

FX market illiquidity and funding liquidity constraints

Chiara Banti and Kate Phylaktis*[†]

Abstract

Using a data for 20 exchange rates over 13 years, we construct two measures of the common component of liquidity across currencies, transaction costs and market depth. Funding liquidity constraints impact on both aspects of FX market liquidity, after controlling for global volatility, FX market returns and seasonality. Funding liquidity relates to market declines when suppliers to liquidity face capital tightness and to the recent crisis when liquidity dry-ups were severe. The analysis on individual currencies with diverse riskiness confirms that a shock to speculator capital leads to a reduction in market liquidity that is stronger for illiquid currencies.

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

JEL Classification: F31; G15.

1 Introduction

Trading volume in the foreign exchange (FX) market is particularly high compared to other financial markets.

Whether the large trading volume corresponds to a highly liquid FX market depends on the definition of

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

[†]Chiara Banti, Chiara.Banti.1@cass.city.ac.uk, Faculty of Finance, Cass Business School, City University, 106 Bunhill Row, London, EC1Y 8TZ, UK; Corresponding author Professor Kate Phylaktis, K.Phylaktis@city.ac.uk, Faculty of Finance, Cass Business School, City University, 106 Bunhill Row, London, EC1Y 8TZ, UK, +44 (0)20 7040 8735.

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 this common component in FX market liquidity exhibits a strong variation through time (Mancini, Ranaldo, and Wrampelmeyer (2012); Banti, Phylaktis, and Sarno (2012)).

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.

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, Roll, and Subrahmanyam (2001)

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

investigation of the determinants of market liquidity in the stock market.

Our paper is related to a recent paper by Mancini et al. (2012) which identifies 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. However, our analysis deviates from theirs in a number of ways (i) it uses a broad data set of 20 currencies from both developed and emerging markets over a period of 13 years, which includes normal times, as well as the recent financial crisis, which enables us to confirm the impact of funding liquidity constraints during all times; (ii) Apart from funding liquidity and FX market volatility, we also identify that FX market returns have a strong impact on FX market liquidity. This is particularly important because it enables us to explore further the impact of funding liquidity constraints during market declines, when dealers find it more difficult to adjust inventory; (iii) Our extended sample period enables us to explore whether liquidity dry-ups are worse during the recent financial crisis, when funding became a serious issue (Brunnermeier and Pedersen (2009)); and (iv) repeating the analysis on individual currencies with diverse riskiness we are able to confirm that a shock to speculator capital would lead to a reduction in market liquidity through a spiral effect that is stronger for illiquid currencies, as proposed by (Brunnermeier and Pedersen (2009)).

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. 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. FX 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 inventories and 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 the recent financial crisis, when liquidity funding became a serious issue. (Brunnermeier and Pedersen (2009)). We show that there is a strong relationship between funding liquidity constraints and market illiquidity during the crisis.

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.

Our final exercise, which confirms the impact of funding liquidity is the analysis of individual currencies. In our sample we have currencies with diverse riskiness. We take that into account in our panel estimation and confirm that shock to speculator capital would lead to a reduction in market liquidity through a spiral effect that is stronger for illiquid currencies (Brunnermeier and Pedersen (2009)).

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

2 Methodology

2.1 Estimation of FX market liquidity

No unique definition of liquidity exists. According to Kyle (1985), liquidity is a “slippery and elusive concept” because of its broadness. In fact, the concept of market liquidity encompasses the properties of “tightness”, “depth”, and “resiliency”. These attributes describe the characteristics of transactions and their price impact. In particular, a market is liquid if the cost of quickly turning around a position is small, the price impact of a transaction is small, and the speed at which prices recover from a random, uninformative shock is high. In our main analysis, we are employing the percentage bid-ask spreads as a proxy for transaction costs. The bid-ask spread is the most widely used measure of liquidity in In the FX market e.g. Bessembinder (1994), Bollerslev and Melvin (1994), Lee (1994), and Hsieh and Kleidon (1996). However, the bid-ask spread suffers from some limitations as a measure for liquidity. For example, Grossman and Miller (1995) highlight that the bid-ask spread gives the cost of providing immediacy of the market maker in the case of a contemporaneous presence of buy and sell transactions. Furthermore, because the spread is valid only for transactions up to a certain size, it provides no information on the prices at which larger transactions might take place, or how the market might respond to a long sequence of transactions in the same direction, which could be generated when a trader breaks a large trade into many smaller ones, that could span several days.

In contrast, measures such as those proxying for price impact capture that aspect better than the bid-ask spread (Vayanos and Wang (2012)). As a result of these possible limitations, we extend our analysis to another liquidity measure, which proxies for the price impact to obtain a more complete picture, a modified version of Pastor and Stambaugh (2003) measure.

2.1.1 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:

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

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:

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

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:

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

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. (2012), 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.

2.2 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.

2.2.1 Funding liquidity constraints

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)).

Empirically 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 in the interbank market: the TED spread (Coffey and Hrung (2009), Cornett, McNutt, Strahan, and Tehranian (2011), Garleanu and Pedersen (2011); Mancini et al. (2012)) and the LIBOR-OIS spread (Acharya and Skeie (2011); Acharya and Viswanathan (2011)).

Conversely, other studies look at funding liquidity aggregates: asset-backed commercial papers, financial commercial papers and repurchase agreements (REPOs) (Brunnermeier and Pedersen (2009)). In particular, Brunnermeier and Pedersen (2009) identify funding constraints for financial intermediaries, and banks,

relating to collateralized borrowing, from other banks, insurance companies and the Federal Reserve Bank, for which we believe REPOs are a reasonable proxy. However, banks also finance their operations through uncollateralized short-term debt.

More specifically in the FX market, Adrian, Etula, and Shin (2010) analyze the funding liquidity ability of US financial intermediaries by considering the amount outstanding of commercial papers and repurchase agreements, and find that changes in funding liquidity affect exchange rate variation of some currencies versus the US dollar. In another paper, Adrian and Shin (2010) show that financial intermediaries adjust their leverage in a procyclical manner, that is increasing leverage during booms and reducing it during busts, and the margin of adjustment in the expansion and contraction of their balance sheets is through repurchase agreements and reverse repurchase agreements. 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 potential 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 REPOs.

Financial commercial papers are unsecured promissory notes issued as a form of short-term financing.

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:

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

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.

2.2.2 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.

2.2.3 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 (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:

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

2.2.4 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 exchange rate moves affect the value of foreign currency denominated assets and through their effect on wealth impact on exchange rate expectations in accord with portfolio balance models of exchange rate determination (Obstfeld and Rogoff

(1996)), prompting changes in inventories and optimal portfolio compositions.

We calculate FX market returns as follows:

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

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

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

3 Empirical analysis

3.1 Preliminary analysis of the data

3.1.1 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).² 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

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

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)³ the ask and bid rates are from actual trades and they are calculated independently as the median of actual trades during a fixing period (one minute). If actual trade rates are not available, quoted rates are reported. For the other currencies (BRL, CLP, KRW), the bid and ask rates are quotes from Reuters.⁴ 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. 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.

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.

3.1.2 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

³For the abbreviations of currencies see notes in Table 1A in Appendix A.

⁴It 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.

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

Global FX volatility is plotted in Figure 3. 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%.

3.2 Regression analysis

3.2.1 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:

$$\begin{aligned} \Delta illiq_t = & \alpha + \beta \Delta FCP_t + \delta VOL_t + \varphi \Delta TS_t + \zeta \Delta FF_t \\ & + \mu MKT_{t-1} + \gamma_1 d_t^{MON} + \gamma_2 d_t^{TUE} + \gamma_3 d_t^{WED} + \gamma_4 d_t^{THUR} \end{aligned} \quad (7)$$

$$+ \sum_{i=1}^4 \theta_i \Delta illiq_{t-i} + \varepsilon_t,$$

where ΔFCP_t is the first difference of the log of the financial commercial paper interest rates at time t , 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. 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 four lags of the dependent variable, 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. We start our analysis by looking at the impact of funding liquidity constraints, without the controlling variables and run 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.⁵ 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 by including the other explanatory variables, FX market

⁵On 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.

volatility, margin requirements and lagged FX market returns. Global FX volatility is significant in explaining the movements in FX market illiquidity, consistently with previous studies at the individual currency level (Bollerslev and Melvin (1994); Bessembinder (1994); Ding (1999)). The coefficient is positive as expected, since an increase in 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 (7) 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.

3.2.2 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:

$$\begin{aligned} \Delta illiq_t = & \alpha + \beta \Delta FCP_t + \mu_1 d_{t-1}^+ MKT_{t-1} + \mu_2 d_{t-1}^- MKT_{t-1} \\ & + \delta VOL_t + \gamma_1 d_t^{MON} + \gamma_2 d_t^{TUE} + \gamma_3 d_t^{WED} + \gamma_4 d_t^{THU} \\ & + \sum_{i=1}^4 \theta_i \Delta illiq_{t-i} + \varepsilon_t, \end{aligned} \quad (8)$$

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.⁶

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:

$$\Delta liq_t = \alpha + \beta \Delta FCP_t + \mu d_{t-1}^{+FUND} d_{t-1}^- MKT_{t-1} + \delta VOL_t \quad (9)$$

⁶Given that the margin constraints measures were not significant in the main analysis above, we exclude them.

$$\begin{aligned}
& +\gamma_1 d_t^{MON} + \gamma_2 d_t^{TUE} + \gamma_3 d_t^{WED} + \gamma_4 d_t^{THUR} \\
& + \sum_{i=1}^4 \theta_i \Delta illiq_{t-i} + \varepsilon_t,
\end{aligned}$$

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 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.

3.2.3 Crisis episodes

Given that market declines are indicative of funding liquidity constraints, we explore whether liquidity dry-ups are worse during the recent financial crisis (Brunnermeier and Pedersen (2009)).⁷

We use a dummy, which takes the value of 1 during the period from Lehman Brothers collapse on September 15th, 2008 to July 2009, when the US recession ended and zero otherwise. We interact this indicator of the recent crisis with our measure of changes in funding constraints, financial commercial paper interest rate (ΔFCP). In detail, we run the following regression:

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

We also include the volatility and lagged market return variables together with four lagged dependent

⁷Indeed, our data set enables us to study several important crisis episodes. However, we restrict the analysis to the latest crisis when funding liquidity became a real constraint for financial intermediaries.

variables and the dummies for the day of the week as in the main analysis above (7). However, we exclude changes in financial commercial paper interest rate from the regression to avoid multicollinearity issues.

Table 5 shows the results of the analysis. The dummy 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 fact stronger than in our main analysis. In addition, global FX volatility and lagged market returns are also significant determinants of changes in illiquidity in the FX market.

4 Robustness tests

4.1 Market depth and funding liquidity

4.1.1 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. Indeed, a market is deep if large trades are executed without a substantial price impact. 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. The FX transaction data is obtained from State Street Corporation (SSC). SSC, one of the major custodian institutions with about 10,000 institutional investor clients and about 12 trillion US dollars under custody, records all the transactions in these portfolios, representing approximately 15 percent of tradable securities. The data provided by SSC is the daily order flow for our 20 currencies, defined as the overall buying pressure on the currency in millions of transactions. However, the transaction data provided by SSC is not exactly the raw net number of transactions, but is the net flow filtered through a ‘normalization’ to increase comparability through time and across currencies and to ensure SSC commitment to client confidentiality.

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:

$$r_{i,t} = \alpha_i + \beta_i \Delta x_{i,t} + \gamma_i \Delta x_{i,t-1} + \varepsilon_{i,t}. \quad (11)$$

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:

$$L_{i,m} = \hat{\gamma}_{i,m}. \quad (12)$$

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:

$$L_m = \frac{1}{N} \sum_{i=1}^N L_{i,m} \quad (13)$$

$$\Delta L_m = L_m - L_{m-1}. \quad (14)$$

Table 6 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 4 shows the strong time variation of the series.

4.1.2 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 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:

$$\Delta FCP_m = \log(FCP_m) - \log(FCP_{m-1}), \quad (15)$$

$$\Delta REPO_m = \log(REPO_m) - \log(REPO_{m-1}), \quad (16)$$

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:

$$\begin{aligned} \Delta L_m = & \alpha + \gamma \Delta REPO_m + \beta \Delta FCP_m + \delta VOL_m \\ & + \varphi \Delta TS_m + \zeta \Delta FF_m + \mu MKT_{m-1} + \theta \Delta L_{m-1} + \varepsilon_m, \end{aligned} \tag{17}$$

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 $\Delta REPO$ from that of the lagged dependent variable we run model (1) in Table 7 without $\Delta REPO$. The R squared is 0.2561. We performed an F test, which confirms the statistical significance of $\Delta REPO$. 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.

4.2 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 model (7) using GMM, which allows for endogeneity. Following Hansen (1982), we improve the identification of the coefficients by employing a set of sample moment conditions from the standard model (7) with the inclusion of an additional moment condition on the lagged FCP variable.⁸ We then proceed to minimize a quadratic form of the moments using an initial weighting identity matrix. After the first iteration, we proceed to estimate the parameters with a new weighting matrix, based on an estimation of the long-run covariance matrix of the moment conditions from the first step corrected for heteroskedasticity with Newey-West (1987). Similarly, we proceed to estimate model (17) via GMM for robustness of the monthly analysis with the alternative measure of illiquidity based on market depth. The results are robust to this alternative estimation (Tables 1B and 2B in Appendix B).

4.3 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.⁹ In detail, we run the following regression:

$$\Delta illiq_t = \alpha + \sum_{i=1}^5 \beta_i \Delta illiq_{t-i} + \varepsilon_t, \quad (18)$$

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 (7). Thus, we run the following regression:

⁸In more detail, the moment conditions for model (7) are $g_T = \frac{1}{T} \sum_{t=1}^T \varepsilon_t Z_t$, where $Z_t = [\Delta FCP_t, \Delta FCP_{t-1}, VOL_t, MKT_{t-1}, d_t^{MON}, d_t^{TUE}, d_t^{WED}, d_t^{THUR}, \Delta illiq_{t-1}, \Delta illiq_{t-2}, \Delta illiq_{t-3}, \Delta illiq_{t-4}, constant]$

and ε are the residuals.

⁹We 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.

$$\begin{aligned}
\Delta^{UNEXP} illiq_t = & \alpha + \beta \Delta FCP_t + \delta VOL_t + \varphi \Delta TS_t \\
& + \zeta \Delta FF_t + \mu MKT_{t-1} + \gamma_1 d_t^{MON} + \gamma_2 d_t^{TUE} \\
& + \gamma_3 d_t^{WED} + \gamma_4 d_t^{THUR} + \varepsilon_t.
\end{aligned} \tag{19}$$

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 robust to the inclusion in our analysis of global FX volatility and lagged market returns. Changes in the margin requirements are unrelated to shocks in FX market illiquidity, similarly to our main analysis (model (2)). As expected, the R^2 is much smaller than in our main analysis.

4.4 Impact of funding liquidity and volatility across currencies

To complete the analysis on the impact of funding liquidity, we turn the attention to the differences across currencies in this section. In more detail, we investigate whether currencies that exhibit higher volatility also present the largest impact of changes in funding liquidity constraints on illiquidity, in accord with proposition 6 (iv) of Brunnermeier and Pedersen (2009).

We begin the analysis by building a measure of changes in illiquidity level of individual currencies. Starting from the individual currency transaction costs calculated in equation (1), we take the first difference of the logs of all series and build a matrix of changes in transaction cost over time for each currency, $\Delta TC_{i,t}$. Next, we include the measures in a panel regression with fixed effects and we estimate the impact on the changes in individual currency illiquidity $\Delta TC_{i,t}$ of changes in funding liquidity interacted with individual currency volatility ($\Delta FCP_t * VOL_{i,t}$). We measure volatility for each currency as the daily absolute currency returns (as in Menkhoff et al. (2012)), as follows:

$$\begin{aligned}
\Delta TC_{i,t} = & \alpha + \beta (\Delta FCP_t * VOL_{i,t}) + \gamma_1 d_t^{MON} + \gamma_2 d_t^{TUE} + \gamma_3 d_t^{WED} \\
& + \gamma_4 d_t^{THUR} + \sum_{n=1}^4 \delta_n \Delta TC_{i,t-n} + \varepsilon_t
\end{aligned} \tag{20}$$

Table 9 presents the results of the regression. The interactive term is statistically significant and positive, so we can conclude that more volatile currencies suffer the higher impact on illiquidity of changes in funding liquidity constraints. Furthermore, the results of the same exercise carried out for the market depth variable at the monthly frequency support these findings. As Table 10 shows, currencies with higher volatility have higher impact of funding liquidity conditions changes on their illiquidity level.

5 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 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.

The results are robust to controlling for volatility, FX market returns and seasonality. 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 the recent crisis times impact on FX market illiquidity. Furthermore, we confirm that a shock to speculator capital would lead to a reduction in market liquidity through a spiral effect that is stronger for

illiquid currencies.

In conclusion, our study finds that funding liquidity constraints are important determinants of FX market illiquidity and supports the impact of liquidity dry-ups on financial markets (Gromb and Vayanos (2002); Brunnermeier and Pedersen (2009); Acharya and Skeie (2011); Acharya and Viswanathan (2011)).

Appendix A. Regression of currencies' illiquidity on market illiquidity

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

	AUD	BRL	CAD	CHF	CLP	CZK	DKK	EUR	GBP	HUF
Constant	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
ΔPS_t	0.0004	0.0018	0.0001	0.0003	0.0007	0.0013	0.0003	0.0002	0.0001	0.0012
<i>AdjustedR</i> ²	8.4932	4.4322	2.8215	9.0788	5.3742	10.4307	9.9348	10.7568	3.0099	10.8784
	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
ΔPS_t	0.0001	0.0023	0.0009	0.0006	0.0011	0.0019	0.0004	0.0002	0.0017	0.0035
<i>AdjustedR</i> ²	3.5932	9.1085	6.6479	10.9386	10.2925	15.1388	9.1919	6.4213	2.0360	12.2277
	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:

$$\Delta PS_{i,t} = \alpha_i + \beta_i \Delta PS_t + \varepsilon_{i,t}. \quad (21)$$

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 2.1575	0.0375 2.2408
VOL_t		0.17609 2.0276
MKT_{t-1}		-1.07246 -3.1558
d_t^{MON}	-0.0285 -5.0017	-0.02952 -5.1498
d_t^{TUE}	-0.0281 -5.4225	-0.02903 -5.5068
d_t^{WED}	-0.02019 -3.9398	-0.02167 -4.1388
d_t^{THUR}	-0.01321 -2.5082	-0.01426 -2.6921
$\Delta illiq_{t-1}$	-0.70130 -28.2930	-0.70536 -28.6215
$\Delta illiq_{t-2}$	-0.49892 -16.9666	-0.50048 -17.0514
$\Delta illiq_{t-3}$	-0.32709 -11.4417	-0.32764 -11.5244
$\Delta illiq_{t-4}$	-0.18440 -8.3198	-0.18363 -8.3282
Constant	0.01752 4.8255	0.0185 5.0076
$AdjustedR^2$	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 (7) 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 4.6023	0.0085 4.4164
ΔFCP_m	-0.0003 -0.2289	0.0000 -0.0059
VOL_m		-0.4405 -3.6437
ΔL_{m-1}	-0.4987 -7.8456	-0.5053 -8.3010
Constant	-0.0001 -0.5051	0.0016 3.4272
$AdjustedR^2$	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 (17) 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.

References

- Acharya, V.V., Skeie, D., 2011. A Model of Liquidity Hoarding and Term Premia in Inter-Bank Markets. Federal Reserve Bank of New York Staff Reports .
- Acharya, V.V., Viswanathan, S., 2011. Leverage, Moral Hazard, and Liquidity. *Journal of Finance* 66, 99–138.
- Admati, A.R., Pfleiderer, P., 1988. A theory of intraday patterns: volume and price variability. *Review of Financial Studies* 1, 3–40.
- Adrian, T., Etula, E., Shin, H.S., 2010. Risk Appetite and Exchange Rates. Federal Reserve Bank of New York Staff Reports 361.
- Adrian, T., Shin, H.S., 2010. Liquidity and leverage. *Journal of Financial Intermediation* 19, 418–437.
- Banti, C., Phylaktis, K., Sarno, L., 2012. Global Liquidity Risk in the Foreign Exchange Market. *Journal of International Money and Finance* 31, 267–291.
- Bessembinder, H., 1994. Bid-ask spreads in the interbank exchange markets. *Journal of Financial Economics* 35, 317–348.
- BIS, 2010. Triennial Central Bank Survey Report on global foreign exchange market activity in 2010. December.
- Bollerslev, T., Melvin, M., 1994. Bid-ask spreads and volatility in the foreign exchange market An empirical analysis. *Journal of International Economics* 36, 355–372.
- Brunnermeier, M.K., Pedersen, L.H., 2009. Market Liquidity and Funding Liquidity. *Review of Financial Studies* 22, 2201–2238.
- Campbell, J.Y., Grossman, S.J., Wang, J., 1993. Trading Volume and Serial Correlation in Stock Returns. *The Quarterly Journal of Economics* 108, 905–939.
- Chordia, T., Roll, R., Subrahmanyam, A., 2001. Market Liquidity and Trading Activity. *The Journal of Finance* 56, 501–530.

- Chordia, T., Roll, R.W., Subrahmanyam, A., 2000. Commonality in Liquidity. *Journal of Financial Economics* 56, 3–28.
- Coffey, N., Hrungr, W.B., 2009. Capital Constraints, Counterparty Risk, and Deviations from Covered Interest Rate Parity. *Federal Reserve Bank of New York Staff Reports* 393.
- Copeland, T.E., Galai, D.A.N., 1983. Information Effects on the Bid-Ask Spread. *Journal of Finance* 38, 1457–1470.
- Cornett, M.M., McNutt, J.J., Strahan, P.E., Tehranian, H., 2011. Liquidity risk management and credit supply in the financial crisis. *Journal of Financial Economics* 101, 297–312.
- De Long, J.B., Shleifer, A., Summers, L.H., Waldmann, R.J., 1990. Noise Trader Risk in Financial Markets. *Journal of Political Economy* 98, 703–738.
- Ding, D.K., 1999. The determinants of bid-ask spreads in the foreign exchange futures market: A microstructure analysis. *Journal of Futures Markets* 19, 307–324.
- Garleanu, N., Pedersen, L.H., 2011. Margin-Based Asset Pricing and Deviations from the Law of One Price. *Review of Financial Studies* 24, 1980–2022.
- Glosten, L.R., Milgrom, P.R., 1985. Bid, ask and transaction prices in a specialist market with heterogeneously informed traders. *Journal of Financial Economics* 14, 71–100.
- Gromb, D., Vayanos, D., 2002. Equilibrium and welfare in markets with financially constrained arbitrageurs. *Journal of Financial Economics* 66, 361–407.
- Grossman, S.J., Miller, M.H., 1995. Liquidity and Market Structure. *The Journal of Finance* 50, 1013.
- Hameed, A., Kang, W., Viswanathan, S., 2010. Stock Market Declines and Liquidity. *The Journal of Finance* 65, 257–293.
- Hansen, L.P., 1982. Large samples properties of generalized method of moments estimators. *Econometrica* 50, 1029–1054.

- Ho, T., Stoll, H.R., 1981. Optimal dealer pricing under transactions and return uncertainty. *Journal of Financial Economics* 9, 47–73.
- Hsieh, D.A., Kleidon, A.W., 1996. Bid-Ask Spreads in Foreign Exchange Markets : Implications for Models of Asymmetric Information. In: *The Microstructure of Foreign Exchange Markets*, January, 41–72.
- Huberman, G., Halka, D., 2001. Systematic liquidity. *Journal of Financial Research* 24, 161–178.
- Kyle, A.S., 1985. Continuous Auctions and Insider Trading. *Econometrica* 53, 1315–1335.
- Lee, T., 1994. Spread and volatility in spot and forward exchange rates. *Journal of International Money and Finance* 13, 375–383.
- Mancini, L., Ranaldo, A., Wrampelmeyer, J., 2012. Liquidity in the Foreign Exchange Market : Measurement, Commonality, and Risk Premiums. *Journal of Finance* Forthcoming.
- Menkhoff, L., Sarno, L., Schmeling, M., Schrimpf, A., 2012. Carry Trades and Global Foreign Exchange Volatility. *Journal of Finance* 67, 681–718.
- Newey, W.K., West, K.D., 1987. A Simple, Positive Semi-Definite, Heteroskedasticity and Autocorrelation Consistent Covariance Matrix. *Econometrica* 55, 703–708.
- Obstfeld, M., Rogoff, K., 1996. *Foundations of International Macroeconomics*. Cambridge, MA and London: MIT Press.
- Pastor, L., Stambaugh, R.F., 2003. Liquidity Risk and Expected Stock Returns. *Journal of Political Economy* 111.
- Phylaktis, K., Chen, L., 2009. Price discovery in foreign exchange markets: A comparison of indicative and actual transaction prices. *Journal of Empirical Finance* 16, 640–654.
- Shleifer, A., Vishny, R.W., 1997. The Limits of Arbitrage. *The Journal of Finance* 52, 35.
- Stoll, H.R., 1978. The Supply of Dealer Services in Securities Markets. *The Journal of Finance* 33, 1133.
- Vayanos, D., 2004. Flight to quality, flight to liquidity, and the pricing of risk. NBER working paper 10327.

Vayanos, D., Wang, J., 2012. Market Liquidity - Theory and Empirical Evidence. NBER working paper series 18251.

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. 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
AdjustedR 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 (7):

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

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		
$d_{t-1}^{+FUND} d_{t-1}^- MKT_{t-1}$			-2.1366	-2.0672
			-3.0261	-2.9672
VOL_t		0.1706		0.1667
		2.1518		2.0980
d_t^{MON}	-0.0286	-0.0293	-0.0279	-0.0285
	-5.1818	-5.3045	-5.0367	-5.1466
d_t^{TUE}	-0.02837	-0.02895	-0.02891	-0.02945
	-5.2623	-5.3660	-5.3558	-5.4484
d_t^{WED}	-0.02010	-0.02123	-0.01932	-0.02043
	-3.8895	-4.0927	-3.7391	-3.9388
d_t^{THUR}	-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
<i>AdjustedR</i> 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. Model (1) reports the results of regression (8) without volatility. Model (2) reports the results of regression (8) with volatility as control variable, but excluding the interaction variable of market returns increases. Models (3) and (4) report the results of regression (9) without and with volatility as control variable. The coefficients are 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

$dummy_t * \Delta FCP_t$	0.0827	0.0797	0.0759
	1.9740	2.0110	1.9522
VOL_t		0.1715	0.1735
		2.1847	2.2161
MKT_{t-1}			-1.0401
			-2.9476
d_t^{MON}	-0.02797	-0.0287	-0.0290
	-5.0575	-5.1715	-5.2369
d_t^{TUE}	-0.02852	-0.02909	-0.02937
	-5.2921	-5.3872	-5.4422
d_t^{WED}	-0.02046	-0.02156	-0.02192
	-3.9583	-4.1559	-4.2262
d_t^{THUR}	-0.01281	-0.01355	-0.01385
	-2.4843	-2.6254	-2.6863
$\Delta illiq_{t-1}$	-0.70178	-0.70193	-0.70562
	-31.5947	-31.6589	-31.8982
$\Delta illiq_{t-2}$	-0.49834	-0.49790	-0.49985
	-17.0563	-17.1034	-17.1946
$\Delta illiq_{t-3}$	-0.32594	-0.32535	-0.32644
	-11.1116	-11.1303	-11.2226
$\Delta illiq_{t-4}$	-0.18386	-0.18382	-0.18314
	-8.0575	-8.0800	-8.0640
Constant	0.01745	0.01809	0.01837
	4.4782	4.6306	4.7083
AdjustedR ²	0.35	0.35	0.35
LM test - pval	0.03	0.02	0.02

Notes: The table reports the results of regression (10):

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

The coefficients are 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
	<i>4.7687</i>	<i>4.4494</i>	<i>4.5598</i>
ΔFCP_m	-0.0003	0.0001	0.0000
	<i>-0.2453</i>	<i>0.0414</i>	<i>-0.0063</i>
VOL_m		-0.3978	-0.4405
		<i>-3.1818</i>	<i>-3.4300</i>
ΔTS_m		-0.0003	
		<i>-0.3899</i>	
ΔFF_m		-0.0002	
		<i>-0.1570</i>	
MKT_{m-1}		0.3387	
		<i>1.8786</i>	
ΔL_{m-1}	-0.4987	-0.5030	-0.5053
	<i>-7.5560</i>	<i>-7.6906</i>	<i>-7.9817</i>
Constant	-0.0001	0.0014	0.0016
	<i>-0.3616</i>	<i>2.9117</i>	<i>3.2653</i>
<i>AdjustedR²</i>	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 (17):

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

The coefficients are 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 1.9831	0.03327 1.9331
VOL_t	0.17051 2.1719	0.18376 2.3070
MKT_{t-1}	-1.02569 -2.9329	-1.03947 -2.9756
ΔTS_t		-0.0182 -0.7636
ΔFF_t		-0.0056 -0.2920
d_t^{MON}	-0.03064 -5.5666	-0.03266 -5.8199
d_t^{TUE}	-0.02793 -5.2705	-0.02764 -5.1637
d_t^{WED}	-0.01998 -3.8515	-0.01930 -3.6778
d_t^{THUR}	-0.01306 -2.5332	-0.01235 -2.3348
Constant	0.01787 4.6333	0.01742 4.4549
<i>AdjustedR</i> 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 (19):

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

Shocks are estimated as the residuals of a AR model of order 5 to eliminate serial correlation. The coefficients are 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 9: Results of the panel regression - Transaction costs

	1	2	3
$(FCP_t * VOL_{i,t})$	2.50668	2.21338	2.30992
	2.7231	2.3999	2.5052
VOL_t		0.22427	0.22208
		3.6394	3.6036
MKT_{t-1}		-1.07946	
		-4.0092	
d_t^{MON}	-0.02079	-0.02200	-0.02165
	-4.8587	-5.1352	-5.0524
d_t^{TUE}	-0.02305	-0.02393	-0.02377
	-5.4053	-5.6067	-5.5689
d_t^{WED}	-0.01505	-0.01674	-0.01649
	-3.6304	-4.0210	-3.9603
d_t^{THUR}	-0.00587	-0.00706	-0.00683
	-1.4100	-1.6935	-1.6380
$\Delta TC_{i,t-1}$	-0.72812	-0.72849	-0.72815
	-184.7576	-184.8490	-184.7832
$\Delta TC_{i,t-2}$	-0.54121	-0.54136	-0.54117
	-115.0150	-115.0663	-115.0176
$\Delta TC_{i,t-3}$	-0.34592	-0.34603	-0.34590
	-73.8151	-73.8533	-73.8183
$\Delta TC_{i,t-4}$	-0.18121	-0.18118	-0.18120
	-46.2021	-46.2044	-46.2052
Constant	0.01230	0.01337	0.01313
	4.1655	4.5157	4.4343
$AdjustedR^2$	0.36	0.36	0.34

Notes: The table reports the results of the panel regression analysis of the determinants of changes in individual currency transaction costs, regression (20):

$$\Delta TC_{i,t} = \alpha + \beta(\Delta FCP_t * VOL_{i,t}) + \gamma_1 d_t^{MON} + \gamma_2 d_t^{TUE} + \gamma_3 d_t^{WED} + \gamma_4 d_t^{THUR} + \sum_{n=1}^4 \delta_n \Delta TC_{i,t-n} + \varepsilon_t$$

The coefficients are in bold when the variable is statistically significant at 5%. t -statistics are reported under the coefficients. The sample period is from January 1998 to December 2010.

Table 10: Results of the panel regression - Market depth

	1	2
$(REPOS_m * VOL_{i,m})$	1.8310	1.8125
	<i>4.4030</i>	<i>4.3132</i>
VOL_m		-0.4780
		<i>-3.3704</i>
MKT_{m-1}		-0.0473
		<i>-0.3331</i>
$\Delta liq_{i,m-1}$	-0.4805	-0.4810
	<i>-27.7709</i>	<i>-27.8506</i>
Constant	-0.0001	0.0017
	<i>-0.4486</i>	<i>3.0924</i>
$AdjustedR^2$	0.24	0.25

Notes: The table reports the results of the panel regression analysis of the determinants of changes in individual currency market depth. The coefficients are in bold when the variable is statistically significant at 5%. *t*-statistics are reported under the coefficients. The sample period is from January 1998 to December 2010.

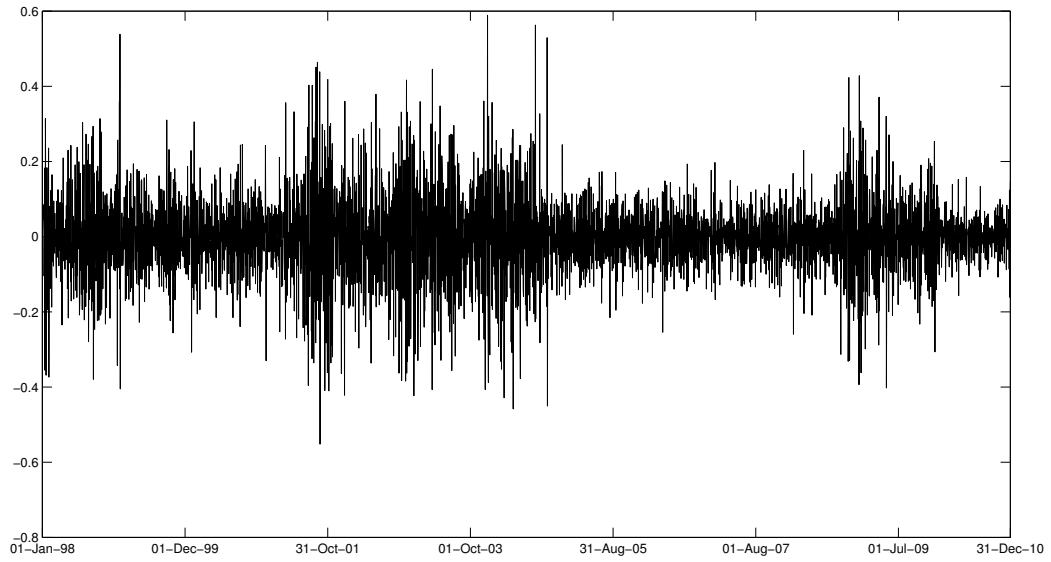


Figure 1: Changes in FX market illiquidity

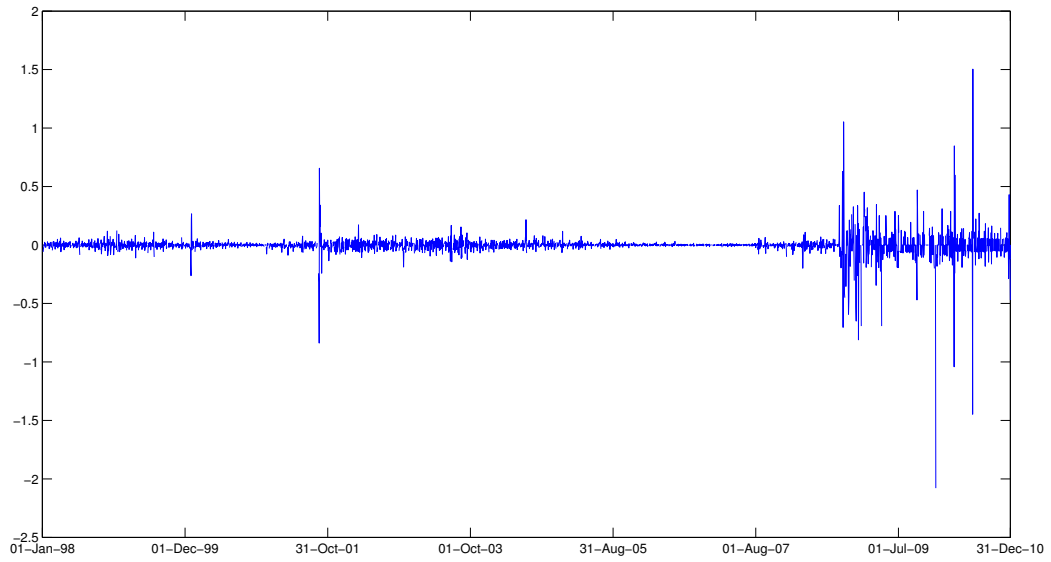


Figure 2: **Changes in financial commercial paper interest rate**

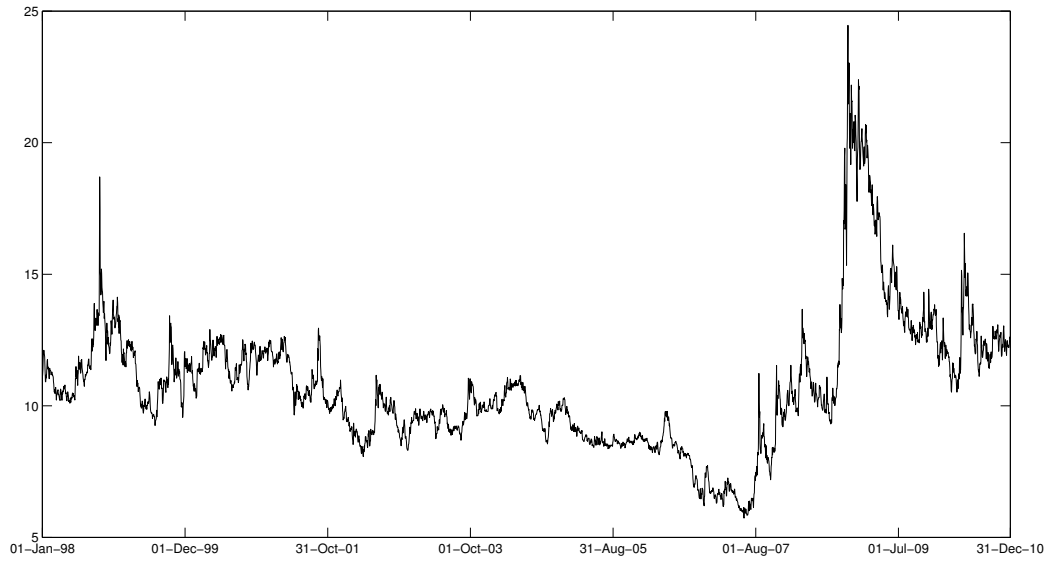


Figure 3: **Global FX volatility**

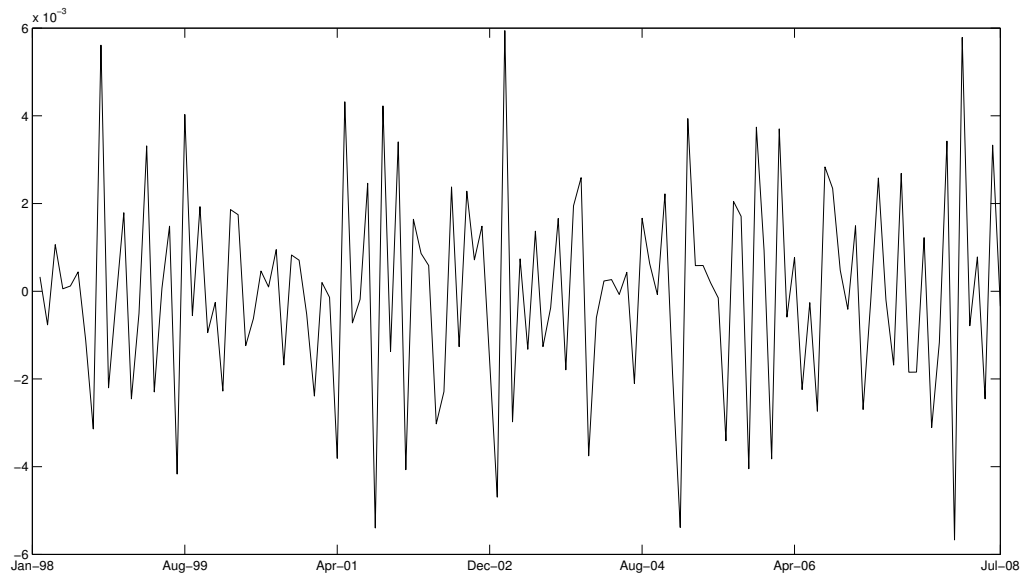


Figure 4: **Changes in monthly FX market depth**