# FX market illiquidity and funding liquidity constraints

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**Abstract**

Using a broad data set for 20 exchange rates of both developed and emerging markets' currencies for 13 years, we find that funding liquidity constraints impact on two different aspects of FX market liquidity, transaction costs and market depth, after controlling for global FX volatility, FX market returns and seasonality. The impact of funding liquidity on FX market liquidity relates to market declines when suppliers to liquidity face capital tightness and during crisis times, when there are severe liquidity dry-ups. There is supporting evidence that the impact of funding liquidity on FX market illiquidity relates also to increases in the demand for liquidity as agents become more risk averse during volatile times.

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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

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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 and that shocks to this 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 in 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 positive relationship between both the VIX and the TED spread measures and FX market liquidity for the most traded currencies during the recent financial crisis. Analyzing individual currency liquidity, some papers investigate the determinants of changes in the bid-ask spreads over time (Glassman (1987); Boothe (1988); Bollerslev 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.

Market microstructure literature identifies two main channels through which dealers' operations affect market liquidity: inventory control and asymmetric information. In this sense, while dealers provide quotes and engage in trading to manage their inventory positions and inventory risk (Stoll (1978); Ho and Stoll (1981)), they also respond to the risk of trading with a better informed party by increasing the spreads (Copeland and Galai (1983); Kyle (1985); Glosten and Milgrom (1985); Admati and Pfleiderer (1988)).

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 liquidity. 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)).

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 for 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. It should be noted that our results are robust to another measure of liquidity 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 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 of 34%. Furthermore, funding liquidity together with our other explanatory variables are found to explain unexpected changes in FX market illiquidity as well.

Following Hameed et al. (2010) we further explore the relationship between FX market liquidity and market movements. We find this relationship to be especially strong during market declines, as it is more difficult to adjust inventory in falling markets than in rising markets.Furthermore this relationship is found and to be indicative of funding constraints in the market.

Our sample period allows us to focus on several crisis episodes[1] to examine whether liquidity dry-ups were worse during crisis times. We show that there is a strong relationship between funding liquidity constraints and market illiquidity during crisis episodes.

We also investigate whether the impact of funding liquidity on FX market illiquidity relates to changes in the demand for liquidity. According to Vayanos (2004), investors become more risk averse and their preference for liquidity increases in volatile times. Therefore, a jump in market liquidity, the main state variable in their model is associated with demand for liquidity. We do not have measures of the demand for liquidity to test this directly. However, we find supporting evidence that volatility plays an important role in the sensitivity of funding liquidity conditions on FX market liquidity. Estimating these sensitivities in different time periods we show that the sensitivities increase in periods of high volatility in the market.

We extend 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

[1] 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.

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.

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. An extension of our analysis with an additional proxy for FX market liquidity is 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[2] 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) 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

[2] 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), Killeen, Lyons, and Moore (2006).

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)). According to Grossman and Miller (1995), the provision of liquidity depends on the cost incurred by the market maker to maintain her presence in the market. In turn, this cost is inversely related to the number of market makers which are operating in the market. As a result, the larger the number of market makers, the lower is the cost for immediacy and the more liquid is the market, resulting in a lower price impact of trades.

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.[3] 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 economic conditions, a high level of debt to be rolled over is related to a strong risk-shifting problem, reducing funding liquidity available to

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

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 (1995) 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.

Apart from measures related to transaction costs, other liquidity measures were developed to proxy the price impact of transactions. 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. Furthermore, Amihud (2002)'s illiquidity ratio measures the elasticity of liquidity. This is calculated as the daily measure of absolute asset returns to dollar volume, averaged over some period.

## 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[4], financial commercial pa-

[4]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.

pers[5] and repurchase agreements[6] (Brunnermeier and Pedersen (2009); Acharya and Viswanathan (2011)). Analyzing funding liquidity ability to forecast foreign exchange rates, Adrian, Etula, and Shin (2010) consider 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 the exchange rate variation of some currencies versus the US dollar. Looking at the effects of balance sheet adjustments of five major US financial intermediaries, Adrian and Shin (2010) find that the main source of the adjustment when liquidity shifts is due to repurchase agreements.

Linking funding liquidity constraints to market downturns, Hameed et al. (2010) show that market declines are associated with declines in stock liquidity and that this relationship is especially strong during periods when there are harder funding constraints.

# 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, 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 the

[5] 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).

[6] 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.

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 higher 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 the changes in market illiquidity by averaging across currencies the first difference of the individual percentage spread series excluding the two most extreme observations (e.g. Chordia, Roll, and Subrahmanyam (2000); Pastor and Stambaugh (2003)), as follows:

$$\Delta PS_{i,t} = (PS_{i,t} - PS_{i,t-1}) \tag{2}$$

$$\Delta PS_t = \frac{1}{N}\sum_{i=1}^{N} \Delta PS_{i,t}. \tag{3}$$

## 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 (maturities are up to 270 days, but usually around 30 days). 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 changes in the financial commercial paper interest rate, we take the first difference of the logs, as follows:

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

where $FCP$ is the daily series of the financial commercial paper interest rate.

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)). The daily series is available from the U.S. Federal Reserve Board.

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 (Coffey and Hrung (2009), Cornett et al. (2011), Garleanu and Pedersen (2011) and Mancini et al. (2011)). The daily series of 3-month Treasury rate is available from the U.S. Federal Reserve Board and the 3-month LIBOR is obtained from Datastream.

### 3.2.3 Global FX volatility

We also include a measure of FX market volatility as a possible determinant of FX market liquidity. 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 calculate the FX volatility measure as the average of the daily squared log returns of the individual currency pairs, as follows:

$$VOL_t = \sum_{i=1}^{20} \left( \frac{r_{i,t}^2}{20} \right), \tag{5}$$

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

### 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 prompt changes in inventories and in 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).[7]

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). Furthermore, in order to estimate FX market volatility as the average daily squared 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 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 the 1998, when the Asian countries and Russia were hit by a severe financial crisis. Furthermore, FX market illiquidity has a positive 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-

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

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 in the end of the sample period, during financial crisis episodes. In particular, the larger spikes coincide with the most recent financial crisis. The other margin requirement variable, changes in FF rate, follows a similar path.

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 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 negatively correlated with changes in financial commercial paper interest rate, with a correlation coefficient around -4%.

## 4.2 Regression analysis

### 4.2.1 Market illiquidity and funding 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:

$$\begin{aligned}\Delta illiq_t = {} & \alpha + \beta \Delta FCP_t + \gamma_1 d_t^{MON} + \gamma_2 d_t^{TUE} + \gamma_3 d_t^{WED} + \gamma_4 d_t^{THUR} \\ & + \theta_1 \Delta illiq_{t-1} + \theta_2 \Delta illiq_{t-2} + \theta_3 \Delta illiq_{t-3} + \theta_4 \Delta illiq_{t-4} + \varepsilon_t,\end{aligned} \tag{7}$$

where $\Delta FCP_t$ 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).

Table 3 reports the results of this regression in model (1). The regression has a high explanatory power, with an adjusted R-square of 34%. 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. 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.[8] 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:

$$\begin{aligned}\Delta illiq_t = {} & \alpha + \beta \Delta FCP_t + \delta_1 VOL_t + \delta_2 VOL_{t-1} + \varphi \Delta TS_t + \zeta \Delta FF_t \\ & + \mu MKT_{t-1} + + \gamma_1 d_t^{MON} + \gamma_2 d_t^{TUE} + \gamma_3 d_t^{WED} + \gamma_4 d_t^{THUR} \\ & + \theta_1 \Delta illiq_{t-1} + \theta_2 \Delta illiq_{t-2} + \theta_3 \Delta illiq_{t-3} + \theta_4 \Delta illiq_{t-4} + \varepsilon_t,\end{aligned} \quad (8)$$

where $VOL_t$ is the proxy for global FX volatility, $\Delta TS_t$ is the changes in the TED spread at time $t$, $\Delta FF_t$ 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. The level of global FX volatility of the previous day is significant in explaining the movements in FX market illiquidity, consistently 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. 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 does not drive out the impact of changes in funding conditions on FX market illiquidity. Indeed, changes in the FCP interest rate stay significant. However, changes in margin requirements, TED

[8] 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.

spread and FF rate, are not statistically significant. In models (3) we present the results by excluding margin requirements.

### 4.2.2 Market liquidity, market declines and funding liquidity

In their recent analysis of US stock market liquidity, Hameed et al. (2010) find that past market returns affect stock liquidity and that the relationship is especially strong during a market decline, confirming the asymmetric effects of stock market movements on liquidity found in Chordia et al. (2001) as well. Price declines induce greater changes in liquidity as market-makers find it more difficult to adjust inventory in falling markets than in rising markets. They further investigate whether this relationship is indicative of capital constraints in the market place by interacting negative market returns with various measures of changes in funding liquidity, including the spread in commercial papers.

Following their analysis, we interact our measure of FX market illiquidity to lagged FX market returns in order to investigate whether the same relationship holds in the FX market.

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:

$$\begin{aligned}\Delta illiq_t = {} & \alpha + \beta \Delta FCP_t + \mu_1 d_{t-1}^{+} MKT_{t-1} + \mu_2 d_{t-1}^{-} MKT_{t-1} \\ & + \delta_1 VOL_t + \delta_2 VOL_{t-1} + \gamma_1 d_t^{MON} + \gamma_2 d_t^{TUE} + \gamma_3 d_t^{WED} + \gamma_4 d_t^{THU} \\ & + \theta_1 \Delta illiq_{t-1} + \theta_2 \Delta illiq_{t-2} + \theta_3 \Delta illiq_{t-3} + \theta_4 \Delta illiq_{t-4} + \varepsilon_t,\end{aligned} \tag{9}$$

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 measures as control variables.[9]

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 re-

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

turns with a dummy for lagged positive changes in the funding constraint variable, as follows:

$$
\begin{aligned}
\Delta liq_t = {} & \alpha + \beta \Delta FCP_t + \mu d_{t-1}^{+FUND} d_{t-1}^{-} MKT_{t-1} + \delta_1 VOL_t \\
& + \delta_2 VOL_{t-1} + \gamma_1 d_t^{MON} + \gamma_2 d_t^{TUE} + \gamma_3 d_t^{WED} + \gamma_4 d_t^{THUR} \\
& + \theta_1 \Delta illiq_{t-1} + \theta_2 \Delta illiq_{t-2} + \theta_3 \Delta illiq_{t-3} + \theta_4 \Delta illiq_{t-4} + \varepsilon_t,
\end{aligned} \tag{10}
$$

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 $d_{t-1}^{+FUND}$ 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 in funding conditions, and then we add the volatility measures as control variables.

As shown in Table 4, the interacting dummy with the measure of funding liquidity constraints is statistically significant (model (3)). Although the level of significance drops to 10% when we include the volatility variables (model (4)), these results are indicative that market declines are related to capital constraints in the market. Furthermore, our funding constraints and FX market volatility variables remain statistically significant. It should be noted that the day of the week effects do not change in this analysis.

#### 4.2.3 Does the impact of funding liquidity on FX market illiquidity relate to changes in the demand for liquidity?

According to Vayanos (2004), a jump in market liquidity is associated with demand for liquidity. During volatile times investors become more risk averse and their preference for liquidity increases. We do not have measures of the demand for liquidity to test this directly. We test for this indirectly by examining whether FX market volatility impacts on the sensitivity of funding liquidity on market illiquidity. We conduct a rolling regression analysis with a two-year window of the changes in FX market illiquidity on the determinants identified above. We then turn to analyze the series of the sensitivities of illiquidity to the determinants. In particular, we look at their time variation and investigate whether it is related to global FX volatility; if the sensitivities increase when volatility increases.

So, we run Regression (8) with a 2-year rolling window and we obtain a series of sensitivities of FX illiquidity to changes in funding liquidity aggregates and global FX volatility level. The sensitivities present a high level of time-variation (Figure 5).

At this point, we proceed to conduct a correlation analysis between the sensitivities and global FX volatility. Looking at the sensitivity of FX market illiquidity to changes in funding liquidity constraints, we find that the sensitivities increase with volatility. So, the higher the volatility level, the stronger the impact of changes in funding liquidity constraints on transaction costs. In detail, we find a correlation coefficient of over 10% on average. In addition, the sensitivity of FX market illiquidity to volatility has a strong correlation to the volatility level, with a correlation coefficient of over 41% on average. When volatility increases, the sensitivity of FX market illiquidity to volatility also increases, so that volatility impact as a determinant is higher for higher levels of volatility.

Thus, there is supporting evidence that the impact of funding liquidity on FX market illiquidity relates to both capital tightness and increases in the demand for liquidity.

#### 4.2.4 Crisis episodes

Given that the impact of the volatility is strong on the sensitivities, we investigate whether our results are driven by the extreme episodes that happened during our sample period. 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[10]. In detail, we run the following regression:

$$\begin{aligned}\Delta illiq_t = {} & \alpha + \beta(TS * \Delta FCP_t) + \delta_1 VOL_t + \delta_2 VOL_{t-1} \\ & + \mu MKT_{t-1} + \gamma_1 d_t^{MON} + \gamma_2 d_t^{TUE} + \gamma_3 d_t^{WED} + \gamma_4 d_t^{THUR} \\ & + \theta_1 \Delta illiq_{t-1} + \theta_2 \Delta illiq_{t-2} + \theta_3 \Delta illiq_{t-3} + \theta_4 \Delta illiq_{t-4} + \varepsilon_t,\end{aligned} \tag{11}$$

where $TS$ is the level of the TED spread that is interacted with changes in FCP rates, $\Delta FCP$. 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.

[10] 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 significantly explains 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.

#### 4.2.5 An extension: 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(4) model of the common illiquidity measure as our proxy.[11] In detail, we run the following regression:

$$\Delta illiq_t = \alpha + \beta_1 \Delta illiq_{t-1} + \beta_2 \Delta illiq_{t-2} + \beta_3 \Delta illiq_{t-3} + \beta_4 \Delta illiq_{t-4} + \varepsilon_t, \tag{12}$$

and we take $\varepsilon_t$ 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:

$$\begin{aligned} \Delta^{UNEXP} illiq_t = {} & \alpha + \beta \Delta FCP_t + \delta_1 VOL_t + \delta_2 VOL_{t-1} + \varphi \Delta TS_t \\ & + \zeta \Delta FF_t + \mu MKT_{t-1} + \gamma_1 d_t^{MON} + \gamma_2 d_t^{TUE} \\ & + \gamma_3 d_t^{WED} + \gamma_4 d_t^{THUR} + \theta \Delta^{UNEXP} illiq_{t-1} + \varepsilon_t, \end{aligned} \tag{13}$$

Differently from the daily regression analysis, one lag of the dependent variable is included here due to the lower autocorrelation in the residuals of the regression.

We report the results in Table 6. 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.

[11] We take an AR(4) 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.

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.

# 5 Further analysis: market depth and funding liquidity

## 5.1 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 the 20 currencies and their order flow for 10 years, from January 01, 1998 to July 17, 2008.[12] The FX transaction data is obtained

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

from State Street Corporation (SSC).[13]

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:

$$r_{i,t} = \alpha_i + \beta_i \Delta x_{i,t} + \gamma_i \Delta x_{i,t-1} + \varepsilon_{i,t}. \tag{14}$$

We estimate this regression using daily data for every month in the sample, and then take the estimated coefficient for $\gamma$ 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:

$$L_{i,m} = \widehat{\gamma}_{i,m}. \tag{15}$$

If the effect of the lagged order flow on the returns is indeed due to illiquidity, $\gamma_i$ should be negative and reverse a portion of the impact of the contemporaneous flow, since $\beta_i$ 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 ($\gamma_i < 0$).[14]

[13]As one of the world's largest custodian institutions, SSC counts about 10,000 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. The raw flows are the same as those used in Froot and Ramadorai (2005), who also normalize the SSC data in their empirical work by dividing the flow by its standard deviation.

[14]Other methodologies have been used in the literature to empirically estimate liquidity using regression analysis applied to order flow data. In particular, in Evans and Lyons (2002b) the contemporaneous impact, changed of sign, corresponds to the measure of market depth from Kyle (1985)'s model. Pastor and Stambaugh (2003) estimate liquidity from a regression of returns on lagged order flow, including lagged returns to account for serial correlation. We specify our regression not including the

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

$$\Delta L_{i,m} = (L_{i,m} - L_{i,m-1}) \tag{16}$$

$$\Delta L_m = \frac{1}{N}\sum_{i=1}^{N} \Delta L_{i,m}. \tag{17}$$

Table 7 shows some descriptive statistics of the variable thus constructed. The variable shows a high standard deviation, indicating a strong variation. Furthermore, it exhibits strong negative serial correlation. Figure 6 shows the strong time variation of the series.

## 5.2 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 pre-agreed 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:

$$\Delta FCP_m = \log(FCP_m) - \log(FCP_{m-1}), \tag{18}$$

$$\Delta REPO_m = \log(REPO_m) - \log(REPO_{m-1}), \tag{19}$$

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

lagged returns but including contemporaneous order flow instead. It is clear that each of these regressions reflects some degree of arbitrariness.

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:

$$\begin{aligned}\Delta L_m = &\alpha + \gamma \Delta REPO_m + \beta \Delta FCP_m + \delta_1 VOL_m + \delta_2 VOL_{m-1} \quad (20)\\ &+\varphi \Delta TS_m + \zeta \Delta FF_m + +\mu MKT_{m-1} + \theta \Delta L_{m-1} + \varepsilon_m,\end{aligned}$$

where $VOL_m$ is the monthly average of the daily measure of global FX volatility, $\Delta TS$ and $\Delta FF$ 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 8 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. 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 global 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 39%.

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.

# 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 FX market illiquidity, an area not yet explored in the literature. In our analysis we use a broad data set for 20 exchange rates of both developed and emerging markets currencies for 13 years.

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 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, 34% in the case of transaction costs and 39% in the monthly variable in the case of market depth.

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.

Finally, we find supporting evidence that the impact of funding liquidity in FX market illiquidity relates not only to capital constraints but also to increases in the demand for liquidity.

In conclusion, our study confirms that funding liquidity constraints are as important in the FX market as they have been found to be in the stock markets.

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

| | $\Delta$illiq | $\Delta$FCP |
|---|---|---|
| mean | -0.00003* | -0.00369 |
| median | 0.00051* | 0 |
| st dev | 0.00010 | 0.09241 |
| min | -0.00073 | -2.07944 |
| max | 0.00092 | 1.50408 |
| skew | 0.08588 | -4.00308 |
| kurt | 6.06717 | 147.02724 |
| AC(1) | -0.45471 | -0.06987 |

Notes: Some 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 interest rates. AC(1) refers to the first order autocorrelation of the series. $*$ indicates that the coefficients have been multiplied by 1000.

Table 2: Correlation matrix

| | $\Delta \boldsymbol{FCP}$ | $\Delta \boldsymbol{FF}$ | $\Delta \boldsymbol{TS}$ |
|---|---|---|---|
| $\Delta \boldsymbol{FF}$ | **0.2686** | | |
| $\Delta \boldsymbol{TS}$ | **-0.0379** | **-0.0383** | |
| $\boldsymbol{VOL}$ | **-0.0420** | **0.0088** | **-0.0169** |

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 daily cross-sectional average of the squared return of the 20 currencies in the data set over the U.S. dollar. A $\Delta$ indicates the daily changes in the variable.

Table 3: Determinants of FX market illiquidity

| | 1 | 2 | 3 |
|---|---|---|---|
| $\Delta FCP_t$ | **0.00003** | **0.00003** | **0.00003** |
| | *2.1980* | *2.0341* | *2.2654* |
| $VOL_t$ | | -0.02063 | -0.02063 |
| | | *-0.6101* | *-0.6153* |
| $VOL_{t-1}$ | | **0.08012** | **0.07845** |
| | | *3.4390* | *3.4048* |
| $MKT_{t-1}$ | | **-0.0010** | **-0.00097** |
| | | *-3.4952* | *-3.4018* |
| $\Delta TS_t$ | | -0.00001 | |
| | | *-0.2965* | |
| $\Delta FF_t$ | | 0.00000 | |
| | | *0.1363* | |
| $d_t^{MON}$ | **-0.00003** | **-0.00003** | **-0.00003** |
| | *-5.0422* | *-5.3908* | *-5.0640* |
| $d_t^{TUE}$ | **-0.00002** | **-0.00003** | **-0.00003** |
| | *-4.9230* | *-4.9292* | *-5.0083* |
| $d_t^{WED}$ | **-0.00002** | **-0.00002** | **-0.00002** |
| | *-3.8785* | *-3.7391* | *-3.8231* |
| $d_t^{THUR}$ | **-0.00001** | **-0.00001** | **-0.00001** |
| | *-2.8296* | *-2.8113* | *-2.9083* |
| $\Delta illiq_{t-1}$ | **-0.68556** | **-0.68820** | **-0.68842** |
| | *-27.4902* | *-26.1864* | *-27.7194* |
| $\Delta illiq_{t-2}$ | **-0.47822** | **-0.47194** | **-0.47895** |
| | *-12.0148* | *-11.1412* | *-12.1148* |
| $\Delta illiq_{t-3}$ | **-0.31794** | **-0.31312** | **-0.31747** |
| | *-8.3999* | *-8.3407* | *-8.4496* |
| $\Delta illiq_{t-4}$ | **-0.17477** | **-0.16906** | **-0.17417** |
| | *-5.9045* | *-5.6781* | *-5.8993* |
| Constant | **0.00002** | **0.00001** | **0.00001** |
| | *4.2904* | *3.8006* | *3.8600* |
| $Adjusted R^2$ | 0.34 | 0.33 | 0.34 |
| LM test - pval | 0.03 | 0.00 | 0.02 |

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

$$\begin{aligned}\Delta illiq_t = &\alpha + \beta \Delta FCP_t + \delta_1 VOL_t + \delta_2 VOL_{t-1} + \varphi \Delta TS_t + \zeta \Delta FF_t \\ &+\mu MKT_{t-1} + \gamma_1 d_t^{MON} + \gamma_2 d_t^{TUE} + \gamma_3 d_t^{WED} + \gamma_4 d_t^{THUR} \\ &+\theta_1 \Delta illiq_{t-1} + \theta_2 \Delta illiq_{t-2} + \theta_3 \Delta illiq_{t-3} + \theta_4 \Delta illiq_{t-4} + \varepsilon_t,\end{aligned}$$

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 |
|---|---|---|---|---|
| $\Delta FCP_t$ | **0.00003** | **0.00003** | **0.00003** | **0.00003** |
| | *2.3109* | *2.2436* | *2.1705* | *2.1828* |
| $d^{+}_{t-1}MKT_{t-1}$ | -0.00001 | | | |
| | *-0.0252* | | | |
| $d^{+}_{t-1}MKT_{t-1}$ | **-0.00180** | **-0.00136** | | |
| | *-3.4745* | *-2.6816* | | |
| $d^{+FUND}_{t-1}d^{-}_{t-1}MKT_{t-1}$ | | | **-0.00174** | -0.00121 |
| | | | *-2.7598* | *-1.6969* |
| $VOL_t$ | | -0.02056 | | -0.01859 |
| | | *-0.6079* | | *-0.5390* |
| $VOL_{t-1}$ | | **0.04809** | | **0.06538** |
| | | *2.0459* | | *2.6845* |
| $d^{MON}_t$ | **-0.00003** | **-0.00003** | **-0.00003** | **-0.00003** |
| | *-5.0710* | *-5.0318* | *-4.9387* | *-4.9226* |
| $d^{TUE}_t$ | **-0.00003** | **-0.00003** | **-0.00003** | **-0.00003** |
| | *-4.9543* | *-4.9787* | *-5.0438* | *-5.0357* |
| $d^{WED}_t$ | **-0.00002** | **-0.00002** | **-0.00002** | **-0.00002** |
| | *-3.8619* | *-3.7897* | *-3.7240* | *-3.6661* |
| $d^{THUR}_t$ | **-0.00001** | **-0.00001** | **-0.00001** | **-0.00001** |
| | *-2.8867* | *-2.8788* | *-2.7385* | *-2.7749* |
| $\Delta illiq_{t-1}$ | **-0.68903** | **-0.68768** | **-0.68806** | **-0.68662** |
| | *-27.6842* | *-27.6402* | *-27.6444* | *-27.6254* |
| $\Delta illiq_{t-2}$ | **-0.48001** | **-0.47868** | **-0.47983** | **-0.47814** |
| | *-12.1098* | *-12.0911* | *-12.1006* | *-12.0936* |
| $\Delta illiq_{t-3}$ | **-0.31913** | **-0.31753** | **-0.32021** | **-0.31798** |
| | *-8.4681* | *-8.4419* | *-8.4854* | *-8.4544* |
| $\Delta illiq_{t-4}$ | **-0.17451** | **-0.17450** | **-0.17641** | **-0.17602** |
| | *-5.8913* | *-5.9142* | *-5.9613* | *-5.9624* |
| Constant | **0.00001** | **0.00001** | **0.00001** | **0.00001** |
| | *3.1373* | *3.3577* | *3.8487* | *3.5847* |
| $Adjusted R^2$ | 0.34 | 0.34 | 0.34 | 0.34 |
| LM test - pval | 0.02 | 0.02 | 0.02 | 0.02 |

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

| | |
|---|---|
| $TS\Delta FCP_t$ | **0.00002** |
| | *2.0906* |
| $VOL_t$ | -0.01971 |
| | *-0.6664* |
| $VOL_{t-1}$ | **0.08154** |
| | *3.3238* |
| $MKT_{t-1}$ | **-0.0010** |
| | *-3.3729* |
| $d_t^{MON}$ | **-0.00003** |
| | *-4.9391* |
| $d_t^{TUE}$ | **-0.00003** |
| | *-5.0167* |
| $d_t^{WED}$ | **-0.00002** |
| | *-3.8193* |
| $d_t^{THUR}$ | **-0.00001** |
| | *-2.7828* |
| $\Delta illiq_{t-1}$ | **-0.68581** |
| | *-26.0912* |
| $\Delta illiq_{t-2}$ | **-0.47801** |
| | *-12.4804* |
| $\Delta illiq_{t-3}$ | **-0.31449** |
| | *-8.3486* |
| $\Delta illiq_{t-4}$ | **-0.17239** |
| | *-5.9778* |
| Constant | **0.00001** |
| | *3.7846* |
| $Adjusted R^2$ | 0.33 |
| LM test - pval | 0.00 |

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

$$\begin{aligned}\Delta illiq_t = &\alpha + \beta(TS * \Delta FCP_t) + \delta_1 VOL_t + \delta_2 VOL_{t-1} + \mu MKT_{t-1} \\ &+\gamma_1 d_t^{MON} + \gamma_2 d_t^{TUE} + \gamma_3 d_t^{WED} + \gamma_4 d_t^{THUR} \\ &+\theta_1 \Delta illiq_{t-1} + \theta_2 \Delta illiq_{t-2} + \theta_3 \Delta illiq_{t-3} + \theta_4 \Delta illiq_{t-4} + \varepsilon_t,\end{aligned}$$

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: Analysis of the determinants of shocks to FX market illiquidity

| | 1 | 2 | 3 |
|---|---|---|---|
| $\Delta FCP_t$ | **0.00003** | **0.00003** | **0.00004** |
| | *2.2396* | *2.0935* | *2.3154* |
| $VOL_t$ | | -0.01997 | -0.02014 |
| | | *-0.5946* | *-0.6033* |
| $VOL_{t-1}$ | | **0.08009** | **0.07842** |
| | | *3.4896* | *3.4349* |
| $MKT_{t-1}$ | | **-0.00101** | **-0.00098** |
| | | *-3.5382* | *-3.4566* |
| $\Delta TS_t$ | | -0.00001 | |
| | | *-0.2832* | |
| $\Delta FF_t$ | | 0.00000 | |
| | | *0.1098* | |
| $d_t^{MON}$ | **-0.00003** | **-0.00003** | **-0.00003** |
| | *-5.0931* | *-5.3981* | *-5.1138* |
| $d_t^{TUE}$ | **-0.00002** | **-0.00002** | **-0.00003** |
| | *-5.0937* | *-5.0204* | *-5.1661* |
| $d_t^{WED}$ | **-0.00002** | **-0.00002** | **-0.00002** |
| | *-3.7929* | *-3.6206* | *-3.7335* |
| $d_t^{THUR}$ | **-0.00001** | **-0.00001** | **-0.00001** |
| | *-2.8065* | *-2.7775* | *-2.8838* |
| $\Delta illiq_{t-1}$ | -0.02701 | -0.02984 | -0.02991 |
| | *-1.0724* | *-1.1164* | *-1.1939* |
| Constant | **0.00002** | **0.00001** | **0.00001** |
| | *4.3234* | *3.7706* | *3.8747* |
| $Adjusted R^2$ | 0.01 | 0.02 | 0.02 |
| LM test - pval | 0.17 | 0.02 | 0.12 |

Notes: The table reports the results of the regression analysis of the determinants of unexpected changes, or shocks, to FX market illiquidity, regression (13):

$$\begin{aligned}\Delta^{UNEXP} illiq_t = & \alpha + \beta \Delta FCP_t + \delta_1 VOL_t + \delta_2 VOL_{t-1} + \varphi \Delta TS_t + \zeta \Delta FF_t \\ & + \mu MKT_{t-1} + \gamma_1 d_t^{MON} + \gamma_2 d_t^{TUE} + \gamma_3 d_t^{WED} + \gamma_4 d_t^{THUR} \\ & + \theta \Delta^{UNEXP} illiq_{t-1} + \varepsilon_t,\end{aligned}$$

Shocks are estimated as the residuals of a AR model of order 4 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.

Table 7: Extension: 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: Some descriptive statistics are reported for the new 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 8: Market depth and funding liquidity

| | 1 | 2 | 3 |
|---|---|---|---|
| $\Delta REPO_m$ | **0.0089** | **0.0092** | **0.0090** |
| | *4.7687* | *4.8612* | *4.8483* |
| $\Delta FCP_m$ | -0.0003 | -0.0005 | -0.0003 |
| | *-0.2453* | *-0.2296* | *-0.2204* |
| $VOL_m$ | | 22.6706 | 24.5767 |
| | | *0.1749* | *0.1926* |
| $VOL_{m-1}$ | | **-315.8284** | **-355.3435** |
| | | *-2.0223* | *-2.4977* |
| $MKT_{m-1}$ | | -0.2323 | |
| | | *-1.0833* | |
| $\Delta TS_m$ | | -0.0004 | |
| | | *-0.4783* | |
| $\Delta FF_m$ | | 0.0000 | |
| | | *-0.0275* | |
| $\Delta L_{m-1}$ | **-0.4987** | **-0.4815** | **-0.4975** |
| | *-7.5560* | *-6.8216* | *-7.3182* |
| Constant | -0.0001 | 0.0002 | 0.0002 |
| | *-0.3616* | *0.8180* | *0.9020* |
| $Adjusted R^2$ | 0.37 | 0.38 | 0.39 |
| LM test - pval | 0.08 | 0.05 | 0.03 |

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 (20):

$$\Delta L_m = \alpha + \gamma \Delta REPO_m + \beta \Delta FCP_m + \delta_1 VOL_m + \delta_2 VOL_{m-1} + \varphi \Delta TS_m + \zeta \Delta FF_m + \mu MKT_{m-1} + \theta \Delta L_{m-1} + \varepsilon_m,$$

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 December 2010.

Figure 1: Changes in FX market illiquidity

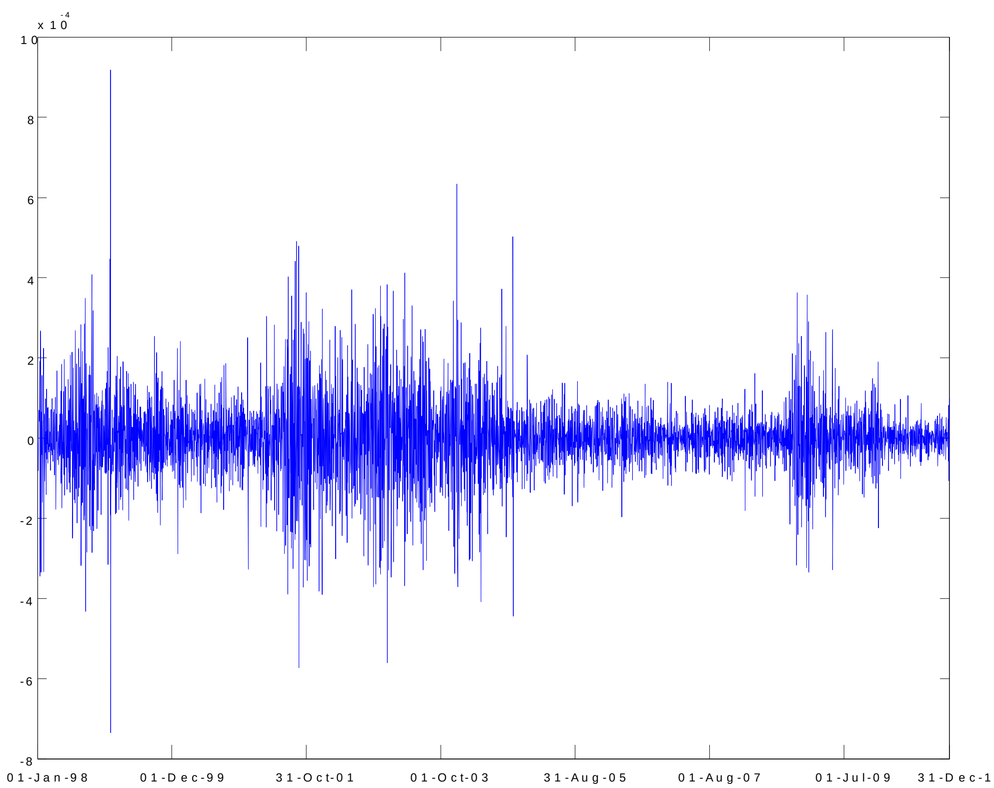

Figure 2: Changes in financial commercial paper interest rate

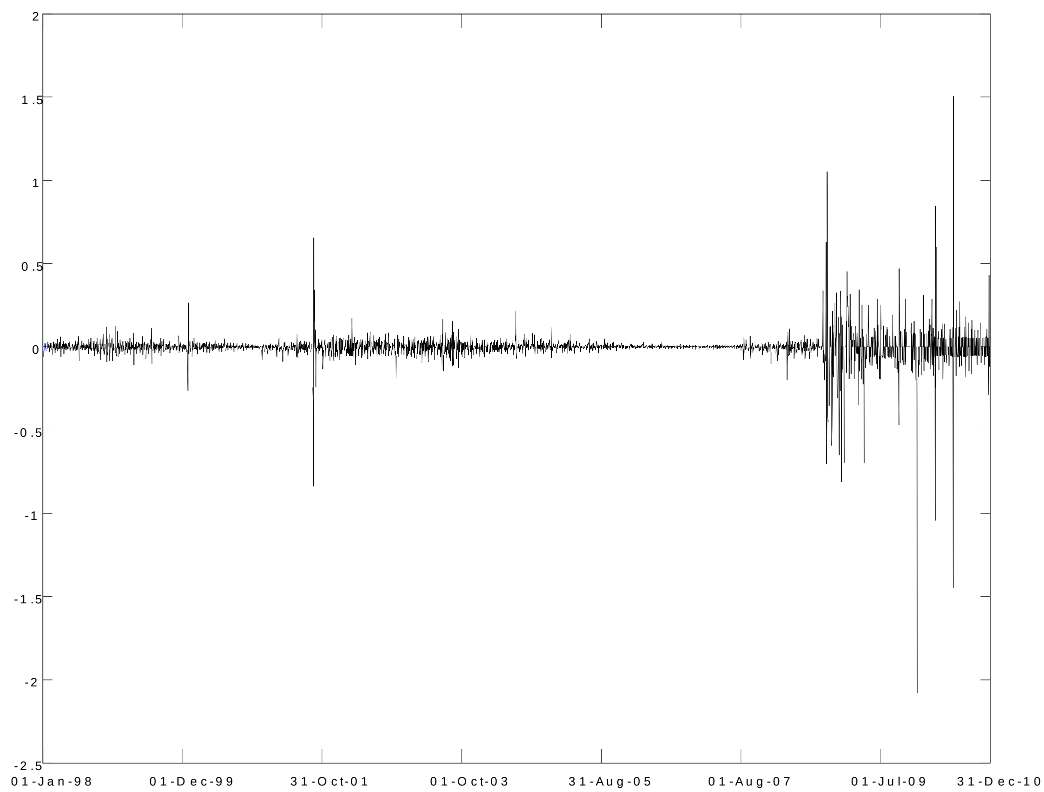

Figure 3: Changes in TED spread

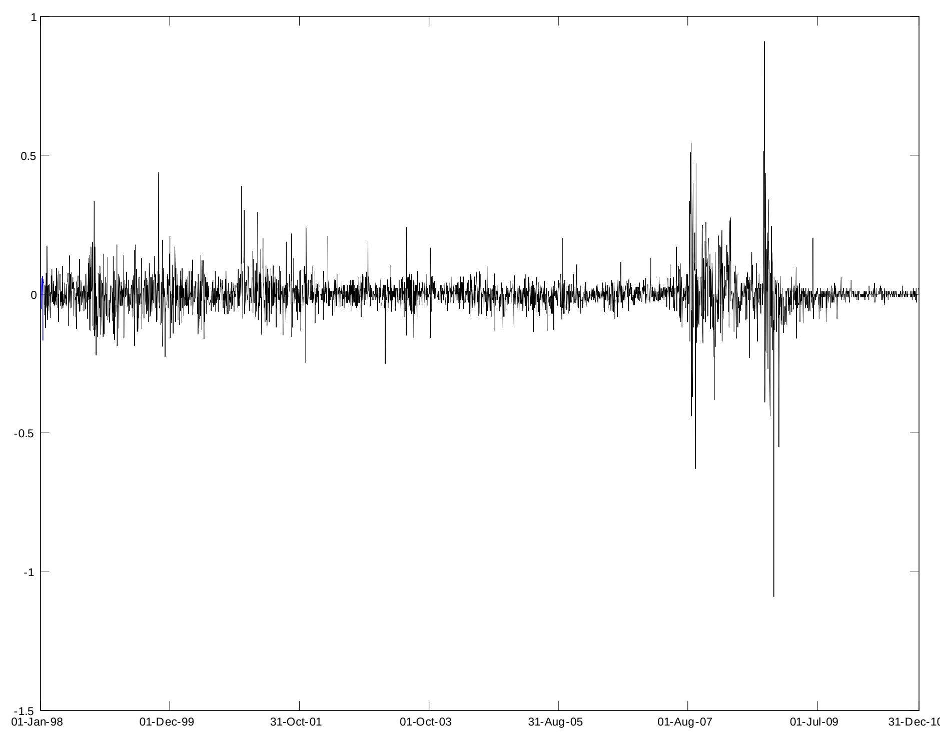

Figure 4: Global FX volatility

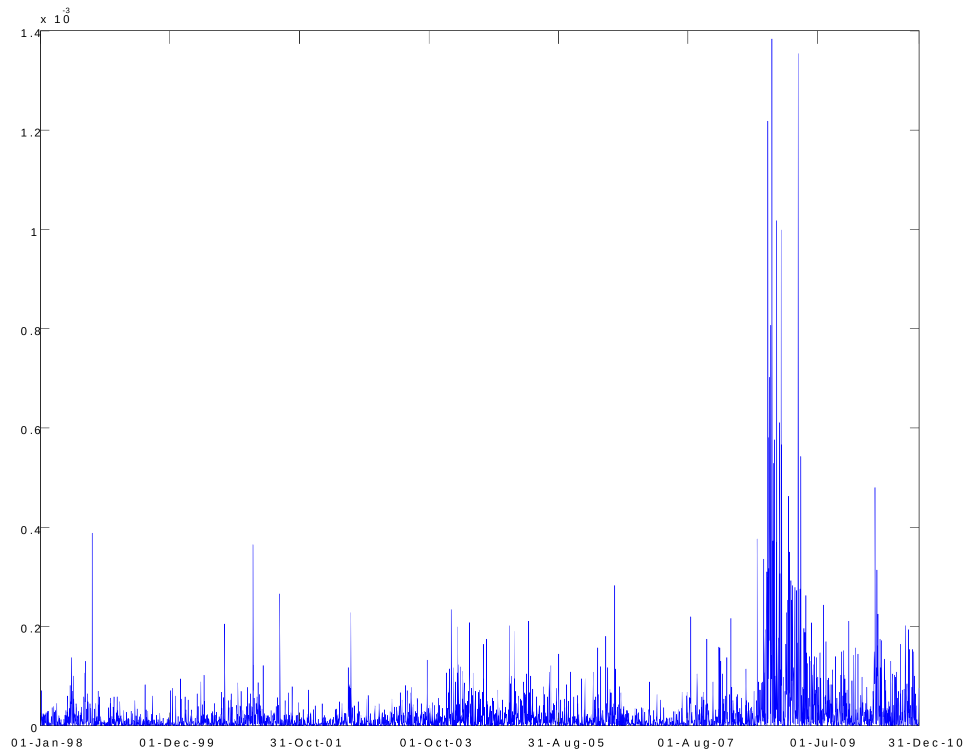

Figure 5: Sensitivities of FX market illiquidity to funding liquidity constraints and volatility

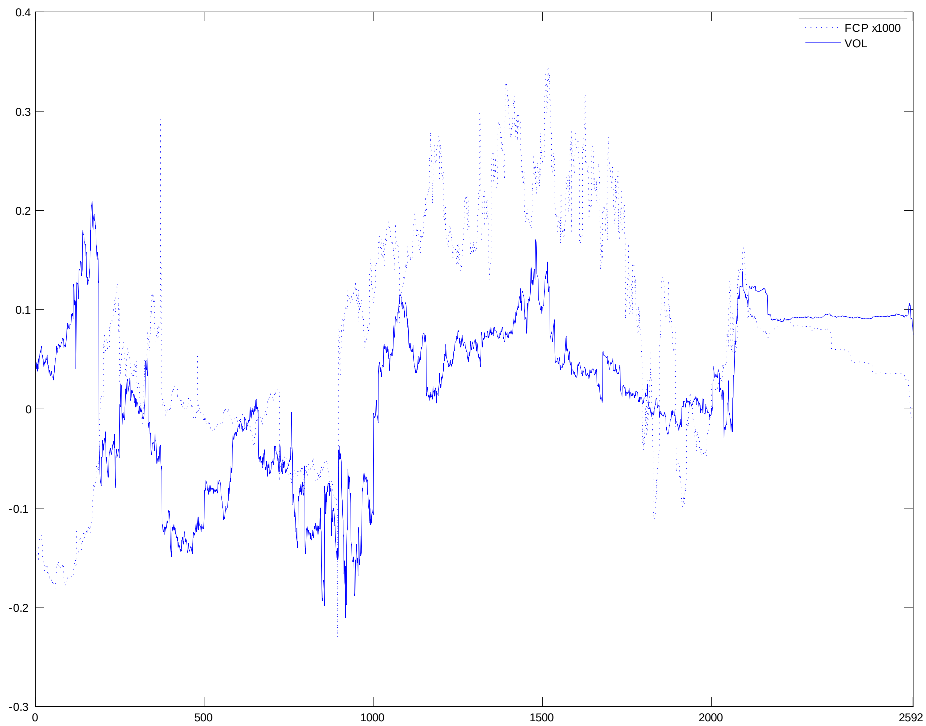

Figure 6: Extension: changes in monthly FX market depth