FX market illiquidity and funding liquidity constraints

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Abstract

Using a broad data set for 20 exchange rates over 13 years, we construct two measures of the common component of liquidity across currencies, transaction costs and market depth. We find that funding liquidity constraints impact on both aspects of FX market liquidity, after controlling for global volatility, market returns and seasonality. The impact of funding liquidity relates to market declines when suppliers to liquidity face capital tightness and to crisis times, when there are severe liquidity dry-ups. Furthermore, funding liquidity together with our other explanatory variables explain unexpected changes in FX market illiquidity as well.

Keywords: foreign exchange; liquidity; order flow; funding liquidity constraints; microstructure.

JEL Classification: F31; G15.

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1 Introduction

Trading volume in the foreign exchange (FX) market is particularly high if 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 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 shocks to this common component are priced in the cross-section of currencies excess returns (Mancini, Ranaldo, and Wrampelmeyer (2011); Banti, Phylaktis, and Sarno (2012)). Interestingly, FX market liquidity exhibits a strong variation through time (Bollerslev and Melvin (1994); Mancini et al. (2011); Banti et al. (2012)).

In this paper we focus on the time-variation of the commonality in FX market liquidity (thereafter referred to as FX market liquidity) and the identification of its determinants, focusing on funding liquidity constraints. To our knowledge this is the first paper that provides a systematic analysis of the impact of funding liquidity on FX market illiquidity. While some papers have investigated the determinants of changes in liquidity cross-sectionally in the stock market (Chordia, Roll, and Subrahmanyam (2001); Huberman and Halka (2001)), in the bond market (Fleming (2003)), and across the stock and bond markets (Chordia, Sarkar, and Subrahmanyam (2005); Goyenko and Ukhov (2009)), the FX market has received little attention. Mancini et al. (2011) identified a negative relationship between both the VIX and the TED spread measures and FX market liquidity for the most traded currencies during the recent financial crisis. A number of papers have analyzed individual currency liquidity and investigated the determinants of changes in the bid-ask spreads over time (Glassman (1987); Boothe (1988); Bollerslev

[1] The other channel is the asymmetric information channel (Copeland and Galai (1983); Kyle (1985); Glosten and Milgrom (1985); Admati and Pfleiderer (1988)).

and Melvin (1994); Bessembinder (1994); Ding (1999)). Among the different variables proposed, an interesting common result is the positive relationship between volatility and the bid-ask spreads of some currencies in different frequencies and time periods.

More 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. The effect also works in the other direction, changes in market liquidity can have a significant impact on the conditions at which funding is available to traders. Under certain conditions, the interaction between market and funding liquidity leads to illiquidity spirals and finally to liquidity dry-ups (Brunnermeier and Pedersen (2009); Acharya and Viswanathan (2011)).

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 financial intermediaries. Indeed, 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. Furthermore, we take into account two variables related to the inventory control risk, namely volatility (Copeland and Galai (1983)) and market movements (Hameed et al. (2010)), and seasonality (Bessembinder (1994)). Our approach is empirical in line with Chordia et al. (2001) investigation of the determinants of market liquidity in the stock market.

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 13 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. 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.

In order to proxy for funding liquidity, we employ the interest rate on financial commercial papers. We show that a lowering in the cost of funding of financial intermediaries is associated with a decrease in transaction costs that is an increase in the liquidity of the FX market. Our findings are robust to controlling for global FX volatility, market movements and seasonality. Global FX volatility is found to increase transactions costs, consistent with previous studies at the individual currency level (Bessembinder (1994); Ding (1999)). Thus, while global FX volatility is able to explain a share of the changes in market liquidity, it does not drive out the effect of funding liquidity on market liquidity. Even though funding liquidity and volatility are intertwined, their effect on market liquidity can be individually measured. Market returns are also found to have a strong impact on FX market illiquidity. A decline in market returns results in an increase in transaction costs the following day. Exchange rate movements trigger changes in investor expectations and through their impact on wealth, prompt changes in optimal portfolio compositions. This confirms the results found for the equity market (Chordia et al. (2001); Huberman and Halka (2001)). There are also strong day of the week effects on FX global liquidity, declining on Fridays and increasing on Mondays, confirming the increase in spreads before weekends (Bessembinder (1994)). Finally, we include lags of the FX market liquidity variables to correct for serial correlation of the residuals. Our explanatory variables capture an appreciable fraction of the daily time series variation in market wide liquidity of 35%. Furthermore, funding liquidity together with our other explanatory variables are found to explain unexpected changes in FX market illiquidity as well.

Funding liquidity constraints are more likely to be hit during market declines (Hameed et al. (2010)). During market declines, dealers find it more difficult to adjust inventory than in rising markets. We expand our analysis to examine whether market declines affect FX market liquidity and whether this relationship is indicative of funding constraints in the market. Having confirmed that this is indeed the case, we explore whether liquidity dry-ups are worse during crisis episodes (Brunnermeier and Pedersen (2009)). Our sample period allows us to focus on several crisis episodes.[2] We show that there is a strong relationship between funding liquidity constraints and market illiquidity during crisis episodes.

[2]Our analysis of crisis periods includes the Asian crisis, the LTCM collapse and Russia crisis in 2008, the events of 9/11, the Argentina crisis in 2001 and the recent collapses of Bear Sterns and Lehman Brothers during 2008.

We check the robustness of our results by extending our analysis to another measure of liquidity, the temporary return reversal inspired by the Pastor and Stambaugh (2003)'s proxy developed for the stock market. While the bid-ask spread measures transaction costs, the return reversal proxy is related to market depth. Conducting our analysis at monthly frequency, we take into account two variables for funding liquidity constraints: the amount outstanding of repurchase agreements of primary dealers in the US and the interest rate on financial commercial papers. Our results confirm the importance of funding liquidity in explaining variations of FX market liquidity, even after controlling for volatility and market returns.

In the next section we review the relevant literature. The methodology for the construction of our liquidity measures and proposed determinants is presented in Section 3. Section 4 reports some preliminary analysis of the data and the results of the regression analysis. Robustness tests, including the extension of our analysis to an additional proxy for FX market liquidity, are conducted in Section 5. Finally, Section 6 concludes.

2 Literature review

2.1 Liquidity and the FX market

In the FX market, dealers provide liquidity to the market and quote prices after receiving orders from customers and other dealers. Due to the heterogeneity of market participants, the FX market is characterized by informational asymmetries, so that dealers gather disperse information from the orders placed by their customers (Lyons (1997)). Indeed, FX market practitioners' surveys highlight how order flow[3] is seen as a preferred channel for dealers to obtain private and dispersed information from customers (Goodhart (1988); Cheung and Chinn (2001); Gehrig and Menkhoff (2004)). Such asymmetry of information influences liquidity (Copeland and Galai (1983); Kyle (1985); Glosten and Milgrom (1985); Admati and Pfleiderer (1988)). In fact, dealers quote prices by balancing the expected total revenues from liquidity trading against the expected total losses from informed trading. Copeland and Galai (1983)

[3] Order flow reflects buying pressure for a currency and it is typically calculated as the sum of signed trades. The sign of a given transaction is assigned with respect to the aggressive party that initiates the trade. Evans and Lyons (2002a) provided the seminal evidence in this literature, showing how order flow is a significant determinant of two major bilateral exchange rates, and obtaining coefficients of determination substantially larger than the ones usually found using standard structural models of nominal exchange rates. Their results are found to be fairly robust by subsequent literature; e.g. see Payne (2003), Bjø nnes and Rime (2005).

suggest that liquidity decreases with greater price volatility in the asset being traded, with a higher asset price level, and with lower volume. In this respect, Bollerslev and Melvin (1994) find a significant positive relationship between the bid-ask spread and exchange rate volatility in the interbank market trading of Deutsche mark-US dollar (DM/USD).

Analyzing the intra-day trading of DM/USD in two interbank FX markets (London and New York), Hsieh and Kleidon (1996) find that the volatility patterns in spreads and trading volume are not consistent with standard asymmetric information models. In fact, the observed shifts in transaction costs and trading volume (which can be viewed as proxies for liquidity) are not related to information flows. They suggest that the high volatility of these measures could be explained by inventory considerations. In his empirical analysis, Bessembinder (1994) finds that bid-ask spreads of major currency pairs widen with forecasts of inventory price risk and with a measure of liquidity costs. In addition, there is a seasonal pattern in changes in spreads: spreads widen before weekends and non-trading intervals. Indeed, dealers' inventory control conditions affect the liquidity of the market. According to the theoretical model by Amihud and Mendelson (1980), the market maker's constraints on her inventory positions influence the level of liquidity of the market. Furthermore, liquidity will depend upon the factors that influence the risk of holding inventory (Stoll (1978); Ho and Stoll (1981)).

Furthermore, dealers' financial constraints can be a source of market illiquidity. Shleifer and Vishny (1997) first introduce financially constrained arbitrageurs that are unable to fully exploit arbitrage opportunities due to the risk of investors' redemption. Gromb and Vayanos (2002) explicitly model the financial constraints, arguing that margin requirements affect arbitrageurs' ability to provide liquidity to the market.[4] Referring to the risk of the worsening of counterparty risk, Brunnermeier and Pedersen (2009) extend the Grossman-Miller model to include the interaction of funding liquidity with the provision of liquidity by traders. Indeed, traders' provision of liquidity depends on their ability to finance their operations. Hence, margin constraints can have a significant role on the determination of market liquidity. However, the ability to finance the operations of traders depends on market liquidity as well. So, under certain conditions, this interaction between market liquidity and funding liquidity can lead to a margin spiral leading to liquidity dry–ups. Acharya and Viswanathan (2011) relate market liquidity and funding liquidity to agency problems that impair the ability of financial intermediaries to roll over their short-term debt. In bad

[4]The asset pricing effects, in terms of return and risk, of margin-constrained traders are also modeled by Garleanu and Pedersen (2011).

economic conditions, a high level of debt to be rolled over is related to a strong risk-shifting problem, reducing funding liquidity available to intermediaries. As a consequence, the constrained intermediaries will have to sell assets in order to repay their debt, in turn affecting market liquidity.

2.2 Measures of market liquidity

The bid-ask spread is the most widely used measure of liquidity in the literature. In this respect, Stoll (1989) determines the relative importance of each of the three components of the spread (order processing costs, inventory control cost and adverse selection costs) from the covariance of transaction returns. In the FX market, much research has been carried out on the bid-ask spread; e.g. see Bessembinder (1994), Bollerslev and Melvin (1994), Lee (1994), and Hsieh and Kleidon (1996). However, Grossman and Miller (1988) highlight a key limitation of the bid-ask spread as a measure for liquidity: this method 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 (2012)).

As a result of these possible limitations, we use in our analysis in addition to the bid-ask spread, a liquidity measure, which proxies for the price impact to obtain a more complete picture. Pastor and Stambaugh (2003) propose a liquidity measure based on the temporary price change, in terms of expected return reversal, due to signed transaction volume. This measure is based on the intuition that lower liquidity is accompanied by a higher volume-related return reversal. Mancini et al. (2011) apply a modified version of Pastor and Stambaugh's measure to the FX market by building a daily measure of liquidity for about one year of order flow data during the recent financial crisis. In their analysis of FX global liquidity risk, Banti et al. (2012) employ a similar measure to estimate the monthly FX market liquidity drawing on both developed and emerging market currencies over 14 years.

Another measure of this kind is the market depth measure of Kyle (1985)'s model, which in its empirical counterpart relies on the contemporaneous relationship between FX returns and order flow. Evans and Lyons (2002b) study time-varying liquidity in the FX market using the slope coefficient in a contemporaneous regression of FX returns on order flow as a proxy for liquidity, in the spirit of Kyle (1985) model. There are other measures of liquidity, such as the Amihud (2002) illiquidity ratio, which measures the elasticity of liquidity, which have not been used in FX market because of lack of data.

2.3 Estimation of funding liquidity

Funding liquidity is defined as the ease with which traders can obtain funding. The presence of constraints to the ability of traders to finance their operations can affect negatively market liquidity (Gromb and Vayanos (2002); Brunnermeier and Pedersen (2009); Acharya and Skeie (2011); Acharya and Viswanathan (2011)).

In the literature, financial constraints are defined as margin requirements (Gromb and Vayanos (2002); Brunnermeier and Pedersen (2009); 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)).

In order to empirically analyze funding liquidity, different proxies are used to measure the conditions with which financial intermediaries can access financing.

Some studies employ measures for funding liquidity based on the interest rate on the interbank market: the TED spread (Coffey and Hrung (2009), Cornett, McNutt, Strahan, and Tehranian (2011), Garleanu and Pedersen (2011); Mancini et al. (2011)) and the LIBOR-OIS spread (Acharya and Skeie (2011); Mancini et al. (2011)). The TED spread is the difference between the three-month London Interbank Offered Rate (LIBOR) and the three-month Treasury rate. Since the Treasury rate is considered as the risk-free rate, the TED spread measures the perceived credit risk of interbank lending. Similarly, the LIBOR-OIS spread is the spread between the LIBOR and the Overnight Interest Swap rate (where the flexible interest rate is usually considered the Federal funds rate). The difference in the interbank interest rates of unsecured term (three months) borrowing and unsecured overnight borrowing is considered as a measure of credit risk in the interbank market. In addition, Chordia et al. (2001) employ two measures for short-selling constraints and margins, the daily first difference in the Federal funds rate and the daily change in the difference between the yield on a constant maturity 10-year Treasury bond and the Federal funds rate. Coffey and Hrung (2009) measure margin requirements through the overnight agency MBS-Treasury repurchase agreement spread, which is the difference in the repurchase agreement rate when the collateral are agency mortgage-backed securities (MBS) and when the collateral are Treasury securities.

Conversely, other studies look at funding liquidity aggregates: asset-backed commercial papers[5], financial commercial papers[6] and repurchase agreements[7] (Brunnermeier and Pedersen (2009); Acharya and Viswanathan (2011)). More specifically in the FX market, Adrian, Etula, and Shin (2010) analyze funding liquidity ability to forecast foreign exchange rates, by considering the amount outstanding of commercial papers and repurchase agreements of US financial intermediaries and find that changes in funding liquidity of intermediaries in the US affect exchange rate variation of some currencies versus the US dollar. In another paper, Adrian and Shin (2010) show that financial intermediaries adjust their balance sheets according to the state of the market by adjusting leverage through repurchase agreements and reverse repurchase agreements, in a pro-cyclical manner, that is increasing leverage during booms and reducing it during busts. Furthermore, they show that the financial intermediaries' response to market conditions is similar to Brunnermeier and Pedersen (2009) "margin spiral" where increased margins and falling prices reinforce market distress. When the price of securities falls, the financial intermediaries adjust leverage by selling securities, which will be leading to further price falls. When there is the possibility of a feedback, since leverage has been found to be pro-cyclical, the adjustment of leverage and price changes will reinforce each other in an amplification of the financial cycle. In view of the above, we use in our analysis financial commercial paper and outstanding repurchase agreements.

3 Methodology

3.1 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,

[5]Asset-backed commercial papers are collateralized commercial papers issued by Special Purpose Vehicles created by the financial intermediary that originally owned the asset collateralized. On the one hand, the original owner of the asset finances itself through the sale of these same assets to the SPV. On the other hand, the SPV finances the purchase of such assets through the issuance of ABCP.

[6]Financial commercial papers are unsecured promissory notes issued as a form of short-term financing (maturities are up to 270 days, but usually around 30 days).

[7]Through a repurchase agreement, a financial institution sells a security and buys it back at a pre-agreed price on a agreed future date. The repurchase agreement is equivalent to a secured loan with the interest rate being the difference in the sale price and the repurchase price.

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 main analysis we are employing the percentage bid-ask spreads as a proxy for transaction costs. In an extension of the main analysis, we also consider another proxy for liquidity: the temporary price impact of transactions or market depth, a modified version of Pastor and Stambaugh (2003)'s measure.

3.1.1 Illiquidity as transaction costs

In order to measure transaction costs, we employ the percentage bid-ask spread to increase the comparability of spreads among currencies.

We build the percentage bid-ask spreads of the USD against other currencies following the American system:

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

where $ask_{i,t}$, $bid_{i,t}$ and $mid_{i,t}$ are the daily series of the ask, bid and mid prices of the USD against currency i.

The percentage bid-ask spread measures the transaction costs. Hence, the larger the spread, the transaction costs and the lower the liquidity level. It is important to note that the percentage spread measure is thus a measure of illiquidity.

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

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

Since we are interested in the changes of market illiquidity, we take the first difference of the logs of the market illiquidity measure just calculated:

$$\Delta PS_t = \log(PS_t) - \log(PS_{t-1}). \tag{3}$$

Furthermore, we examine percentage changes as we were not able to reject the hypothesis that PS is non-stationary.

Table 1A in Appendix A shows that market illiquidity explains a substantial proportion of the movements in individual currencies' illiquidity. Furthermore, in accord with Mancini et al. (2011), 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 and the Hungarian forint/USD.

3.2 Identifying the determinants of market liquidity

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. In addition, we take into account variables which are related to the inventory control risk such as volatility and FX market returns, and seasonality.

3.2.1 Funding liquidity constraints

Financial commercial papers are unsecured promissory notes issued as a form of short-term financing. The daily observations of the overnight AA financial commercial paper interest rate data is available from the U.S. Federal Reserve Board and it is collected by The Depository Trust & Clearing Corporation (DTCC), a national clearinghouse for the settlement of securities trades and a custodian for securities. The FCP interest rate index elaborated by the Federal Reserve Board is an aggregation of the interest rates on the trades of financial commercial papers by dealer and direct issuer to investors (supply side), which are weighted according to the face value of the relevant commercial paper. As such, the daily interest rate on financial commercial papers is representative of the interest rates on the actual trades during the day.

Since we are interested in the tightening of funding liquidity, we take the first difference of the logs of financial commercial paper interest rate, as follows:

$$\Delta FCP_t = \log(FCP_t) - \log(FCP_{t-1}), \tag{4}$$

where FCP is the daily series of the overnight financial commercial paper interest rate. Furthermore, we take the first difference as we were not able to reject the hypothesis that that FCP is nonstationary.

We expect to find a positive relationship between changes in funding liquidity and changes in FX market illiquidity. In detail, a decrease in the financial commercial paper interest rates is associated with a decrease in the cost of funding to traders. As a result, traders are expected to increase their operations leading to an increase in FX market liquidity.

3.2.2 Margin requirements

In addition to the measure of funding liquidity constraints, we look at proxies for margin requirements. Hence, we include in our analysis the variation in the Federal funds effective rate to proxy for short-selling constraints and margins in the stock market liquidity (Chordia et al. (2001)).

We also build the TED spread, the difference between the 3-month LIBOR and the 3-month Treasury rate, which is another widely used measure of this kind as it has been noted above.

3.2.3 Global FX volatility

We also include a measure of FX market volatility as a possible determinant of FX market liquidity (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 (Glassman (1987); Boothe (1988); 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. Since the series exhibits non stationarity, we take the first difference of the logs of the measure, as follows:

$$VOL_t = \log(VXY_t) - \log(VXY_{t-1}), \tag{5}$$

3.2.4 FX market returns

Following Chordia et al. (2001) and Hameed et al. (2010), we include recent market activity as one of our explanatory variables. Although, there is no equivalent market index in the FX market, participants are following closely what is happening in the key exchange rate markets. Recent price moves trigger changes in investor expectations and through their impact on wealth, prompt changes in inventories and optimal portfolio compositions.

We calculate FX market returns as follows:

$$MKT_t = \sum_{i=1}^{20} \left(\frac{r_{i,t}}{20} \right), \tag{6}$$

where $r_{i,t}$ is the log return of the USD against currency i at time t.

3.2.5 Weekly Seasonality

According to Bessembinder (1994) there is a seasonal pattern in changes in spreads of major currency pairs. Spreads widen before weekends and non-trading intervals. This is due to several reasons: higher costs of carrying liquid currency inventories as the weekend approaches, higher opportunity costs over weekends because inventories are held for more days; and the risk of changes in inventory value. Thus we include day of the week dummies to test whether such seasonality exists for FX market liquidity, an issue not examined before in the literature.

We include in our analysis dummies for Monday, Tuesday, Wednesday and Thursday.

4 Empirical analysis

4.1 Preliminary analysis of the data

4.1.1 Description of the data

The data set analyzed in this paper comprises daily data for 20 bid, ask and mid exchange rates of the USD versus 20 currencies for a time period of 13 years, from January 01, 1998 to December 31, 2010. 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).[8] The selection of the currencies reflected the importance of the currencies in FX trading according to BIS (2010) and the availability of data.

To build the percentage bid-ask spreads of the USD against these currencies, we obtained the daily series of the ask, bid and mid prices of the USD against the currencies 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. For a large sample of the currencies in our data set (AUD, CAD, CHF, CZK, DKK, EUR, GBP, HUF, JPY, MXN, NOK, NZD, PLN, SGD, SEK, TRY, ZAR) the ask

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

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.[9] Furthermore, in order to estimate FX market returns as the average daily log returns of individual currency pairs, we calculate log returns as the difference of the log of the FX spot exchange rates of the US dollar versus the 20 currencies, also obtained from Datastream. They are the WM/Reuters Closing Spot Rates, provided by Reuters at around 16 GMT.

As a proxy for funding liquidity constraints, our data set comprises overnight AA financial commercial paper (FCP) interest rate. The daily data of the FCP interest rate is available from the U.S. Federal Reserve Board and it is collected by The Depository Trust & Clearing Corporation (DTCC), a national clearinghouse for the settlement of securities trades and a custodian for securities.

In addition, we employ two series to proxy for margin requirements: the Federal Funds (FF) rate and the TED spread. The daily series of the Federal Funds rate is available from the U.S. Federal Reserve Board. To construct the TED spread, we obtain the 3-month LIBOR from Datastream and the 3-month Treasury rate from the U.S. Federal Reserve Board.

4.1.2 Preliminary analysis of the variables

Table 1 reports the descriptive statistics of our main variables, changes in FX market illiquidity and changes in financial commercial paper interest rate. In detail, our proxy of changes in FX market illiquidity exhibits a strong variability, with a high standard deviation. The strong variation through time can be seen in Figure 1. Indeed, transaction costs exhibit a high variation during the first part of the sample period. In particular, there are spikes in illiquidity during 1998, when the Asian countries and Russia were hit by a severe financial crisis. Furthermore, FX market illiquidity has a negative skewness and kurtosis, which indicates fat tails of the observations. Interestingly, our measure presents a high serial correlation.

Changes in financial commercial paper interest rate exhibit a high standard deviation as well. The series shows strong variation during some crisis periods, such as 1998, 2001, and during the latest financial crisis (see Figure 2). The negative skewness and the large positive kur-

[9] 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.

tosis indicate that the series exhibits fat tail on the negative side.

Figure 3 shows the daily changes in the TED spread. The variables show strong variation at the beginning and at the end of the sample period, during financial crisis episodes. In particular, the larger spikes coincide with the most recent financial crisis. Brunnermeier (2009) and Cornett et al. (2011) give a vivid account of the behavior of TED spread during the recent financial crisis. The other margin requirement variable, changes in FF rate, follows a similar path (not shown).

Global FX volatility is plotted in Figure 4. It shows a strong variation through time, but significantly high spikes during the latest financial crisis.

The correlation matrix reported in Table 2 shows the correlation coefficients among our funding liquidity variables and global FX volatility. The correlation between the changes in financial commercial paper interest rate and the Federal funds rate is strong, in excess of 26%. Changes in the proxies for margin requirements, FF rate and TED spread, are negatively correlated, with a coefficient of -4%. In addition, global FX volatility is positively correlated with changes in financial commercial paper interest rate, with a correlation coefficient of over 3%.

4.2 Regression analysis

4.2.1 Market illiquidity and funding liquidity constraints

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

We start our analysis by looking at funding liquidity constraints. So, we run the following regression of the changes in market illiquidity on the proposed determinants:

$$\Delta illiq_t = \alpha + \beta \Delta FCP_t + \gamma_1 d_t^{MON} + \gamma_2 d_t^{TUE} + \gamma_3 d_t^{WED} + \gamma_4 d_t^{THUR} + \sum_{i=1}^{4} \theta_i \Delta illiq_{t-i} + \varepsilon_t, \quad (7)$$

where ΔFCP_t is the first difference of the log of the financial commercial paper interest rates at time t. We take into account the day of the week effect including in our regression the dummies for Monday, Tuesday, Wednesday and Thursday, d_t^{MON}, d_t^{TUE}, d_t^{WED}, and d_t^{THUR} respectively. Finally, we include in the regression the lagged dependent variables, $\Delta illiq_{t-1}$, $\Delta illiq_{t-2}$, $\Delta illiq_{t-3}$, and $\Delta illiq_{t-4}$, to account for the strong serial correlation in the residuals. We run the regression using OLS and adjusting standard errors via Newey and West (1987). As a robustness test we repeat the estimation in a subsequent section using GMM.

Table 3 reports the results of this regression in model (1). The regression has a high explanatory power, with an adjusted R-square of 35%. Looking at funding liquidity constraints, changes in the interest rates of financial commercial papers (ΔFCP) is significant in explaining changes in daily transaction costs. In detail, the positive coefficient tells us that an increase in the funding liquidity constraints results in an increase in transaction costs. As expected given the high serial correlation of our illiquidity measure, the lagged dependent variables are statistically significant. In order to differentiate the statistical significance of ΔFCP from that of the lagged dependent variables and day of the week effects, we run model (1) in Table 3 without ΔFCP. The R squared is 0.3393. We performed an F test, which confirms the statistical significance of ΔFCP. The day of the week dummies are all significant and negative, suggesting that market liquidity declines on Friday. Monday has the largest absolute coefficient suggesting that liquidity appreciably increases on Monday.[10] This confirms the findings of Bessembinder (1994) and Ding (1999) of increases in FX spreads before weekends. A similar pattern was found in Chordia et al. (2001) for the equity market.

At this point, we extend our regression analysis to include other explanatory variables, FX market volatility, margin requirements and lagged FX market returns as follows:

$$\begin{aligned}\Delta illiq_t = {} & \alpha + \beta \Delta FCP_t + \delta VOL_t + \varphi \Delta TS_t + \zeta \Delta FF_t \\ & + \mu MKT_{t-1} + \gamma_1 d_t^{MON} + \gamma_2 d_t^{TUE} + \gamma_3 d_t^{WED} + \gamma_4 d_t^{THUR} \\ & + \sum_{i=1}^{4} \theta_i \Delta illiq_{t-i} + \varepsilon_t,\end{aligned} \tag{8}$$

where VOL_t is the proxy for global FX volatility, ΔTS_t is the changes in the TED spread at time t, ΔFF_t is the changes in the Federal Funds rate at time t, and MKT_{t-1} are the lagged FX market returns. As above, we add dummies for the day of the week as well as the lagged dependent variables.

Model (2) in Table 3 presents the results. Global FX volatility is significant in explaining the movements in FX market illiquidity, con-

[10] On Fridays, when the four day of the week dummies are zero, the positive intercept implies an increase in transaction costs, i.e. a decline in FX market liquidity. If Monday instead of Friday is the zero base case for day of the week dummies, the intercept is statistically significant and its sign is reversed confirming our interpretations of the day of the week dummies. Results can be made available on request.

sistently with previous studies at the individual currency level (Glassman (1987); Boothe (1988); Bollerslev and Melvin (1994); Bessembinder (1994); Ding (1999)). The coefficient is positive as expected, since an increase in volatility is associated with an increase in transaction costs. Furthermore, the impact of volatility on market illiquidity was further confirmed when we investigated the sensitivity of funding liquidity on FX market illiquidity obtained by running regression (8) with a 2-year rolling window and conducting a correlation between the obtained series of the sensitivities and global FX volatility, proxied by the standard deviation of FX market returns. The correlation was over 20%, indicating that the higher the volatility, the stronger the impact of changes in funding liquidity constraints on transaction costs. This supports Vayanos (2004) suggestion that if transaction costs are higher during volatile times the impact of volatility would be even stronger emphasising the connection between changes in market volatility and liquidity. As expected, FX market returns on the previous day have a strong impact on FX market illiquidity. Given the negative sign of the coefficient, a decline in the market returns results in an increase in transaction costs the following day. Importantly, volatility and lagged market returns do not drive out the impact of changes in funding conditions on FX market illiquidity. Indeed, changes in the FCP interest rate stay significant. Realizing that some European banks might have been cut off from the FCP market and our measure of US liquidity might not represent the conditions facing some banks we used an alternative proxy for funding liquidity, LIBOR-OIS spread (Bloomberg available from 2001) and the Euribor-Eonia spread (Datastream available from 1999). Neither proxy was found to be statistically significant. There could be two reasons for that. First, the accuracy of LIBOR rates during the crisis became an important subject of controversy, as pointed out by McAndrews (2009). Secondly, LIBOR rates are only available at 11 am London time, thus not matching our foreign exchange quotes. This issue is bound to have been important especially during the crisis given the extreme market volatility. Changes in margin requirements, TED spread and FF rate, are not statistically significant. In model (3) we present the results by excluding margin requirements.

4.2.2 Market liquidity, market declines and funding liquidity

Having confirmed the importance of funding liquidity in explaining variations in FX market illiquidity, we explore in this section whether funding liquidity constraints are more likely to be hit during market declines (Hameed et al. (2010)). Price declines induce greater changes in liquidity as market-makers find it more difficult to adjust inventory in falling markets than in rising markets. We thus examine first whether market returns induce asymmetric effects on FX market illiquidity and then investigate whether this relationship is indicative of capital constraints in the market place by interacting negative market returns with changes in funding liquidity constraints.

We start our analysis by examining whether the impact of market returns is asymmetric by interacting lagged market returns with a dummy for negative market returns and a dummy for positive market returns, as follows:

$$\begin{aligned}\Delta illiq_t = {} & \alpha + \beta \Delta FCP_t + \mu_1 d^{+}_{t-1} MKT_{t-1} + \mu_2 d^{-}_{t-1} MKT_{t-1} \\ & + \delta VOL_t + \gamma_1 d_t^{MON} + \gamma_2 d_t^{TUE} + \gamma_3 d_t^{WED} + \gamma_4 d_t^{THU} \\ & + \sum_{i=1}^{4} \theta_i \Delta illiq_{t-i} + \varepsilon_t,\end{aligned} \tag{9}$$

where d^{+}_{t-1} is a dummy for increases in lagged market returns, d^{-}_{t-1} is a dummy for declines in lagged market returns and MKT_{t-1} is the lagged market return. Given the focus of the analysis, we first include the main variables, changes in FCP interest rates, the interactive variables for market declines and market increases and the day of the week dummies, and then we add the volatility measure as control variable.[11]

Model (1) in Table 4 shows that the effect of market declines alone affects future transaction costs. The dummy for market rises is not statistically significant, confirming Chordia et al. (2001) for the US equity market. The funding liquidity constraint variable stays statistically significant. Again, while statistically significant, the inclusion of FX market volatility does not change our results (model (2)).

We proceed with our analysis to test whether the impact of market declines is indicative of capital constraints by interacting FX market returns with a dummy for lagged positive changes in the funding constraint variable, as follows:

$$\begin{aligned}\Delta liq_t = {} & \alpha + \beta \Delta FCP_t + \mu d^{+FUND}_{t-1} d^{-}_{t-1} MKT_{t-1} + \delta VOL_t \\ & + \gamma_1 d_t^{MON} + \gamma_2 d_t^{TUE} + \gamma_3 d_t^{WED} + \gamma_4 d_t^{THUR} \\ & + \sum_{i=1}^{4} \theta_i \Delta illiq_{t-i} + \varepsilon_t,\end{aligned} \tag{10}$$

[11] Given that the margin constraints measures were not significant in the main analysis above, we exclude them.

where MKT_{t-1} is the lagged market return, d^{-}_{t-1} is a dummy for declines in market returns in the previous day, and d^{+FUND}_{t-1} is a dummy for positive changes in funding liquidity constraints in the previous day. We first run the regression with the main variables, changes in FCP interest rates and the interactive variable for market declines and worsening funding conditions, and then we add the volatility measure as control variable.

As shown in Table 4, the interacting dummy with the measure of funding liquidity constraints is statistically significant (model (3)). Furthermore, it stays significant once we include the volatility variable (model (4)), indicating that market declines are related to capital constraints in the market. Furthermore, our funding constraints and FX market volatility variable remain statistically significant. It should be noted that the day of the week effects do not change in this analysis.

4.2.3 Crisis episodes

Given that market declines are indicative of funding liquidity constraints, we explore whether liquidity dry-ups are worse during crisis episodes (Brunnermeier and Pedersen (2009)). Indeed, our data set enables us to study several important crisis episodes. These are: the Asian crisis from October 1997 until February 1998, the LTCM collapse and the Russian crisis from May until September 1998, the events of 9/11, the Argentinean default in December 2001 and the more recent events of the collapse of Bear Sterns in May 2008 and Lehman Brothers from September 2008 until December 2008.

We take the level of the TED spread as an indicator for crisis periods and interact it with our measure of changes in funding constraints, financial commercial paper interest rate[12]. In detail, we run the following regression:

$$\begin{aligned}\Delta illiq_t = {} & \alpha + \beta(TS_t * \Delta FCP_t) + \delta VOL_t + \mu MKT_{t-1} \\ & +\gamma_1 d_t^{MON} + \gamma_2 d_t^{TUE} + \gamma_3 d_t^{WED} + \gamma_4 d_t^{THUR} \\ & + \sum_{i=1}^{4} \theta_i \Delta illiq_{t-i} + \varepsilon_t, \end{aligned} \qquad (11)$$

where TS is the level of the TED spread that is interacted with changes in FCP rates, ΔFCP. We also include four lagged dependent variables and the dummies for the day of the week as in the main analysis above (8). However, we exclude changes in financial commercial paper interest rate from the regression to avoid multicollinearity issues.

[12] The TED spread is a better indicator of crisis periods than a 0/1 dummy, which appears to be a crude proxy, not being able to pick accurately the severity of crises, such as the Lehman Brothers collapse (Cornett et al. (2011)).

Table 5 shows the results of the analysis. The TED spread interacted with changes in financial commercial paper interest rate explains significantly changes in transaction costs. Thus, during crisis periods, the changes in funding liquidity constraints have a strong positive impact on FX market illiquidity. In addition, global FX volatility and lagged market returns are also significant determinants of changes in illiquidity in the FX market.

5 Robustness tests

5.1 Market depth and funding liquidity

5.1.1 Market depth as an alternative measure of FX Market liquidity

Liquidity is a broad concept and compasses different aspects of the functioning of a market. As a result, several tools have been developed to measure it. 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. Following Pastor and Stambaugh (2003), we measure liquidity as the expected temporary return reversal accompanying order flow. Pastor and Stambaugh's measure is based on the theoretical insights of Campbell, Grossman, and Wang (1993). Extending the literature relating time-varying stock returns to non-informational trading (e.g. De Long, Shleifer, Summers, and Waldmann (1990)), Campbell, Grossman and Wang develop a model relating the serial correlation in stock returns to trading volume. A change in the stock price can be caused by a shift in the risk-aversion of non-informed (or liquidity) traders or by bad news about future cash flows. While the former case will be accompanied by an increase in trading volume, the latter will be characterized by low volume, as risk-averse market makers will require an increase in returns to accommodate liquidity traders' orders. The serial correlation in stock returns should be directly related to trading volume. The Pastor-Stambaugh measure of liquidity captures the return reversal due to the behavior of risk-averse market makers, thus identifying market depth. While Pastor and Stambaugh use signed trading volume as a proxy for order flow, we employ actual order flow.

In detail, we employ a data set of daily FX spot exchange rates of the USD over our 20 currencies and their order flow for 10 years, from January 01, 1998 to July 17, 2008.[13] The FX transaction data is obtained from State Street Corporation (SSC).[14]

[13] The same order flow data set was employed in Banti et al. (2012).

[14] As one of the world's largest custodian institutions, SSC counts about 10,000

Following closely Banti et al. (2012), we estimate the return reversal associated with order flow regressing the contemporaneous and lagged order flow on the contemporaneous foreign exchange log returns:

$$r_{i,t} = \alpha_i + \beta_i \Delta x_{i,t} + \gamma_i \Delta x_{i,t-1} + \varepsilon_{i,t}. \tag{12}$$

We estimate this regression using daily data for every month in the sample, and then take the estimated coefficient for γ to be our proxy for liquidity. Given the construction of our proxy and the availability of daily data of order flow, we conduct our analysis of market depth at monthly frequency. Thus, the monthly proxy for liquidity of a specific exchange rate is:

$$L_{i,m} = \widehat{\gamma}_{i,m}. \tag{13}$$

If the effect of the lagged order flow on the returns is indeed due to illiquidity, γ_i should be negative and reverse a portion of the impact of the contemporaneous flow, since β_i is expected to be positive. In other words, contemporaneous order flow induces a contemporaneous appreciation of the currency in net demand ($\beta_i > 0$), whereas lagged order flow partly reverses that appreciation ($\gamma_i < 0$).

Next, we construct a measure of changes in common liquidity by averaging across currencies the individual monthly liquidity measures and taking the first difference:

$$L_m = \frac{1}{N} \sum_{i=1}^{N} L_{i,m} \tag{14}$$

$$\Delta L_m = L_m - L_{m-1}. \tag{15}$$

Table 6 shows some descriptive statistics of the variable thus constructed. The variable shows a high standard deviation, indicating a

institutional investor clients with about 12 trillion US dollars under custody. SSC records all the transactions in these portfolios, including FX operations. The data provided by SSC is the daily order flow aggregated per currency traded. Order flow data is defined by SSC as the overall buying pressure on the currency and is expressed in millions of transactions (number of buys minus number of sells in a currency). The measures of investor behavior developed at SSC reflect the aggregate flows (and holdings) of a fairly homogenous group of the world's most sophisticated institutional investors and represent approximately 15 percent of tradable securities across the globe. The data are used by SSC for the construction of the Foreign Exchange Flow Indicator (FXFI), an indicator of net buying pressure for currencies. The FXFI data available to us is the net flow for 20 currencies, derived from currency-level transactions and aggregated to ensure client confidentiality. The data is therefore not derived from broker/intermediary flow. However, it is important to note that the FXFI is not exactly the raw net of buy and sell number of transactions (net flow), but is the net flow filtered through a 'normalization' designed to increase comparability across currencies and through time as well as to reflect the SSC commitment to client confidentiality.

strong variation. Furthermore, it exhibits strong negative serial correlation. Figure 5 shows the strong time variation of the series.

5.1.2 Are funding liquidity conditions a determinant of market depth?

We now turn our attention to monthly funding liquidity conditions. Since we are interested in the monthly frequency, we take the last observation available in each month for overnight AA financial commercial paper interest rates. Furthermore, an interesting measure of funding liquidity condition is available at lower frequency, the amount outstanding of repurchase agreements. Repurchase agreements are contracts under which a financial institution sells a security and buys it back at a preagreed price on a agreed future date. According to Adrian and Shin (2010) it represents the most significant source of financing for financial intermediaries. The data of the amount outstanding in repurchase agreements 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. Since we are interested in the monthly effects of funding liquidity on the movements of FX market liquidity, we construct the monthly series by averaging the weekly amount outstanding.

Since we are interested in the variation of funding liquidity, we take the first difference of the log of the funding liquidity variables, as follows:

$$\Delta FCP_m = \log(FCP_m) - \log(FCP_{m-1}), \tag{16}$$
$$\Delta REPO_m = \log(REPO_m) - \log(REPO_{m-1}), \tag{17}$$

where FCP and $REPO$ are the series of the financial commercial paper interest rates and amount outstanding of repurchase agreements respectively and the subscript $_m$ indicates the monthly frequency.

Now that we have identified the measures of funding liquidity conditions, we investigate whether changes in the availability of funding liquidity have an impact on the changes in FX market liquidity. So, we run the following regression:

$$\begin{aligned}\Delta L_m = {} & \alpha + \gamma \Delta REPO_m + \beta \Delta FCP_m + \delta VOL_m \\ & + \varphi \Delta TS_m + \zeta \Delta FF_m + + \mu MKT_{m-1} + \theta \Delta L_{m-1} + \varepsilon_m,\end{aligned} \tag{18}$$

where VOL_m is the monthly standard deviation of daily currency returns, ΔTS and ΔFF are the monthly series of changes in the TED spread and the Federal funds rate respectively, and MKT_{m-1} is the lagged monthly FX market returns. We include the lagged dependent variable to account for autocorrelation in the residuals.

Table 7 shows the results. In model (1) we present the results without the controlling variables. As expected, the coefficient associated with changes in the amount outstanding of REPOs is positive and statistically significant. In fact, an increase in the availability of funding to dealers increases FX market liquidity, measured as market depth. In order to differentiate the statistical significance of ΔREPO from that of the lagged dependent variable we run model (1) in Table 7 without ΔREPO. The R squared is 0.2561. We performed an F test, which confirms the statistical significance of ΔREPO. Conversely to the daily analysis of transaction costs, changes in FCP interest rates are not statistically significant in explaining changes in FX market depth. Including the control variables in model (2) we find FX volatility to be significant, the negative sign implying that an increase in FX market volatility is associated with a decrease in market depth. In contrast, the variation in the TED spread and FF rate and lagged market returns do not explain changes in FX market liquidity. In model (3) we present the results without these variables. Our explanatory variables explain a substantial proportion of the variation of monthly market depth, of 41%.

In conclusion, extending our analysis of the relationship between FX market liquidity and funding liquidity constraints to another measure of liquidity and a different frequency, the availability of funding liquidity to traders is still an important determinant of FX market liquidity.

5.2 GMM estimation

A concern about our analysis is endogeneity. 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(Brunnermeier and Pedersen (2009); Acharya and Viswanathan (2011)). In view of that we run a VAR to test for Granger causality. We found that there was no causality running from FX market illiquidity to FCP. However, there could be further endogeneity issues related to the other variables so we check the robustness of our results by estimating the models using GMM, which allows for endogeneity. The results are robust to this alternative estimation (Tables 1B and 2B in Appendix B).

5.3 Unexpected changes in FX market illiquidity

In the analysis of the determinants of 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.

In order to identify the unexpected component of changes in FX market illiquidity, we take the residuals of an AR(5) model of the common illiquidity measure as our proxy.[15] In detail, we run the following regression:

$$\Delta illiq_t = \alpha + \sum_{i=1}^{5} \beta_i \Delta illiq_{t-i} + \varepsilon_t, \tag{19}$$

and we take ε_t to be our measure of shocks in FX market illiquidity, $\Delta^{UNEXP} illiq_t$.

Next, we regress our measure of shocks in FX market, $\Delta^{UNEXP} illiq_t$, on the determinants identified above in regression (8). Thus, we run the following regression:

$$\begin{aligned} \Delta^{UNEXP} illiq_t = &\alpha + \beta \Delta FCP_t + \delta VOL_t + \varphi \Delta TS_t \\ &+\zeta \Delta FF_t + \mu MKT_{t-1} + \gamma_1 d_t^{MON} + \gamma_2 d_t^{TUE} \\ &+\gamma_3 d_t^{WED} + \gamma_4 d_t^{THUR} + \varepsilon_t, \end{aligned} \tag{20}$$

We report the results in Table 8. Indeed, the analysis of shocks does confirm the determinants found to be significant in explaining changes in FX market illiquidity. In model (1), the changes in the interest rate on FCP have a strong impact on unexpected changes in transaction costs. This result is strong to the inclusion in our analysis of global FX volatility and lagged market returns (model (2)). As expected, shocks in FX market illiquidity are related to the level of volatility and lagged market returns (model (2)). Conversely, changes in the margin requirements are unrelated to shocks in FX market illiquidity, similarly to our main analysis. In model (3) we run the regression by excluding changes in margin requirements. As expected, the R^2 is much smaller than in our main analysis.

6 Conclusions

The recent financial crisis brought attention to the effects of variations in funding liquidity. In this paper, we investigate the role of funding liquidity on the commonality of FX market illiquidity, an area not yet explored in the literature. We examine the commonality of FX market

[15] We take an AR(5) 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.

illiquidity of 20 exchange rates of both developed and emerging markets currencies over 13 years. Our results confirm the prediction of Brunnermeier and Pedersen (2009) that funding liquidity is a driving state variable of commonality in liquidity.

We study two different aspects of FX market liquidity, transaction costs and market depth. We find funding liquidity constraints to be important determinants of FX market liquidity. The results are similar for both liquidity measures, even though financial commercial papers are relevant for transaction costs and repurchase agreements for market depth. Funding liquidity is also found to explain unexpected changes in FX market illiquidity.

The results are robust to controlling for volatility, FX market returns and seasonality. Global FX volatility is found to increase transactions costs, consistent with previous studies at the individual currency level (Bessembinder (1994); Ding (1999)). Market returns are also found to have a strong impact on FX market illiquidity. A decline in market returns results in an increase in transaction costs the following day. Exchange rate movements trigger changes in investor expectations, and through their impact on wealth prompt changes in optimal portfolio compositions. This confirms the results found for the equity market (Chordia et al. (2001); Huberman and Halka (2001)). There are also strong day of the week effects on FX global liquidity, declining on Fridays and increasing on Mondays, confirming the increase in spreads before weekends (Bessembinder (1994)). Our explanatory variables capture an appreciable fraction of the daily time series variation in market wide liquidity, 35% in the case of transaction costs and 41% in the monthly variable in the case of market depth. Funding liquidity and our other explanatory variables are found to explain unexpected changes in FX market illiquidity as well. Our results are robust to alternative methods of estimation, such as GMM, which allows for endogeneity, which could be a concern in our analysis.

We also find that market declines impact negatively on FX liquidity, suggesting that inventory accumulation concerns are more important in declining markets, and that this relates to periods when the suppliers of liquidity are likely to face capital tightness. This is further confirmed when we find that liquidity dry-ups during crisis times impact on FX market illiquidity.

In conclusion, our study finds that funding liquidity constraints are important determinants of the commonality of FX market illiquidity and supports the impact of liquidity dry-ups on financial markets (Shleifer and Vishny (1997); Gromb and Vayanos (2002)).

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	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	-0.0234	*0.0148*	*0.0399*	*-0.0015*	*-0.0687*	*-0.0012*	*0.0078*	*-0.0236*	*0.0052*	*0.1184*
ΔPS_t	**0.0004**	**0.0018**	**0.0001**	**0.0003**	**0.0007**	**0.0013**	**0.0003**	**0.0002**	**0.0001**	**0.0012**
	8.4932	*4.4322*	*2.8215*	*9.0788*	*5.3742*	*10.4307*	*9.9348*	*10.7568*	*3.0099*	*10.8784*
$Adjusted R^2$	0.041	0.050	0.005	0.055	0.045	0.079	0.053	0.064	0.004	0.065
	JPY	**KRW**	**MXN**	**NOK**	**NZD**	**PLN**	**SEK**	**SGD**	**TRY**	**ZAR**
Constant	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	-0.0009	*0.0162*	*-0.0570*	*0.0734*	*-0.0336*	*-0.0465*	*-0.0002*	*-0.0726*	*0.0015*	*0.0225*
ΔPS_t	**0.0001**	**0.0023**	**0.0009**	**0.0006**	**0.0011**	**0.0019**	**0.0004**	**0.0002**	**0.0017**	**0.0035**
	3.5932	*9.1085*	*6.6479*	*10.9386*	*10.2925*	*15.1388*	*9.1919*	*6.4213*	*2.0360*	*12.2277*
$Adjusted R^2$	0.006	0.084	0.073	0.079	0.090	0.128	0.055	0.020	0.002	0.157

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

$$\Delta PS_{i,t} = \alpha_i + \beta_i \Delta PS_t + \varepsilon_{i,t}.$$

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 1998 to December 2010. 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 Britain 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.

Appendix B. Alternative estimation via GMM

Table 1B: Transaction costs and funding liquidity via GMM

	1	2
ΔFCP_t	**0.0389**	**0.0375**
	2.1575	*2.2408*
VOL_t		**0.17609**
		2.0276
MKT_{t-1}		**-1.07246**
		-3.1558
d_t^{MON}	**-0.0285**	**-0.02952**
	-5.0017	*-5.1498*
d_t^{TUE}	**-0.0281**	**-0.02903**
	-5.4225	*-5.5068*
d_t^{WED}	**-0.02019**	**-0.02167**
	-3.9398	*-4.1388*
d_t^{THUR}	**-0.01321**	**-0.01426**
	-2.5082	*-2.6921*
$\Delta illiq_{t-1}$	**-0.70130**	**-0.70536**
	-28.2930	*-28.6215*
$\Delta illiq_{t-2}$	**-0.49892**	**-0.50048**
	-16.9666	*-17.0514*
$\Delta illiq_{t-3}$	**-0.32709**	**-0.32764**
	-11.4417	*-11.5244*
$\Delta illiq_{t-4}$	**-0.18440**	**-0.18363**
	-8.3198	*-8.3282*
Constant	**0.01752**	**0.0185**
	4.8255	*5.0076*
$Adjusted R^2$	0.35	0.35
LM test - pval	0.02	0.01

Notes: The table reports the results of the regression analysis of the determinants of FX market liquidity, measured as transaction costs, in regression (8) estimated via GMM. 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 1998 to December 2010.

Table 2B: Market depth and funding liquidity via GMM

	1	2
$\Delta REPOS_m$	**0.0089**	**0.0085**
	4.6023	*4.4164*
ΔFCP_m	-0.0003	0.0000
	-0.2289	*-0.0059*
VOL_m		**-0.4405**
		-3.6437
ΔL_{m-1}	**-0.4987**	**-0.5053**
	-7.8456	*-8.3010*
Constant	**-0.0001**	**0.0016**
	-0.5051	*3.4272*
$Adjusted R^2$	0.37	0.41
LM test - pval	0.08	0.12

Notes: The table reports the results of the regression analysis of the determinants of FX market liquidity, measured with the Pastor-Stambaugh measure, in regression (18) estimated via GMM. 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 1998 to July 2008.

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Table 1: Descriptive statistics of changes in FX market illiquidity and changes in financial commercial paper interest rate

	Δilliq	ΔFCP
mean	-0.00003	-0.00369
median	0.00071	0
st dev	0.11454	0.09241
min	-0.55196	-2.07944
max	0.58896	1.50408
skew	-0.01154	-4.00308
kurt	2.32023	147.02724
AC(1)	-0.46000	-0.06987

Notes: Descriptive statistics are reported for the measure of changes in market illiquidity and changes in financial commercial paper interest rate. The latter is the overnight AA financial commercial paper interest rate. The measure for the variation is obtained as the difference of the daily log of the series. AC(1) refers to the first order autocorrelation of the series.

Table 2: Correlation matrix

	ΔFCP	ΔFF	ΔTS
ΔFF	**0.2686**		
ΔTS	**-0.0379**	**-0.0383**	
ΔVOL	**0.0322**	**0.0794**	**0.1781**

Notes: The correlation matrix reports the correlation coefficients between the variables. FCP indicates the daily series of overnight AA financial commercial paper interest rate. TS indicates the TED spread. FF is the Federal funds rate. VOL is the FX market volatility, estimated as the JP Morgan implied volatility index, VXY. A Δ indicates the daily changes in the variable.

Table 3: Determinants of FX market illiquidity

	1	2	3
ΔFCP_t	**0.03892**	**0.03512**	**0.03752**
	2.0436	*2.0007*	*2.1144*
VOL_t		**0.18953**	**0.1761**
		2.3540	*2.2110*
MKT_{t-1}		**-1.08659**	**-1.0724**
		-3.1042	*-3.0555*
ΔTS_t		-0.02296	
		-0.9288	
ΔFF_t		-0.00040	
		-0.0205	
d_t^{MON}	**-0.02847**	**-0.03192**	**-0.02952**
	-5.1479	*-5.6702*	*-5.3350*
d_t^{TUE}	**-0.02814**	**-0.02869**	**-0.02903**
	-5.2224	*-5.2851*	*-5.3823*
d_t^{WED}	**-0.02018**	**-0.02113**	**-0.02167**
	-3.9048	*-4.0304*	*-4.1781*
d_t^{THUR}	**-0.01321**	**-0.01389**	**-0.01426**
	-2.5573	*-2.6143*	*-2.7584*
$\Delta illiq_{t-1}$	**-0.70127**	**-0.70711**	**-0.70536**
	-31.6545	*-31.5916*	*-31.9579*
$\Delta illiq_{t-2}$	**-0.49889**	**-0.50156**	**-0.50048**
	-17.0825	*-16.9590*	*-17.2240*
$\Delta illiq_{t-3}$	**-0.32712**	**-0.32910**	**-0.32764**
	-11.1426	*-11.2492*	*-11.2588*
$\Delta illiq_{t-4}$	**-0.18440**	**-0.18308**	**-0.18363**
	-8.0731	*-7.9921*	*-8.0808*
Constant	**0.01752**	**0.01822**	**0.01848**
	4.4966	*4.6068*	*4.7333*
$Adjusted R^2$	0.35	0.35	0.35
LM test - pval	0.02	0.01	0.01

Notes: The table reports the results of the different specifications of regression (8):

$$\begin{aligned}\Delta illiq_t = {} & \alpha + \beta \Delta FCP_t + \delta VOL_t + \varphi \Delta TS_t + \zeta \Delta FF_t \\ & + \mu MKT_{t-1} + \gamma_1 d_t^{MON} + \gamma_2 d_t^{TUE} + \gamma_3 d_t^{WED} + \gamma_4 d_t^{THUR} \\ & + \sum_{i=1}^{4} \theta_i \Delta illiq_{t-i} + \varepsilon_t,\end{aligned}$$

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 1998 to December 2010.

Table 4: FX market illiquidity and market returns

	1	2	3	4
ΔFCP_t	**0.03953**	**0.03811**	**0.03737**	**0.03606**
	2.1490	*2.1674*	*2.0136*	*2.0273*
$d^{+}_{t-1}MKT_{t-1}$	0.07004			
	0.1210			
$d^{-}_{t-1}MKT_{t-1}$	**-2.22438**	**-2.18597**		
	-3.7228	*-3.8672*		
$d^{+FUND}_{t-1}d^{-}_{t-1}MKT_{t-1}$			**-2.1366**	**-2.0672**
			-3.0261	*-2.9672*
VOL_t		**0.1706**		**0.1667**
		2.1518		*2.0980*
d^{MON}_t	**-0.0286**	**-0.0293**	**-0.0279**	**-0.0285**
	-5.1818	*-5.3045*	*-5.0367*	*-5.1466*
d^{TUE}_t	**-0.02837**	**-0.02895**	**-0.02891**	**-0.02945**
	-5.2623	*-5.3660*	*-5.3558*	*-5.4484*
d^{WED}_t	**-0.02010**	**-0.02123**	**-0.01932**	**-0.02043**
	-3.8895	*-4.0927*	*-3.7391*	*-3.9388*
d^{THUR}_t	**-0.01349**	**-0.01422**	**-0.01269**	**-0.01342**
	-2.6204	*-2.7593*	*-2.4611*	*-2.5970*
$\Delta illiq_{t-1}$	**-0.70500**	**-0.70522**	**-0.70393**	**-0.70400**
	-31.9596	*-32.0436*	*-31.8204*	*-31.8553*
$\Delta illiq_{t-2}$	**-0.50067**	**-0.50026**	**-0.50071**	**-0.50021**
	-17.2558	*-17.2820*	*-17.2444*	*-17.2792*
$\Delta illiq_{t-3}$	**-0.32822**	**-0.32762**	**-0.32964**	**-0.32894**
	-11.2819	*-11.2981*	*-11.2877*	*-11.2989*
$\Delta illiq_{t-4}$	**-0.18415**	**-0.18406**	**-0.18610**	**-0.18600**
	-8.0805	*-8.1104*	*-8.1539*	*-8.1726*
Constant	**0.01367**	**0.01451**	**0.01575**	**0.01643**
	3.1902	*3.6126*	*3.9956*	*4.1573*
$Adjusted R^2$	0.35	0.35	0.35	0.35
LM test - pval	0.01	0.01	0.02	0.01

Notes: The table reports the results of the analysis of the interaction of market illiquidity and market returns. Models (1) reports the results of regression (9) without volatility. Model (2) reports the results of regression (9) with volatility as control variable, but excluding the interaction variable of market returns increases. Models (3) and (4) report the results of regression (10) without and with volatility as control variable. The coefficients are reported and 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 1998 to December 2010.

Table 5: Market illiquidity and crisis episodes

$TS_t \Delta FCP_t$	**0.02084**
	2.3908
VOL_t	**0.1687**
	2.1683
MKT_{t-1}	**-1.0564**
	-2.9509
d_t^{MON}	**-0.02972**
	-5.3412
d_t^{TUE}	**-0.02911**
	-5.3587
d_t^{WED}	**-0.02158**
	-4.1404
d_t^{THUR}	**-0.01402**
	-2.6957
$\Delta illiq_{t-1}$	**-0.70693**
	-31.5688
$\Delta illiq_{t-2}$	**-0.50251**
	-17.3148
$\Delta illiq_{t-3}$	**-0.32850**
	-11.2533
$\Delta illiq_{t-4}$	**-0.18301**
	-8.1009
Constant	**0.01848**
	4.6914
$Adjusted R^2$	0.35
LM test - pval	0.01

Notes: The table reports the results of regression (11):

$$\begin{aligned}\Delta illiq_t = & \alpha + \beta(TS_t * \Delta FCP_t) + \delta VOL_t + \mu MKT_{t-1} \\ & + \gamma_1 d_t^{MON} + \gamma_2 d_t^{TUE} + \gamma_3 d_t^{WED} + \gamma_4 d_t^{THUR} \\ & \sum_{i=1}^{4} \theta_i \Delta illiq_{t-i} + \varepsilon_t,\end{aligned}$$

The coefficients are reported and 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 1998 to December 2010.

Table 6: Descriptive statistics of changes in market depth

mean	**median**	**st dev**	**min**	**max**	**skew**	**kurt**	**AC(1)**
-0.00001	0.00006	0.0024	-0.0057	0.0059	0.0153	-0.0085	-0.5119

Notes: Descriptive statistics are reported for the monthly measure of changes in market liquidity. FX market liquidity is calculated as the return reversal associated with transaction volume. AC(1) refers to the first order autocorrelation of the series.

Table 7: Market depth and funding liquidity

	1	2	3
$\Delta REPO_m$	**0.0089**	**0.0086**	**0.0085**
	4.7687	*4.4494*	*4.5598*
ΔFCP_m	-0.0003	0.0001	0.0000
	-0.2453	*0.0414*	*-0.0063*
VOL_m		**-0.3978**	**-0.4405**
		-3.1818	*-3.4300*
ΔTS_m		**-0.0003**	
		-0.3899	
ΔFF_m		-0.0002	
		-0.1570	
MKT_{m-1}		0.3387	
		1.8786	
ΔL_{m-1}	**-0.4987**	**-0.5030**	**-0.5053**
	-7.5560	*-7.6906*	*-7.9817*
Constant	-0.0001	**0.0014**	**0.0016**
	-0.3616	*2.9117*	*3.2653*
$AdjustedR^2$	0.37	0.41	0.41
LM test - pval	0.08	0.17	0.12

Notes: The table reports the results of the regression analysis of the determinants of FX market liquidity, measured with the Pastor-Stambaugh measure, in regression (18):

$$\Delta L_m = \alpha + \gamma \Delta REPO_m + \beta \Delta FCP_m + \delta VOL_m$$
$$+ \varphi \Delta TS_m + \zeta \Delta FF_m + \mu MKT_{m-1} + \theta \Delta L_{m-1} + \varepsilon_m,$$

The coefficients are reported and 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 1998 to July 2008.

Table 8: Analysis of the determinants of shocks to FX market illiquidity

	1	2
ΔFCP_t	**0.03404**	**0.03327**
	1.9831	*1.9331*
VOL_t	**0.17051**	**0.18376**
	2.1719	*2.3070*
MKT_{t-1}	**-1.02569**	**-1.03947**
	-2.9329	*-2.9756*
ΔTS_t		-0.0182
		-0.7636
ΔFF_t		-0.0056
		-0.2920
d_t^{MON}	**-0.03064**	**-0.03266**
	-5.5666	*-5.8199*
d_t^{TUE}	**-0.02793**	**-0.02764**
	-5.2705	*-5.1637*
d_t^{WED}	**-0.01998**	**-0.01930**
	-3.8515	*-3.6778*
d_t^{THUR}	**-0.01306**	**-0.01235**
	-2.5332	*-2.3348*
Constant	0.01787	0.01742
	4.6333	*4.4549*
$Adjusted R^2$	0.02	0.02
LM test - pval	0.01	0.00

Notes: The table reports the results of the regression analysis of the determinants of unexpected changes, or shocks, to FX market illiquidity, regression (20):

$$\begin{aligned}\Delta^{UNEXP} illiq_t = {} & \alpha + \beta \Delta FCP_t + \delta VOL_t + \varphi \Delta TS_t + \zeta \Delta FF_t \\ & + \mu MKT_{t-1} + \gamma_1 d_t^{MON} + \gamma_2 d_t^{TUE} + \gamma_3 d_t^{WED} + \gamma_4 d_t^{THUR} \\ & + \varepsilon_t,\end{aligned}$$

Shocks are estimated as the residuals of a AR model of order 5 to eliminate serial correlation. The coefficients are reported and 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 1998 to December 2010.

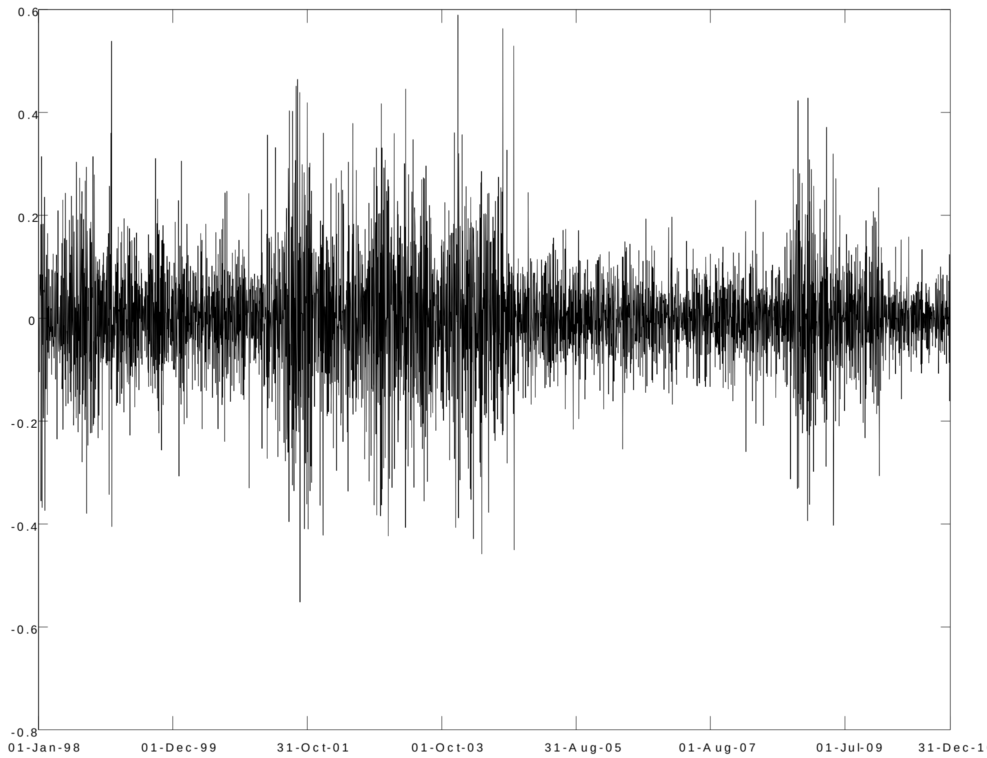

Figure 1: Changes in FX market illiquidity

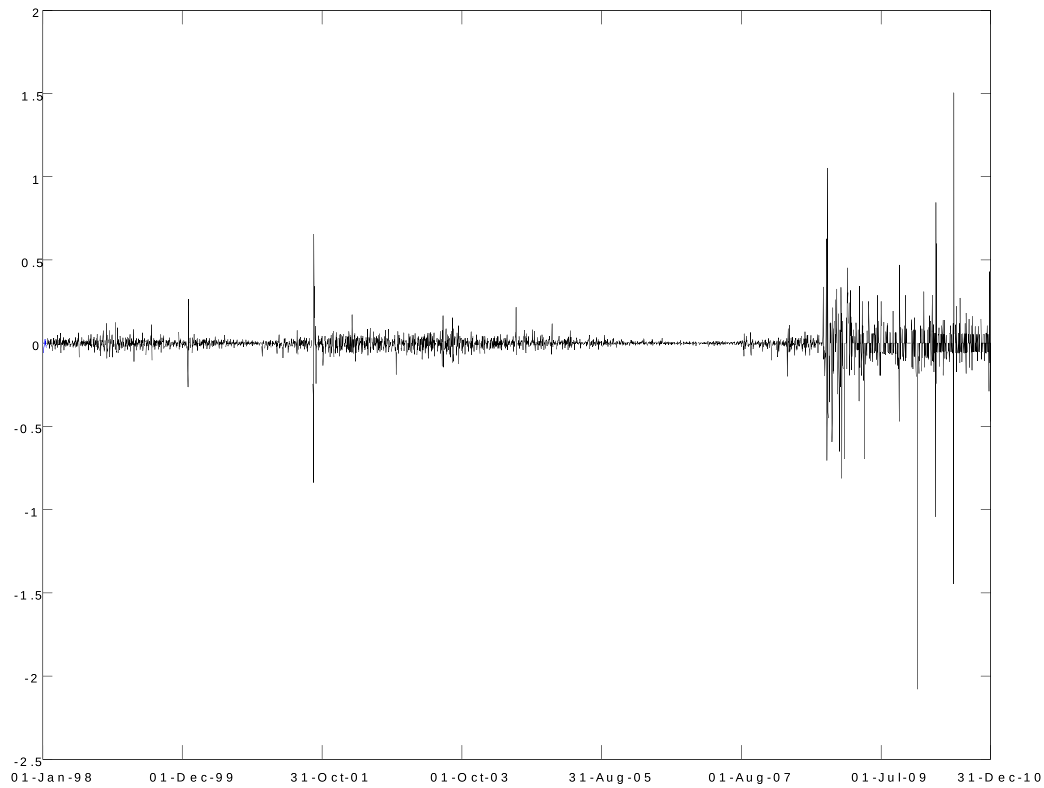

Figure 2: Changes in financial commercial paper interest rate

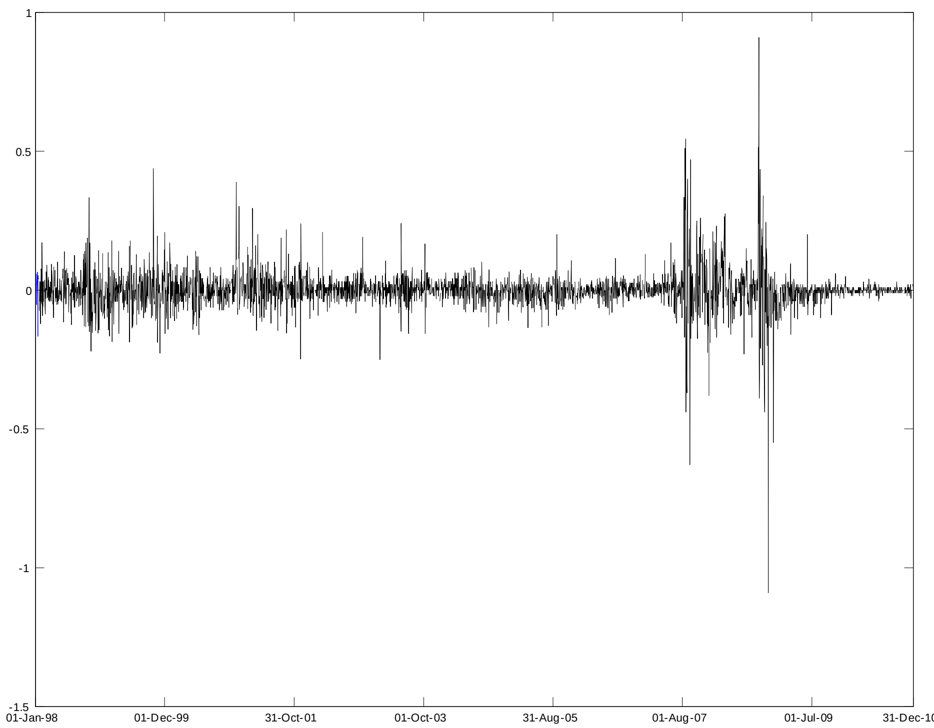

Figure 3: Changes in TED spread

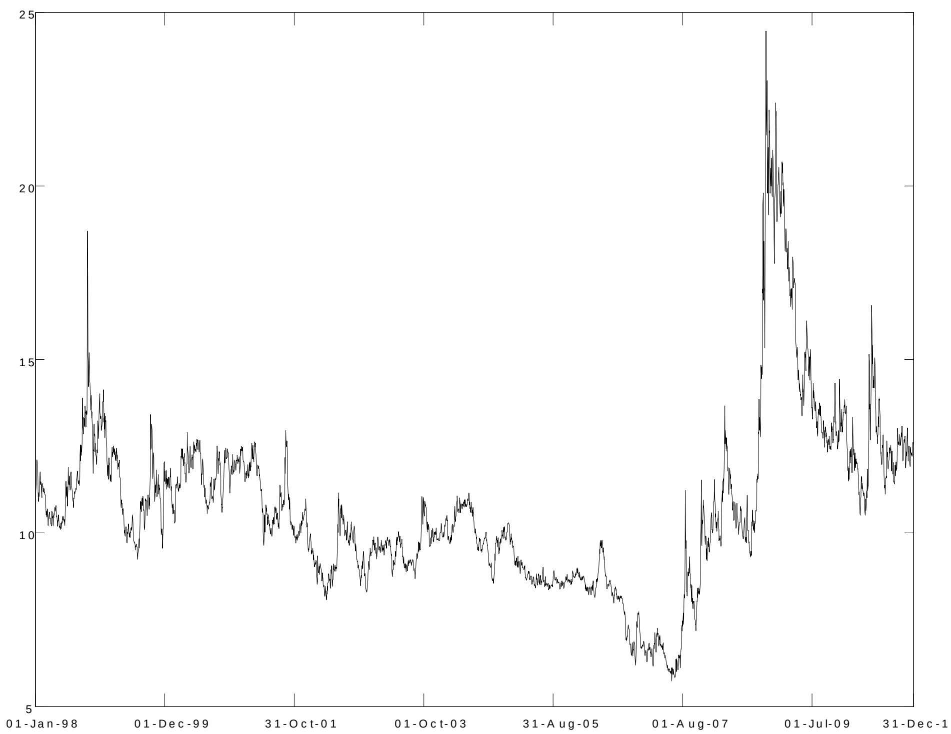

Figure 4: Global FX volatility

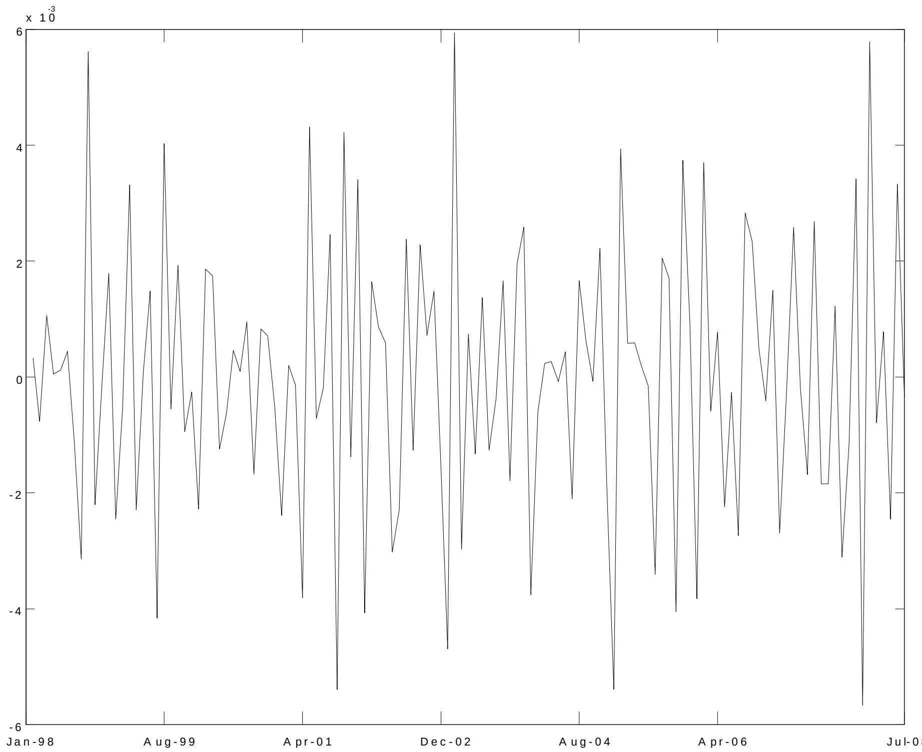

Figure 5: Changes in monthly FX market depth