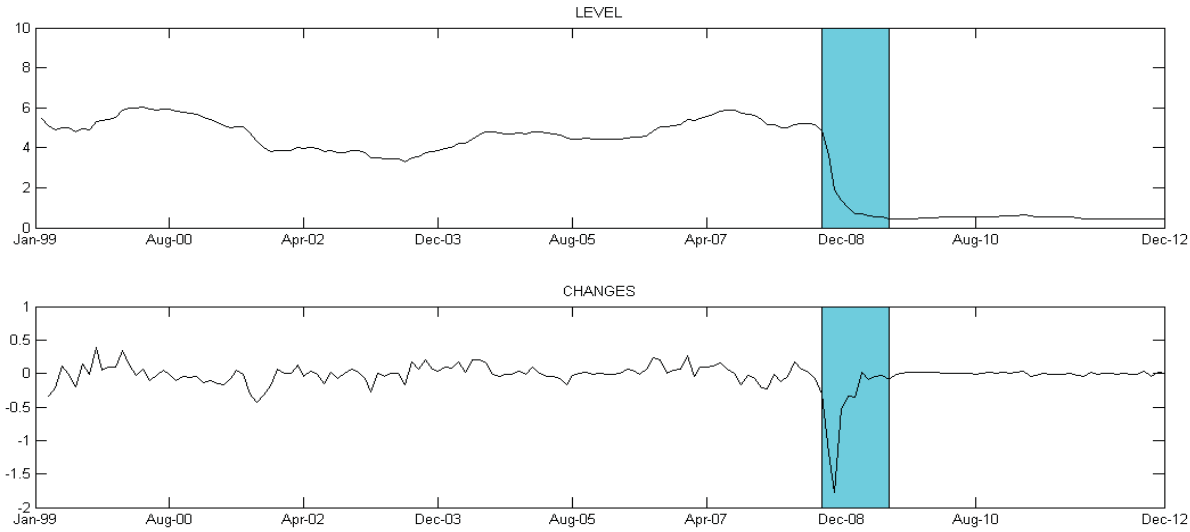


(b) UK

Figure 3: **Repo amount outstanding in the US and UK.** The amount outstanding in the US is in millions of USD and the amount outstanding in the UK is in millions of GBP. The shaded area indicates the recent financial crisis from September 2008 to June 2009.



(a) US



(b) UK

Figure 4: **Repo rates in the US and UK.** Repo rates in the US are proxied by the 3-month LIBOR-OIS spread, starting from 2001, and it is in percentage points. Repo rates in the UK are the 3-month Gilt repo rates, and are expressed in percentage points. The shaded area indicates the recent financial crisis from September 2008 to June 2009.

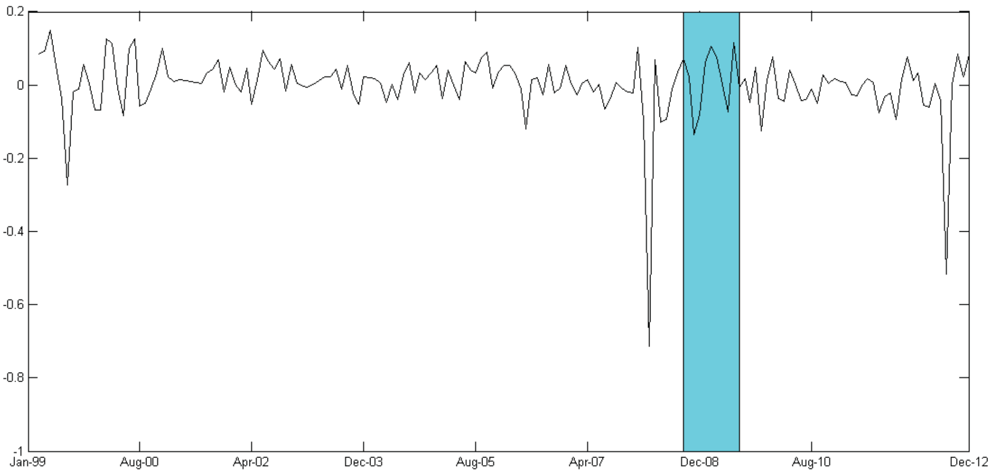


Figure 5: **Financial firms' excess returns** The graph shows the common component in financial firms' excess returns in the US. Excess returns are obtained as the residuals from a one factor model and they are the value-weighted average across firms. The shaded area indicates the recent financial crisis from September 2008 to June 2009.

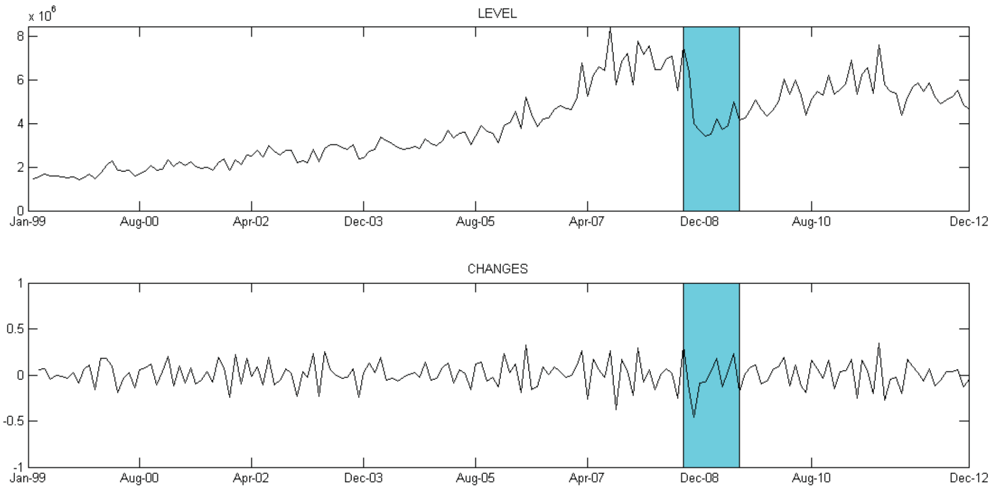


Figure 6: **Aggregated capital flows** The graph shows the aggregated flows of equity and bond investments between the US and foreign countries. The flows are the sum of the inflows and outflows aggregated across countries. The shaded area indicates the recent financial crisis from September 2008 to June 2009.

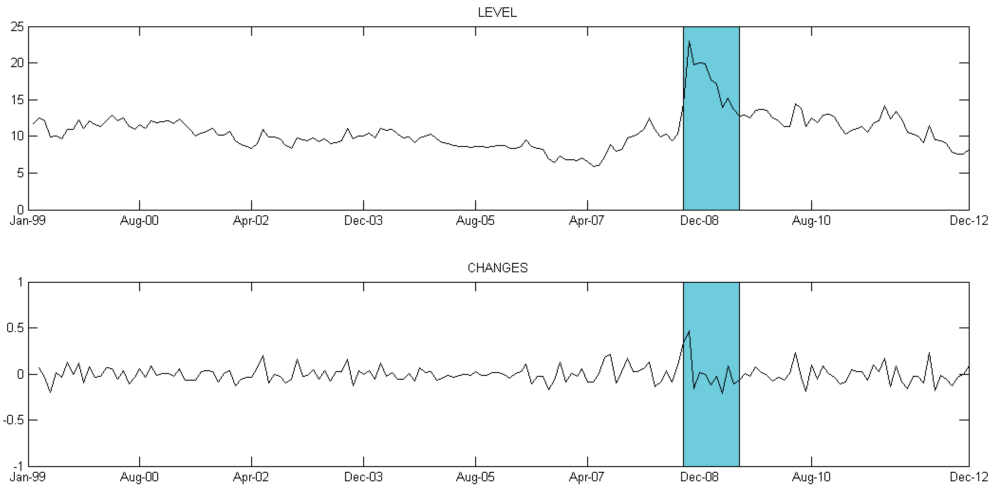


Figure 7: **Global FX volatility** The graph shows the global FX volatility implied in currency options. The shaded area indicates the recent financial crisis from September 2008 to June 2009.