Liquidity in the Foreign Exchange Market

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Abstract

Using a broad data set of 20 US dollar exchange rates and order flow of institutional investors over 14 years, we construct a measure of liquidity in the foreign exchange (FX) market. Our global FX liquidity measure is the analogue of the well-known Pastor-Stambaugh liquidity measure for the US stock market. We show that this measure has reasonable properties, and that there is a strong common component in liquidity across currencies. Finally, we provide evidence that liquidity risk is priced in the cross-section of currency returns, and estimate the liquidity risk premium in the FX market around 5% per annum.

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

JEL Classification: F31; F37; G12; G15.

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I INTRODUCTION

The foreign exchange (FX) market is considered to be highly liquid. In terms of turnover, the average daily market activity in April 2010 was $3.98 trillion (BIS (2010)).[1] However, given its partly decentralized and opaque dealership structure, its price formation process is not fully understood (Lyons (2001)). 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. With the increase in data availability, a literature analyzing the price impact of order flow has emerged in the last decade, documenting that order flow can successfully explain a sizable share of the movements in the exchange rates (Evans and Lyons (2002a)).[2]

Using a unique data set comprising daily order flow data for 20 exchange rates spanning 14 years, we build a measure of liquidity based on the Pastor and Stambaugh (2003) measure, which was originally developed for the US stock market. Analyzing the properties of the individual currency liquidity measures, we find that they are highly correlated, suggesting the presence of a common component across them. The presence of a common component is

[1] There are large differences, however, across currencies: 66% of the FX market average daily turnover in April 2010 involves the six most traded pairs of currencies.

[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. Payne (2003), Bjønnes and Rime (2005), Killeen, Lyons and Moore (2006)). Moreover, Evans and Lyons (2005a, 2006) argue that gradual learning in the FX market can generate not only explanatory, but also forecasting power in order flow, as documented, for example, in Rime, Sarno and Sojli (2010).

consistent with the notion that liquidity is largely driven by shocks that affect the FX market as a whole rather than individual currencies. We then construct a measure of innovations in global FX liquidity (unexpected liquidity) and show that it explains a sizeable share of liquidity innovations in individual currencies.

In the stock market literature, several papers find significant co-movement of liquidity cross-sectionally (Datar, Naif, and Radcliffe (1998), Huberman and Halka (2001), Chordia, Roll, and Subrahmanyam (2000, 2001), Hasbrouck and Seppi (2001), Lesmond (2005)). In contrast, the FX market has received much less attention. The presence of such co-movement in the FX market during the recent crisis period is documented in Mancini, Ranaldo, and Wrampelmeyer (2010). However, to our knowledge, this is the first paper to study global FX liquidity covering a long sample period which includes both crisis and non-crisis periods drawing on the behavior of both developed and emerging market currencies, where liquidity is more of an issue.

Next, taking the perspective of a US investor, we ask whether unexpected changes (innovations) in FX market liquidity affect exchange rate movements. In other words, we examine whether there is a systematic liquidity risk premium in the FX market. Adopting different proxies for liquidity, some studies find a relationship between changes in liquidity and expected stock returns, detecting a liquidity risk premium in the stock market (Pastor and Stambaugh (2003), Acharya and Pederson (2005), Chen (2005), Korajczyk and Sadka (2008), Hasbrouck (2009), Lee (2011)). Estimating systematic liquidity risk as the covariance of exchange rate returns and innovations in common liquidity, we identify a liquidity risk premium by employing standard empirical asset pricing tests and the portfolio construction techniques first applied to FX data by Lustig and Verdelhan (2007). These methods allow us to eliminate currency-specific sources of returns by taking into account the common component of the excess returns related to systematic liquidity risk. Our empirical asset pricing results are supportive of the presence of a risk premium associated with FX market liquidity. Furthermore, the market price of liquidity risk stays significant even after conditioning on other common risk factors in FX asset pricing analysis, such as the dollar and carry risk factors.

The paper is organized as follows. Section 2 provides an overview of the relevant literature. In Section 3 we describe the data set and provide some descriptive statistics. The methodology for the construction of the liquidity measure, the estimation of the innovation in common liquidity, the investigation of the presence of a systematic liquidity risk premium, and the empirical asset pricing exercise are described in Section 5. The empirical results are reported in Section 6, where we document the presence of a common component in liquidity across currencies, we identify a liquidity risk premium, and we estimate its market price. Finally, Section 7 concludes.

II LITERATURE REVIEW

A Liquidity in the FX market

In the FX market, dealers provide liquidity to the market and quote a price after receiving orders from customers and other dealers. In other words, dealers gather private information from the order flow they receive (e.g. Lyons (1997)). Indeed, FX market practitioners' surveys highlight how order flow 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)). In this sense, the information channel works from the dealer's own customer order flow and from the aggregate market customer order flow which can be inferred from the interdealer and brokered trading. As a consequence, the presence of asymmetric information in the market influences liquidity (Copeland and Galai (1983), Kyle (1985), Glosten and Milgrom (1985), Admati and Pfleiderer (1988)). Dealers quote a price by balancing the expected total revenues from liquidity trading against the expected total losses from informed trading. In this respect, 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.

Apart from the information channel, the quotation of the price by the dealer depends also on inventory considerations. Market liquidity is provided by market makers who stand ready to act as the counterparty of the traders in the market. The presence of market makers gives the trader the possibility of shifting the risk of a price change and trade immediately. According to Grossman and Miller (1988), the provision of liquidity depends on the cost incurred by the market maker to maintain its presence in the market. 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 in the market, the lower is the cost for immediacy and the more liquid is the market, in terms of lower price impact of trades.

Besides the costs of maintaining a position in the market, risk-averse dealers quote a certain price based on inventory control considerations: a dealer with a larger currency inventory than desired will set a lower price to attract buyers, known as 'quote shading'. For example, Comerton-Forde, Hendershott, Jones, Moulton, and Seasholes (2010) find that in the specialist NYSE market, market makers revise the bid-ask spread after losses on inventory and when holding large inventories. According to the theoretical model by Amihud and Mendelson (1980), the market maker's constraints on his short and long stock 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)). In addition, focusing on the liquidity provided by the traders in the market, Brunnermeier and Pedersen (2009) extend the Grossman and Miller's model to include the interaction of funding liquidity with the provision of liquidity by speculators. Under certain conditions, this interaction leads the market to a liquidity spiral: speculators' liquidity constraints reduce market liquidity that will further tighten the constraints.

In his empirical analysis of a dealer's trading activity in the DM/USD market, Lyons (1995) finds positive evidence of the effects of both the inventory control and the informational asymmetry channels. Specifically, running a regression of the changes in exchange rate on the incoming orders, the dealer's inventory at the beginning of the period and other variables, Lyons (1995) reports positive and significant coefficients associated with the two variables of interest, transaction orders and inventory at the beginning of the period. In contrast, Bjønnes and Rime (2005) do not find a significant effect of the inventory control channel, while documenting a strong information effect on the trading activity of four dealers from a large Scandinavian bank. They find these results both taking into account the size of the orders and considering the direction of trades.

B Measures of 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. However, Grossman and Miller (1988) highlight a key limitation of the bid-ask spread as a measure for liquidity: this method gives the cost of providing immediacy of the market maker in the case of a contemporaneous presence of buy and sell transactions. In reality, this is almost never the case, also considering that the presence of the market maker is justified by the need to provide immediacy to the transaction needs of the customers.[3]

In order to obtain a proxy for the spread when quotes are not available, Roll (1984) proposes an estimator of the implicit spread in the pattern followed by prices. This method is based on two assumptions: informationally efficient market and the stationarity of the distribution of observed price changes. In the event of no new information arriving on the market, Roll shows that the spread can be measured as a function of the square root of the covariance of consecutive returns.[4]

Furthermore, Lesmond, Ogden and Trzcinka (1999) develop a transaction cost measure which is an estimate of the implicit cost required for an asset price not to move (zero return) when the market as a whole moves. This implies that the wider is the transaction cost band around the price, the less liquid is the market. Its rationale is that a zero return is evidence that the transaction cost threshold has not been exceeded.

Apart from measures related to the transaction cost, other measures were developed to proxy the price impact of transactions. Pastor and Stambaugh (2003) propose a liquidity cost method that measures the temporary price change, in terms of expected 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. Another measure of this kind is the

[3] Much research has been carried out on the determinants of the bid-ask spread in the FX market, on the relationship between trading volume and information flows, and the implications for empirical asset pricing; e.g. see Bessembinder (1994), Lee (1994), Bessembinder, Chan and Seguin (1996), Hsieh and Kleidon (1996), and Asparouhova, Bessembinder and Kalcheva (2010).

[4] Since Roll's estimation can only be calculated when the covariance is negative, Harris (1990) modifies the formula to take the absolute value of the covariance of the returns. However, Naes, Skjeltorp, and Ødegaard (2010) argue that this modification implies a potentially negative spread and, as such, it is counterintuitive.

Amihud (2002)'s illiquidity ratio, which measures the elasticity of liquidity. This is calculated as the daily measure of absolute stock returns to its dollar volume, averaged over some period.

These liquidity measures have been developed and tested mainly for the stock market (e.g. see Naes, Skjeltorp, and Ødegaard (2010)). In fact, their application to the FX market can be quite problematic due to its specific characteristics. For this reason and the difficulty of gathering order flow data for the FX market, liquidity has been investigated in only a few papers.

Evans and Lyons (2002b) address the issue of time-varying liquidity in the FX market using the price impact of order flow as a proxy for liquidity. More recently, Mancini, Ranaldo, and Wrampelmeyer (2010) 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 our paper, we also apply the Pastor and Stambaugh's measure of liquidity but we are able to rely on 14 years of order flow data and 20 exchange rates.

C Liquidity risk premium

Starting from the seminal paper by Amihud and Mendelson (1986), several papers model and empirically test the relationship between liquidity and expected stock returns (Brennan and Subramahmanyan (1996), Brennan, Chordia, and Subrahmanyam (1998), Datar, Naif, and Radcliffe (1998)). A higher return is demanded by traders when stock liquidity is lower and transaction costs are higher. Most of the papers study the US stock market, but the same result is documented by Bekaert, Harvey, and Lundblad (2007) for emerging markets. The same result holds true for other assets: Amihud and Mendelson (1991), among others, find a significant spread in the yields of Treasury notes and bills due to a liquidity risk premium.

Having investigated the effect of the level of liquidity on expected equity returns, some studies also focus on the time variation of liquidity and on its co-movements cross-sectionally. Chordia, Roll, and Subrahmanyam (2000) analyze the correlated movements of liquidity both at industry and at market level. After controlling for determinants of liquidity such as volatility, prices and volume, they document significant common innovations in liquidity in the stock market. Similar conclusions are reached also by other authors. Huberman and Halka (2001) find that there is a systematic and time-varying component in stock market liquidity. A less clear-cut conclusion is reached by Hasbrouck and Seppi (2001), who find evidence of weak co-movement in stock market liquidity measures constructed from intra-daily data. Employing a longer data set of intra-daily stock market data, Chordia, Roll, and Subrahmanyam (2001) confirm the presence of a common component in stock market liquidity, and then present an investigation of the possible determinants of the observed variation in market liquidity and trading activity over time. The determinants they consider are inventory control variables (such as daily returns and volatility) and informed trading variables (such as dummies for macroeconomic announcement dates).

Finally, some studies examine the implications of the documented time-variation in common liquidity for asset returns, controlling for the presence of a priced liquidity risk in stock returns. In their analysis, Pastor and Stambaugh (2003) find that the sensitivities of stock returns to common liquidity innovations are priced. Acharya and Pederson (2005) broaden the analysis of a security's liquidity risk to include the commonality in the liquidity risk and the covariance of individual assets' liquidity with the market return, as well as Pastor and Stambaugh's liquidity measure. By doing so, they develop a liquidity-adjusted Capital Asset Pricing Model (CAPM) and find empirical support for the presence of a priced liquidity risk. Defining the common liquidity risk proxy as the common component of different liquidity measures, Chen (2005) and Korajczyk and Sadka (2008) find evidence that systematic liquidity risk is priced. Employing a different proxy for liquidity, Hasbrouck (2009) also finds a positive relation between liquidity and stock returns, but reports two problematic issues: the relationship is affected by seasonality and the coefficients are too large to be explained only by the changes in traders' compensation for providing liquidity. In an empirical application of Acharya and Pedersen's (2005) liquidity-adjusted CAPM, Lee (2011) identifies a systematic global liquidity risk premium in stock returns. In particular, he finds a premium related both to the commonality in liquidity and the covariance of individual stocks' liquidity and the stock market return.

III DATA

A Description of the data

The data set analyzed in this paper comprises daily data of 20 exchange rates and their order flow for a time period of 14 years, from April 14, 1994 to July 17, 2008. Its uniqueness is the wide cross section of currencies available for a long time period, including a significant number of emerging markets. According to the classification of the International Monetary Fund (IMF (2010)), 13 currencies in the data set are of developed economies (Australian dollar, Canadian dollar, Czech koruna, Danish krone, euro, Great Britain pound, Japanese yen, Korean won, New Zealand dollar, Norwegian kroner, Singapore dollar, Swedish krona, and Swiss franc) and 7 are of emerging markets (Brazilian real, Chilean peso, Hungarian forint, Mexican peso, Polish zloty, South African rand, and Turkish lira). The abbreviations for these currencies used in the paper are given in Appendix A.

Log returns are calculated from the FX spot exchange rates of the US dollar versus the currencies and are obtained from Datastream. They are the WM/Reuters Closing Spot Rates. These rates are provided by Reuters at around 16 GMT. While the longest sample available is from April 15, 1994 to July 17, 2008, for some currencies the sample period begins at a later date due to limited availability of the spot rates from Datastream: for the Brazilian real it starts on July 05, 1994, for the Czech koruna on December 12, 1994, and for the Polish zloty on January 4, 1995.

Furthermore, for some currencies the start date of the sample differs due to the exchange rate arrangements in place. These arrangement indications are taken from the IMF system classification. The Brazilian real observations are considered from January 15, 1999, when the real was introduced as national currency and defined as independently floating. The observations for the Chilean peso are considered from September 2, 1999, when the peso was allowed to freely float. The Czech koruna and the Korean won were allowed to float on January 1, 1998 and they are considered from that date onwards. The Mexican peso has been floating since January 1, 1995. The Polish zloty was allowed to freely float from January 1, 2000. Finally, the Turkish lira was left free to float from January 1, 2001.

Log-exchange rate returns are calculated as:

$$r_t = \ln(S_t) - \ln(S_{t-1}) \tag{1}$$

where S_t is the FX spot rate of the US dollar versus the currency.

In order to calculate FX excess returns, one month forward exchange rates are obtained from Datastream and provided by WM/Reuters. Due to limited data availability, the excess returns are calculated from January 1, 1997 to July 16, 2008. For some currencies, the sample period starts on a later date due to lack of data from Datastream: the Brazilian real and the Chilean peso start on March 29, 2004, the Hungarian forint starts on October 27, 1997, the

Korean won and the Polish zloty start on February 11, 2002. The euro starts on December 31, 1998. Excess returns are calculated as follows:

$$er_t = \ln(S_{t+1}) - \ln(F_t) \tag{2}$$

where F_t is the one-month forward exchange rate.

Turning to order flow, the FX transaction data is obtained from State Street Corporation (SSC). As one of the world's largest custodian institutions, SSC counts nearly 10,000 institutional investor clients with 11.9 trillion US dollar under custody. They record 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 as the overall buying pressure on the currency and is expressed in millions of transactions.

The sample period is generally from April 14, 1994 to July 17, 2008. For some currencies the sample is shorter due to limited data availability from the provider: for the Chilean peso observations start on October 4, 1995, for the Hungarian forint on September 30, 1994, and for the Polish zloty on August 22, 1995.

B Descriptive statistics

Table 1 presents some descriptive statistics of the log returns, grouped in developed and emerging countries. In general, emerging markets' currencies present a higher standard deviation than developed countries' currencies. Furthermore, log returns of developed currencies present low first and second order autocorrelation. In contrast, most of the emerging market currencies exhibit positive significant first-order autocorrelation and negative significant second-order autocorrelation.

- Insert Table 1 here -

Table 2 shows some descriptive statistics for the order flow data. On average, the largest positive order flow during the sample for developed countries is for AUD and CAD, confirming the anecdotal evidence of strong net demand for commodity currencies during this sample period, whereas the lowest is for DKK. In emerging markets, the largest average order flow is for CLP, and the lowest for BRL. The order flow for emerging markets generally presents a higher standard deviation than for developed countries. Furthermore, the order flow data exhibit strong autocorrelation for all currencies in the sample, ranging from 76% for AUD up to 89% for TRY. For most of the emerging markets, the second-order autocorrelation is also significant.

In the last column we report the correlation between the order flow and the log return of the US dollar versus the currency. The correlation is significant for most of the currencies. It is higher for the currencies of the most advanced economies in the sample (AUD, CAD, CHF, DKK, EUR, GBP, JPY, NOK, NZD and SEK). All the correlations are positive, as expected. A positive order flow indicates buying pressure for the currency, which causes the currency to appreciate. The results of the correlation analysis are comparable to the ones reported by Froot and Ramadorai (2005), who use a similar data set from the same source over a shorter sample.[5]

- Insert Table 2 here -

[5] However, note that order flow in Froot and Ramadorai (2005) is measured in millions of dollars, whereas our order flow series is defined as in the majority of papers since Evans and Lyons (2002a), in terms of net number of transactions. Nevertheless, the descriptive statistics suggest that the properties of the data are qualitatively the same.

IV METHODOLOGY

A Construction of the liquidity measure

Starting from Evans and Lyons (2002a), several papers document a significant price impact of order flow in the FX market. The contemporaneous impact of order flow on the exchange rate can be explained as the information discovery process of the dealer, who updates her quotes after receiving orders from her clients and other dealers. Nevertheless, there is also a part of this that reflects inventory concerns on the dealer side that are related to her function as a liquidity provider in the market.

Running the simple Evans and Lyons regression of log returns on contemporaneous order flow:[6]

$$r_{i,t} = \alpha_i + \beta_i \Delta x_{i,t} + \varepsilon_{i,t} \tag{3}$$

we expect to find a positive coefficient associated with the contemporaneous order flow Δx. A positive order flow causes the currency to appreciate, which leads to an increase in the exchange rate quoted as US dollar versus the foreign currency.

Following Pastor and Stambaugh (2003), we measure liquidity as the expected 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

[6] As reported in the data description section, the order flow is related to all the transactions in a specific currency, irrespective of the currency against which the transaction takes place. However, in the regression analysis, we consider the exchange rate of the US dollar versus the currency, assuming the US dollar to be the major currency against which the transactions are made.

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 flow. While the former case will be accompanied by an increase in trading volume, the latter will be characterized by low volume. In fact, 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 the trading volume. The Pastor and Stambaugh's measure captures this relationship and builds a proxy for liquidity given this return reversal due to the behavior of risk-averse market makers. While they use signed trading volume as a proxy for order flow, we employ directly order flow.

Hence, we extend regression (3) above to include lagged order flow:

$$r_{i,t} = \alpha_i + \beta_i \Delta x_{i,t} + \gamma_i \Delta x_{i,t-1} + \varepsilon_{i,t}. \tag{4}$$

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. Hence, our monthly proxy for liquidity of a specific exchange rate is:

$$L_{i,t} = \widehat{\gamma}_{i,t}. \tag{5}$$

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 ($\gamma_i < 0$).

B Estimation of a common liquidity measure

Subsequently, we construct a measure of common liquidity (DL_t) by averaging across currencies the individual monthly liquidity measures (e.g. Chordia, Roll, and Subrahmanyam (2000), Pastor and Stambaugh (2003)), excluding the two most extreme observations:

$$DL_{i,t} = (L_{i,t} - L_{i,t-1}) \tag{6}$$

$$DL_t = \frac{1}{N}\sum_{i=1}^{N} DL_{i,t}. \tag{7}$$

In order to account for potential autocorrelation of some of the individual liquidity series and isolate liquidity innovations, the unexpected component of common liquidity (DL_t^C) is obtained as the residual of an AR(1) model of the common liquidity measure.[7] In other words, we estimate:

$$DL_t = \rho_0 + \rho_1 DL_{t-1} + \varepsilon_t \tag{8}$$

and set $DL_t^C = \widehat{\varepsilon}_t$.

Following Chordia, Roll, and Subrahmanyam (2000), we then regress the individual liquidity measures ($DL_{i,t}$) on the measure of unexpected common liquidity risk (DL_t^C) to further investigate the commonality in the liquidity innovations across currencies:

$$DL_{i,t} = \delta_{0i} + \delta_{1i} DL_t^C + \epsilon_{i,t}. \tag{9}$$

[7] An AR(1) model is enough to eliminate serial correlation in the residuals. Also note that we use the term ‘common’, ‘systematic’ and ‘aggregate’ liquidity interchangeably in this paper.

C Analysis of systematic liquidity risk

Next, we investigate whether common liquidity risk is priced in FX returns. In order to do so, we construct four portfolios for each year based on the ranking of the historical sensitivities of currencies' returns to common liquidity risk.[8] Linking the return of each of the four portfolios year after year, the returns of the portfolios are then compared, and we expect the portfolios more sensitive to liquidity risk to have a higher excess return than the less sensitive portfolios.

The analysis starts from January 1997 to account for the start date of the forward rate data from Datastream and it is conducted at every year-end. For each currency, the liquidity measure is estimated by the coefficient associated with the lagged order flow from regression (4), run with the past observations available at each year-end starting from January 1997. At each year-end, the monthly series of common liquidity for the past available period is also calculated according to equations (6) to (8).

Then, the sensitivity of each currency's return to the common liquidity innovation is estimated with a regression of the monthly returns on the common liquidity measure estimated at each year end:

$$r_{i,t} = \zeta_{0i} + \zeta_{1i} DL_t^C + \varepsilon_{i,t}. \tag{10}$$

At this point, the currencies are sorted according to the estimated parameter ζ_1, which captures the sensitivity to common liquidity. Based on this ranking, four portfolios are constructed with five equally-weighted currencies at each year-end: the first portfolio containing the least sensitive currencies to liquidity risk and the fourth being made of the most sensitive

[8] In other words, we estimate the sensitivity to unexpected common liquidity for each exchange rate using non-overlapping years, and this gives us an estimate of the sensitivity per year for each exchange rate. Then, we sort currencies on the basis of the estimated sensitivities into four portfolios, which are rebalanced yearly.

ones. The return of each portfolio for the following year is then calculated from the returns of each of the five equally-weighted currencies. For each portfolio a return series is obtained by linking the return calculated in each year. Having constructed the portfolios based on their sensitivity to our liquidity measure, we expect the most sensitive portfolio to be associated with a higher return in compensation for the higher liquidity risk associated with it.

D Empirical asset pricing

Following the comparison of the liquidity-sorted portfolios' excess returns, we proceed to investigate whether systematic liquidity risk is priced in the cross-section of excess returns of the portfolios.

In order to establish whether systematic liquidity risk is priced, we conduct a Fama-MacBeth (1973) analysis starting from January 1997. Taking the perspective of a US investor, we test whether a liquidity risk factor prices the excess returns of the portfolios sorted according to the sensitivities of the currencies' return to the common liquidity measure (liquidity-sorted portfolios). We test the significance of liquidity risk also conditioning on other factors, i.e. we check whether the systematic liquidity risk factor remains priced when accounting for other sources of systematic risk. The natural candidates for this test are the dollar risk and carry risk factors, proposed by Lustig, Roussanov, and Verdelhan (2010).

Applying the standard Fama-MacBeth procedure, we begin by estimating the sensitivities of the portfolios' excess returns to systematic liquidity and some common risk factors through a time-series regression of the form:

$$er_{j,t} = \alpha_j + \beta_j f_t^{LIQ} + \beta_j f_t^{other} + \epsilon_{j,t} \qquad \text{for } j = 1, ..., 4. \tag{11}$$

where f_t^{LIQ} is the proposed liquidity risk factor DL_t^C, and f_t^{other} is an additional risk factor. This could be either the carry risk factor, developed as the difference in the excess returns of the high interest currencies portfolio and the low interest currencies portfolio, or the dollar risk factor, constructed as the cross-sectional average of the portfolios excess returns.

At this point, we proceed to determine the cross-sectional impact of the sensitivities on the excess returns. A cross-sectional regression of the excess returns on the sensitivities is run at each point in time as follows:

$$er_{j,t} = \beta_j \lambda_t^{LIQ} + \beta_j \lambda_t^{other} + \varepsilon_{j,t} \qquad \text{for } t = 1, ..., T \tag{12}$$

where λ_t is the market price of a specific risk factor at time t and β_j is calculated from the first step presented above. The market price of risk is the average of the λs estimated at each point in time. The same applies to the pricing errors, as follows:

$$\widehat{\lambda^{LIQ}} = \frac{1}{T}\sum_{t=1}^{T} \lambda_t^{LIQ} \tag{13}$$

$$\widehat{\lambda^{other}} = \frac{1}{T}\sum_{t=1}^{T} \lambda_t^{other} \tag{14}$$

$$\widehat{\varepsilon_i} = \frac{1}{T}\sum_{t=1}^{T} \varepsilon_{i,t}. \tag{15}$$

In order to validate our hypothesis that liquidity risk is a priced factor in the FX market, we require the market price to be positive and significant. Furthermore, we expect the price to stay significant once other factors are added in the analysis.[9]

[9] The standard errors of the estimates are calculated from the deviation of the estimates of the cross-sectional regressions from their mean, as follows: $\sigma^2(\widehat{\lambda_t^{LIQ}}) = \frac{1}{T^2}\sum_{t=1}^{T}(\widehat{\lambda_t^{LIQ}} - \widehat{\lambda^{LIQ}})^2$; $\sigma^2(\widehat{\lambda_t^{other}}) = \frac{1}{T^2}\sum_{t=1}^{T}(\widehat{\lambda_t^{other}} - \widehat{\lambda^{other}})^2$; $\sigma^2(\widehat{\varepsilon_i}) = \frac{1}{T^2}\sum_{t=1}^{T}(\widehat{\varepsilon_{i,t}} - \widehat{\varepsilon_i})^2$. We employ the portfolio construction technique so that the estimates of the sensitivities of excess returns to the factors are more precise. However, when calculating the standard errors, we also employ the Shanken (1992) adjustment.

E Empirical asset pricing: extension

Adjusting the CAPM for liquidity, Acharya and Pedersen (2005) extend the definition of liquidity risk to include the covariance of an individual asset liquidity and market liquidity, and the covariance of an individual asset liquidity and the market return, in addition to the covariance of an asset return and market liquidity already presented by Pastor and Stambaugh (2003). Following their model, we extend our analysis to estimate liquidity risk as both the covariance of currencies return and market liquidity, and the covariance of currencies liquidity and market liquidity.[10] The rationale behind this is that an investor requires a premium to hold a currency that is illiquid when the market as a whole is illiquid. As a consequence, expected currencies returns will be negatively correlated to the covariance of individual currencies liquidity and market liquidity.

Thus, the βs measuring systematic liquidity risk are estimated from the following regressions:

$$er_{j,t} = \alpha_j + \beta_j^1 DL_t^C + \varepsilon_{j,t} \tag{16}$$

$$DL_{j,t} = \kappa_j + \beta_j^2 DL_t^C + \varepsilon\prime_{j,t}. \tag{17}$$

The first regression is the equivalent of regression (11), with innovations in common liquidity as the only common risk factor. In addition, we run the second regression in order to estimate the Acharya and Pedersen (2005) additional measure of liquidity risk, given by the regression of innovations in individual liquidity on innovations in common liquidity.

Hence, our 'net' βs measuring systematic liquidity risk are given by:

[10] We thus leave out the additional measure of liquidity risk, given by the covariance of innovations of individual liquidity with the market return, since there is no stock market return equivalent for the FX market.

$$\widehat{\beta}_j = \widehat{\beta}^1_j - \widehat{\beta}^2_j \tag{18}$$

At this point, we conduct the same empirical asset pricing analysis as above in equations (12) to (15) and we quantify this enhanced measure of liquidity risk.

V EMPIRICAL RESULTS

A The FX liquidity measure

Table 3 reports the results from estimating regression (4), where FX returns are regressed on contemporaneous and lagged order flow; the estimation is carried out by OLS and with standard errors calculated following Newey and West (1987). The coefficients associated with contemporaneous flow are generally positive and highly significant. This was expected since the data set includes orders from institutional investors, which are considered to be informed traders in the FX market, so their order flow is expected to convey information to the market. The exception is the MXN.[11] In contrast, the coefficients of lagged order flow are negative and generally significant, which is consistent with our priors since they capture the return reversal. For the currencies of the advanced economies, the regressions have particularly high explanatory power, exceeding 18% for CHF.

- Insert Table 3 here -

Running the same regression for each independent month in the sample period gives a time series of monthly γs for each currency. These series represent our monthly proxies of overall

[11] Even though formally considered a floating system, the Mexican peso arrangement might be affected by the movements in the FX reserves which are particularly strong due to the accumulation in US dollar deposits of the revenues from oil exports (Frankel and Wei (2007)).

liquidity for the currencies considered.[12] As in Pastor and Stambaugh (2003), we calculate a systematic (or aggregate) liquidity measure from the liquidity measures of individual currencies. Indeed, given that there is a common component in the cost of providing liquidity in the FX market, it seems reasonable to expect the time-variation in liquidity to be correlated across currencies. The results of papers conducted on the stock market are supportive of this hypothesis. Regarding the FX market, Mancini, Ranaldo, and Wrampelmeyer (2010) conduct a similar analysis for 9 exchange rates for the years of the last financial crisis (2007-2008) and find a strong positive correlation in liquidity cross-sectionally. Given the particular market conditions in which the co-movement has been tested, it does not follow that the same result can be generalized to normal market conditions. Since the data set analyzed here includes crisis and non-crisis periods, an answer to this question can be given irrespective of market conditions. Furthermore, our large number of currencies, including both developed and emerging countries, allows us to establish fairly robust and general results.

A preliminary analysis of the correlations between the individual liquidity innovation measures shows that 68% of the series are positively correlated and that over 22% of the correlations are statistically significant. This is a first sign of the presence of a common liquidity component.

Next, we construct the common liquidity measure according to equations (6) to (8). The proxy captures the innovation in common liquidity across currencies. Some descriptive statistics are given in Table 4, whereas in Figure 1 we show the evolution over time of both systematic liquidity and its unexpected component. Regression (9) is run to investigate the ability of the proxy to capture systematic liquidity across currencies. The regression is esti-

[12] Overall, 79% of the betas are correctly signed (39% are also statistically significant), and 76% of the gammas are correctly signed (31% are also statistically significant).

mated by OLS and the standard errors are adjusted according to Newey and West (1987). The results are highly supportive of the presence of commonality (see Table 5). All the coefficients are positive and statistically significant, except CAD, BRL, and TRY. Furthermore, about 70% of the regressions have an R^2 in excess of 5%. Hence, the common liquidity proxy does generally explain some fraction of the movements of individual currencies' liquidity.

- Insert Table 4 here -

- Insert Table 5 here -

B Is there a liquidity risk premium?

Next, we build four portfolios based on the ranking of the sensitivities of the currencies' returns to the common liquidity measure. This exercise reveals that portfolios with higher sensitivity dominate the ones with lower sensitivity to liquidity risk, as one would expect. Table 6 (Panel A) shows some descriptive statistics for the excess returns of the four portfolios. It includes in the last column the return of a strategy that goes long on the most sensitive portfolio and short on the least sensitive one. The spread in average returns is substantial and gives empirical support to the presence of a systematic liquidity risk premium.

In order to check whether the results of our analysis are driven by the Turkish lira extreme behavior during the 2001 crisis, we cap the monthly currencies' excess return to +/- 10%.[13] Table 6 (Panel B) shows that the most sensitive portfolios still receive higher excess returns on average. This is also evident from the graphical analysis of the cumulative excess returns of the four portfolios in Figure 2.

[13] During 2001 and part of 2002, the Turkish crisis led to a collapse of the Turkish lira, that experimented massive returns. In detail, during the year 2001, the monthly excess return of the USD/TRY was in excess of -50%.

- Insert Table 6 here -

C Liquidity risk: a priced common risk factor

Table 7 shows the results of the Fama-MacBeth procedure with different equation specifications. Panel A reports the analysis with the systematic liquidity risk as common risk factor. The λ coefficient associated with the systematic liquidity risk is positive and strongly statistically significant. In particular, we estimate an annualized liquidity risk premium in excess of 5%.

What happens to the market price of liquidity risk when other sources of risk are included in the regression analysis? Panels B and C show the results with the inclusion of the dollar risk and the carry risk factors. In both cases, the λ associated with the systematic liquidity risk remains statistically significant and does not change significantly.

In Panel B, the dollar risk factor is marginally significant, so the result is not as strong as in Lustig, Roussanov, and Verdelhan (2010) where the dollar risk factor does not explain any of the cross-sectional variation of the portfolios' excess returns. However, the inclusion of the dollar risk factor makes the pricing errors statistically different from zero. Furthermore, as Lustig, Roussanov, and Verdelhan (2010), we do find that the sensitivities of the portfolios' excess returns to the dollar risk factor are not different from one, so the inclusion of a constant in the cross-sectional regression is not appropriate.[14] More clearly, Panel C shows that the carry risk factor is not statistically significant in explaining the cross-sectional variation of the liquidity-sorted portfolios' excess returns, once introduced in the analysis together with the liquidity risk factor. Hence, we conclude that systematic liquidity risk is priced in the FX market.

[14] These results are confirmed in the analysis of Menkhoff, Sarno, Schmeling and Schrimpf (2011).

- Insert Table 7 here -

In their analysis of liquidity across 9 developed countries' currencies during the recent financial crisis, Mancini, Ranaldo, and Wrampelmeyer (2010) identify a liquidity risk premium as high as 20%. Our lower estimate of the liquidity risk premium can be explained by the inclusion in our sample of both crisis and non-crisis periods. From this comparison, we can suggest that the FX liquidity risk premium is time-varying. Following the theoretical model developed by Vayanos (2004), the liquidity risk premium is time-varying due to the changes in investors' liquidity preferences. In other words, during a financial crisis, investors' need to liquidate their assets becomes more likely and leads to a higher liquidity risk premium. However, our results show that a liquidity risk premium is present and significant in the FX market irrespective of the market conditions.

D Liquidity risk premium: extension

In the analysis above, we have measured the sensitivity of a currency to liquidity risk from the covariance of currency returns with innovations to aggregate liquidity in the FX market (regression (11)). Following Acharya and Pedersen (2005), we extend our definition of systematic liquidity risk to include also the covariance of unexpected changes in a currency individual liquidity with shocks to market liquidity, as described in Section 4.5. The high significance of the betas (β_j^2) is a strong sign of the presence of a kind of liquidity risk not captured by the above measure alone (β_j^1).

Table 8 shows the results of the extended analysis. For liquidity-sorted portfolios, the λ coefficient is still positive and significant (Panel A). In this case, the estimated annualized liquidity premium is above 4%. With the inclusion of the dollar risk factor as an additional common risk factor, the premium stays significant, even though it decreases to around 2.6% on an annualized basis (Panel B). However, when the carry risk factor is included, the premium reduces to slightly above 2% and is marginally significant (Panel C). Overall, therefore, the results are qualitatively unchanged when allowing for the additional effects in the definition of liquidity risk in Acharya and Pedersen (2005), but the magnitude of the liquidity risk premium is reduced when we also condition on other common FX risk factors.

- Insert Table 8 here -

VI CONCLUSIONS

In this paper, we study liquidity in the FX market of 20 US dollar exchange rates over 14 years. Defining liquidity as the expected return reversal associated with order flow, the well-known Pastor-Stambaugh measure for stocks, we estimate individual currency liquidity measures. As for the stock market, we observe that the individual FX liquidity measures are correlated across currencies. We document the presence of a common component in liquidity across currencies, which is consistent with the literature that identifies the dealers' inventory control constraints and preferences as significant channels influencing price formation. In fact, some of the dealers' considerations regarding their inventory positions may be irrespective of the particular currencies involved in the trades. In other words, the dealers' response to incoming orders of different currencies has a common part dictated by their inventory position considerations. Furthermore, the commonality can be explained by the need for funding liquidity on the side of traders. In this sense, changes in the funding conditions affect the provision of liquidity in all the currencies in which an investor trades.

The aggregate liquidity measure exhibits strong variation through time. Our focus in this paper is on unexpected changes in aggregate liquidity. In this sense, the paper's main contribution is the identification and estimation of a systematic liquidity risk premium that significantly explains part of the cross-section variation in exchange rates.

If there is a liquidity risk premium in the FX market, an investor will require a higher return to hold a currency more sensitive to unexpected liquidity. The higher is the sensitivity of a currency to innovations in liquidity, the greater is the premium for holding that currency. Taking the perspective of a US investor, we group the currencies in 4 portfolios based on the historical currencies' sensitivities to the liquidity measures. Comparing the returns of the portfolios, we find that the returns are higher for the portfolios containing the more sensitive currencies.

At this stage, to verify whether the sensitivity of the currencies to innovations in liquidity is indeed priced in the market, we perform standard asset pricing tests. Applying the Fama-MacBeth procedure to a cross-section of liquidity-sorted portfolios, we estimate an annualized systematic liquidity risk premium in excess of 5%. Furthermore, we control for other variables as a source of risk that can potentially explain variation in the cross-section of currency returns. The results do not change: the liquidity risk factor stays significant even after taking into account the dollar risk and the carry risk factors. In addition, we extend the definition of liquidity risk to include the commonality in liquidity, and confirm a positive and significant liquidity risk premium. Therefore, we can conclude that liquidity risk is a priced factor in the cross-section of currency returns and that it is both statistically and economically significant.

A Appendix: ABBREVIATIONS

List of the abbreviations used in the paper for currencies:

AUD: Australian dollar

BRL: Brazilian real

CAD: Canadian dollar

CHF: Swiss franc

CLP: Chilean peso

CZK: Czech koruna

DKK: Danish krone

DM: Deutsche mark

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

USD: United States dollar

ZAR: South African rand

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Table 1: **DESCRIPTIVE STATISTICS OF LOG RETURNS**

Currencies	Mean *(*100)*	Median *(*100)*	St dev *(*100)*	Skew	Kurt	AC(1)	pAC(2)
Developed countries							
USD/AUD	0.008	0.027	0.643	-0.309	7.101	0.023	-0.041*
USD/CAD	0.009	0.000	0.426	-0.050	5.086	-0.006	-0.018
USD/CHF	0.009	-0.012	0.651	0.263	4.705	-0.013	0.006
USD/CZK	0.018	0.000	0.641	-0.441	11.767	0.044*	-0.025
USD/DKK	0.010	0.000	0.573	0.204	4.330	0.004	0.002
USD/EUR	0.009	0.000	0.564	0.187	4.342	0.004	0.005
USD/GBP	0.008	0.009	0.483	0.006	4.240	0.016	-0.004
USD/JPY	0.000	-0.015	0.680	0.578	8.081	0.018	0.008
USD/KRW	-0.006	0.000	0.867	0.766	140.078	0.163*	-0.064*
USD/NOK	0.010	0.000	0.616	0.007	5.982	0.037*	-0.006
USD/NZD	0.008	0.022	0.689	-0.386	6.724	0.031	-0.048*
USD/SEK	0.008	0.004	0.602	0.078	4.171	0.037*	-0.021
USD/SGD	0.004	0.000	0.345	0.810	18.775	-0.034*	0.008
Emerging markets							
USD/BRL	-0.014	0.000	0.903	-0.588	31.004	0.103*	-0.079*
USD/CLP	-0.004	0.000	0.506	-0.182	7.470	0.044*	-0.040*
USD/HUF	-0.009	-0.018	0.631	-0.385	7.882	0.045*	-0.002
USD/MXN	-0.030	0.000	0.956	-3.378	113.929	-0.084*	-0.056*
USD/PLN	0.005	0.000	0.586	-0.409	6.765	0.082*	0.018
USD/TRY	-0.094	-0.082	1.186	-8.967	297.445	0.086*	-0.138*
USD/ZAR	-0.020	0.000	0.880	-0.135	10.089	0.032	-0.050*

Notes: The sample period is generally from April 15, 1994 to July 17, 2008. For some currencies the sample period is shorter due to availability of the spot rates from Datastream: for the Brazilian real observations start on July 05, 1994, for the Czech koruna on December 12, 1994, and for the Polish zloty on January 4, 1995. The first two columns show the mean and the median of the log exchange rate returns. The third, fourth and fifth columns report the daily standard deviation, the skewness, and the kurtosis of the log returns. The sixth and seventh columns show the autocorrelation and the second-order partial autocorrelation of the data. * indicates statistical significance at the 5% significance level.

Table 2: **DESCRIPTIVE STATISTICS OF ORDER FLOW DATA**

Currencies	Mean	Median	St dev	Skew	Kurt	AC(1)	pAC(2)	Corr(r,f)
Developed countries								
AUD	0.038	0.049	0.465	-0.268	1.042	0.760*	-0.016	0.248*
CAD	0.028	0.024	0.498	0.914	6.307	0.792*	0.078*	0.179*
CHF	-0.004	-0.025	0.562	0.152	1.017	0.843*	0.017	0.248*
CZK	0.012	0.002	1.410	4.885	72.394	0.836*	0.112*	0.049*
DKK	-0.043	-0.012	0.694	-3.194	29.454	0.847*	0.057*	0.126*
EUR	-0.004	-0.008	0.475	0.055	1.039	0.817*	0.113*	0.220*
GBP	-0.013	0.017	0.497	-0.202	0.859	0.832*	0.004	0.195*
JPY	0.000	-0.002	0.496	-0.013	0.958	0.783*	0.116*	0.264*
KRW	-0.037	0.003	2.411	-5.275	87.355	0.881*	0.145*	0.046*
NOK	-0.007	0.000	0.832	0.341	6.932	0.855*	-0.018	0.122*
NZD	-0.003	0.014	0.656	-0.675	7.264	0.818*	-0.027	0.171*
SEK	0.004	0.013	0.513	-0.271	2.541	0.822*	0.020	0.199*
SGD	0.017	0.040	0.737	-0.492	5.712	0.803*	0.097*	0.036*
Emerging markets								
BRL	-0.049	0.015	1.977	-4.959	57.035	0.880*	-0.013	0.035
CLP	0.282	0.005	4.509	4.464	67.590	0.888*	0.041*	0.102*
HUF	0.052	0.023	1.416	0.187	10.050	0.839*	0.110*	0.029
MXN	-0.008	-0.006	1.361	1.819	21.037	0.835*	0.082*	0.015
PLN	0.185	0.002	2.067	3.649	33.211	0.863*	0.082*	0.096*
TRY	0.222	0.001	3.597	12.102	204.278	0.893*	0.076*	0.087*
ZAR	-0.026	0.003	1.094	-0.842	10.575	0.823*	0.038*	0.094*

Notes: Order flow data are defined as the net buying pressure on the currency. The sample period is generally from April 14, 1994 to July 17, 2008. For some currencies the sample period is shorter due to availability of data from the provider: for the Chilean peso observations start on October 04, 1995, for the Hungarian forint on September 30, 1994, and for the Polish zloty on August 22, 1995. The first two columns show the mean and the median of the order flow. The third, fourth and fifth columns report the daily standard deviation, the skewness, and the kurtosis. The sixth and seventh columns report the autocorrelation and the partial second-order autocorrelation of the data. The eighth column reports the correlation between the log returns of the US dollar against the currency and the currency's order flow. * indicates statistical significance at the 5% significance level.

Table 3: **REGRESSION OF RETURNS ON ORDER FLOW**

Curr	β	γ	R^2	DW	LM	Curr	β	γ	R^2	DW	LM
	Developed countries						*Emerging markets*				
AUD	0.0082	-0.0063	0.15	1.89	11.62	**BRL**	0.0029	-0.0028	0.02	1.79	24.99
	(17.23)	(-15.10)					(4.34)	(-4.01)			
CAD	0.0041	-0.0032	0.08	1.97*	0.89*	**CLP**	0.0013	-0.0010	0.02	1.92*	4.12*
	(11.49)	(-9.87)					(4.78)	(-3.82)			
CHF	0.0092	-0.0075	0.18	2.04*	1.27*	**HUF**	0.0004	-0.0004	0.00	1.90	8.31
	(20.46)	(-17.49)					(2.64)	(-2.39)			
CZK	0.0017	-0.0016	0.02	1.92*	4.44*	**MXN**	-0.0001	0.0003	0.00	2.19	42.96
	(5.93)	(-5.60)					(-0.30)	(0.73)			
DKK	0.0035	-0.0029	0.05	1.95*	2.45*	**PLN**	0.0009	-0.0004	0.01	1.83	15.21
	(7.85)	(-7.61)					(2.36)	(-1.24)			
EUR	0.0076	-0.0061	0.14	1.96*	1.04*	**TRY**	0.0037	-0.0029	0.02	1.81	17.42
	(15.68)	(-13.02)					(5.41)	(-3.97)			
GBP	0.0061	-0.0051	0.12	1.96*	1.85*	**ZAR**	0.0023	-0.0019	0.03	1.94*	3.54*
	(17.48)	(-15.60)					(7.69)	(-6.46)			
JPY	0.0085	-0.0062	0.15	1.96*	1.61*						
	(15.26)	(-12.58)									
KRW	0.0012	-0.0011	0.01	1.86	13.21						
	(4.15)	(-3.85)									
NOK	0.0035	-0.0030	0.06	1.87	15.03						
	(10.21)	(-8.85)									
NZD	0.0055	-0.0045	0.09	1.87	16.48						
	(11.87)	(-10.53)									
SEK	0.0068	-0.0055	0.11	1.87	16.58						
	(15.21)	(-13.16)									
SGD	0.0004	-0.0003	0.00	2.07*	4.66*						
	(3.13)	(-2.49)									

Notes: Regression (4):

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

is run for each currency i in the data set. t-statistics are calculated according to Newey and West (1987) and are reported in brackets under the coefficients. The Durbin-Watson and the LM test statistics are reported in the last 2 columns. * indicates statistical significance at the 5% significance level.

Table 4: **DESCRIPTIVE STATISTICS OF INNOVATIONS OF COMMON LIQUIDITY**

Mean *(*100)*	Median *(*100)*	St dev *(*100)*	Skew	Kurt	AC(1)
-0.004	0.011	0.219	-0.307	0.164	-0.129

Notes: The series of the innovation of common liquidity is calculated as the residual of an AR(1) regression for aggregate liquidity. Aggregate liquidity is calculated by averaging across the changes in the liquidity of individual currencies, excluding the two most extreme values. Individual liquidity for each currency is obtained from the sensitivity of currency returns to lagged order flow, as in Pastor and Stambaugh (2003).

Table 5: **REGRESSION OF CURRENCIES' LIQUIDITY ON COMMON LIQUIDITY**

Curr	δ_1	R^2	DW	LM	Curr	δ_1	R^2	DW	LM
	Developed countries					*Emerging markets*			
AUD	0.768	0.08	2.19*	1.52*	**BRL**	0.574	0.02	2.09*	0.35*
	(3.57)					(1.83)			
CAD	0.352	0.02	2.28*	3.45*	**CLP**	1.373	0.08	1.91*	0.18*
	(1.46)					(3.10)			
CHF	0.907	0.08	1.96*	0.02*	**HUF**	0.449	0.03	2.16*	1.23*
	(3.37)					(2.33)			
CZK	1.175	0.07	2.18*	1.41*	**MXN**	1.499	0.09	2.23*	2.26*
	(3.50)					(2.90)			
DKK	1.157	0.15	2.13*	0.72*	**PLN**	0.653	0.04	2.10*	0.49*
	(5.83)					(2.66)			
EUR	0.945	0.11	2.15*	1.15*	**TRY**	1.187	0.02	2.20*	1.65*
	(5.29)					(1.77)			
GBP	0.604	0.05	2.18*	1.40*	**ZAR**	0.930	0.04	2.07*	0.41*
	(2.90)					(2.38)			
JPY	1.178	0.14	2.20*	1.81*					
	(5.19)								
KRW	0.817	0.05	2.19*	1.58*					
	(3.56)								
NOK	0.801	0.07	2.09*	0.35*					
	(2.96)								
NZD	1.063	0.12	2.02*	0.02*					
	(5.42)								
SEK	1.390	0.19	2.16*	1.68*					
	(6.44)								
SGD	0.337	0.06	2.07*	0.30*					
	(3.25)								

Notes: Regression (9):

$$DL_{i,t} = \delta_{0i} + \delta_{1i} DL_t^C + \varepsilon_{i,t}$$

is run for each currency i in the data set, where $DL_{i,t}$ is liquidity of currency i and DL_t^C is the unexpected component to aggregate liquidity. Standard errors are calculated according to Newey and West (1987). t-statistics are reported in brackets under the coefficients. The Durbin-Watson and the LM test statistics are reported in the last 2 columns. * indicates statistical significance at the 5% significance level.

Table 6: **DESCRIPTIVE STATISTICS OF THE PORTFOLIOS**

Panel A					
Portfolio	***1***	***2***	***3***	***4***	***4−1***
mean	-0.1348	0.0360	0.0338	0.0835	0.2184
median	-0.0221	0.0137	0.0208	0.1335	0.1022
st dev	0.1853	0.0693	0.0754	0.0958	0.1782
sharpe ratio	-0.7274	0.5195	0.4482	0.8719	1.2255

Panel B					
Portfolio	***1***	***2***	***3***	***4***	***4−1***
mean	0.0108	0.0360	0.0338	0.0962	0.0854
median	-0.0221	0.0137	0.0208	0.1271	0.0979
st dev	0.0816	0.0693	0.0754	0.0753	0.0700
sharpe ratio	0.1326	0.5195	0.4482	1.2779	1.2198

Notes: The portfolios are constructed by sorting the currencies according to the sensitivity of their returns to systematic liquidity risk. Each portfolio contains 5 currencies. The first four columns in Panel A report the annualized descriptive statistics for the excess returns of the individual portfolios. The fifth column shows the annualized descriptive statistics of the excess returns of the portfolio constructed by taking a short position on the first portfolio and long on the fourth portfolio. Portfolio 1 contains the currencies with the lowest sensitivities to liquidity risk, while Portfolio 4 contains the currencies with the highest sensitivity. Panel B shows the results of the same analysis with a cap on the individual currency monthly excess returns of +/- 10%.

Table 7: **RESULTS OF THE CROSS-SECTIONAL PRICING ANALYSIS**

		PANEL A		
	LIQ	***constant***	$\chi 2$	
λ	0.0045	-	0.5463	
t-stat (SH)	*(2.8884)*			
		PANEL B		
	LIQ	***AVE***	$\chi 2$	
λ	0.0042	0.0036	0.0012	
t-stat (SH)	*(3.4017)*	*(1.9569)*		
		PANEL C		
	LIQ	***HML***	***constant***	$\chi 2$
λ	0.0043	-0.0033	-	0.0253
t-stat (SH)	*(3.5383)*	*(-0.3998)*		

Notes: Estimations are obtained via the Fama-MacBeth procedure. LIQ indicates the systematic liquidity risk factor. AVE is the dollar risk factor and is calculated as the average of the cross-sectional portfolios' monthly excess returns. HML refers to the carry risk factor, which is the return of a strategy long in the high interest rate portfolio and short in the low interest rate portfolio. t-statistics corrected with the Shanken (1992) adjustment are reported in brackets below the estimated coefficients. The p-values of the $\chi 2$ test of pricing errors jointly zero are adjusted according to Shanken (1992). A constant is included in the cross-sectional regressions, but it is only reported when statistically significant. However, as in Lustig, Roussanov, and Verdelhan (2010), we find that the sensitivities of the portfolios' excess returns to the dollar risk factor are not different from one, so we do not include a constant in the cross-sectional regression of Panel B.

Table 8: **RESULTS OF THE EXTENDED CROSS-SECTIONAL PRICING ANALYSIS**

		PANEL A		
	LIQ^{AP}	***constant***	$\chi 2$	
λ	0.0037	-	0.0010	
t-stat (SH)	*(3.0336)*			
		PANEL B		
	LIQ^{AP}	***AVE***	$\chi 2$	
λ	0.0022	0.0025	0.0000	
t-stat (SH)	*(2.4182)*	*(1.4049)*		
		PANEL C		
	LIQ^{AP}	***HML***	***constant***	$\chi 2$
λ	0.0018	0.0095	-	0.0100
t-stat (SH)	*(1.9248)*	*(1.7013)*		

Notes: This table reports the estimation of the systematic liquidity risk premium, where liquidity risk is estimated with the Acharya-Pedersen definition (LIQ^{AP}). Estimations are obtained via the Fama-MacBeth procedure. AVE is the dollar risk and is calculated as the average of the cross-sectional portfolios' monthly excess returns. HML refers to the carry risk factor, which is the return of a strategy long in the high interest rate portfolio and short in the low interest rate portfolio. *t*-statistics corrected with the Shanken (1992) adjustment are reported in brackets below the estimated coefficients. The *p*-values of the $\chi 2$ test of pricing errors jointly zero are adjusted according to Shanken (1992). A constant is included in the cross-sectional regressions, but it is only reported when statistically significant. However, as in Lustig, Roussanov, and Verdelhan (2010), we find that the sensitivities of the portfolios' excess returns to the dollar risk factor are not different from one, so we do not include a constant in the cross-sectional regression of Panel B.

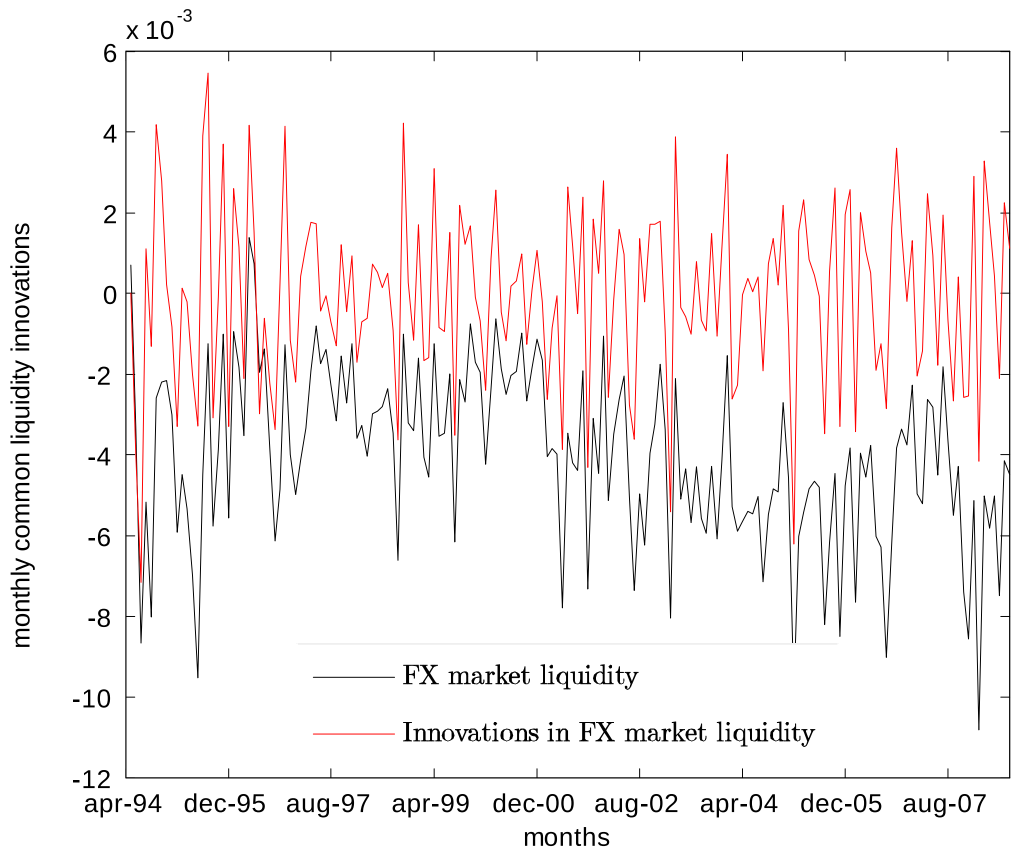

Figure 1: FX market liquidity and its unexpected component.

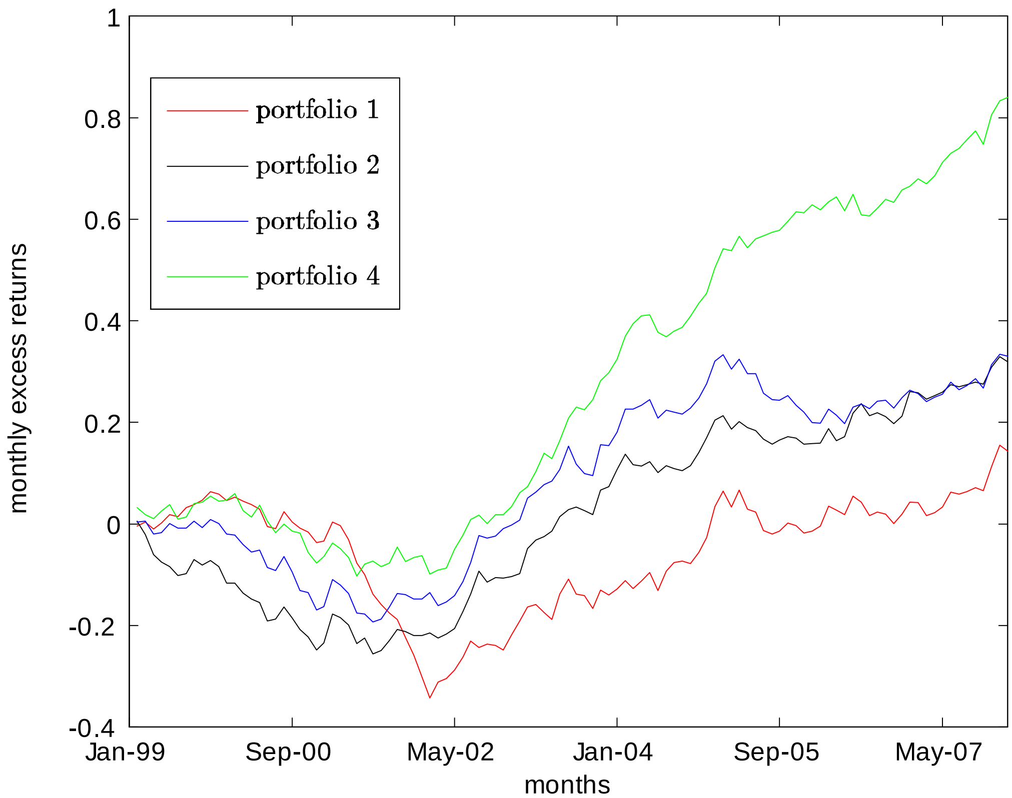

Figure 2: Cumulative excess returns of portfolios.
Notes: Portfolio 1 contains the currencies with the lowest sensitivities to liquidity risk, while Portfolio 4 contains the currencies with the highest sensitivities.