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FUNDING LIQUIDITY RISK AND DEVIATIONS FROM INTEREST-RATE PARITY DURING THE FINANCIAL CRISIS OF 2007-2009

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Abstract

Significant deviations from covered interest parity were observed during the financial crisis of 2007-2009. This paper finds that before the failure of Lehman Brothers the market-wide funding liquidity risk was the main determinant of these deviations in terms of the premiums on swap-implied US dollar interest rates for the euro, British pound, Hong Kong dollar, Japanese yen, Singapore dollar and Swiss Franc. This suggests that the deviations can be explained by the existence and nature of liquidity constraints. After the Lehman default, both counterparty risk and funding liquidity risk in the European economies were the significant determinants of the positive deviations, while the tightened liquidity condition in the US dollar was the main driving factor of the negative deviations in the Hong Kong, Japan and Singapore markets. Federal Reserve Swap lines with other central banks eased the liquidity pressure and reduced the positive deviations in the European economies.

JEL classification: F31; F32; F33
Key words: Sub-prime crisis, funding liquidity, covered interest parity, FX swaps

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EXECUTIVE SUMMARY

- *This paper analyses the impact of the market-wide funding liquidity risk during the financial crisis of 2007-2009 on the money and foreign exchange (FX) swap markets. Uncertainty about losses incurred in banks and banks' deleveraging process increased the liquidity needs of banks as well as their reluctance to lend to each other in the money market. Significant deviations from covered interest parity (CIP) reflected such dislocations in the money and FX-swap markets.*

- *Before the Lehman default, the funding liquidity risk measured by the LIBOR-overnight-index-swap spreads, which was the main determinant of the changes in the CIP deviations for* the euro (EUR), British pound (GBP), Hong Kong dollar (HKD), Japanese yen (JPY), Singapore dollar (SGD) and Swiss Franc (CHF) *could explain for 75% to 80% of the changes. The contraction of non-US banks' balance sheets during their deleveraging process that drove the liquidity down added premiums on the swap-implied US-dollar (USD) interest rate. The existence of this linkage provides evidence about how the funding liquidity conditions across economies determine the corresponding CIP deviations. This evidence supports the rationalisation of CIP deviations offered in terms of the existence and nature of liquidity constraints.*

- *After the Lehman default, both counterparty risk and funding liquidity risk in the European economies were the significant determinants of the changes in the CIP deviations for the EUR, GBP and CHF, that drove up the premiums on the swap-implied US-dollar interest rate. This shows that the turbulence in money markets had spilled over to the FX-swap markets amid a reappraisal of counterparty risks of the US and European banks, resulting in substantial deviations from CIP during this period of the crisis. As European banks needed to secure US-dollar funding to support their US conduits but US banks were cautious in lending to them, forcing the European banks to resort to converting their EUR, GBP and CHF into dollars in the swap market. However, the liquidity injected through Federal Reserve Swap lines with other central banks significantly reduced the premiums.*

- *On the other hand, the tightened liquidity condition in the USD was the main driving factor of the discounts on the swap-implied USD interest rates in the HKD, JPY and SGD. This means that the funding liquidity risk was lower in these three Asian economies compared with that in the US. Counterparty risk was not considered as a concern in the money and FX-swap markets of these economies.*

I. INTRODUCTION

The sub-prime crisis emerged in the United States in mid-2007 and spilled over to Europe and other economies. From mid-2007 to mid-2008, the spillovers were relatively modest. The situation began to change in mid-2008. Following the bankruptcy of Lehman Brothers in mid-September 2008, developments took a dramatic turn for the global financial crisis. One channel for spillovers was severe disruptions in international money markets, especially the US-dollar denominated money markets. Uncertainty about losses incurred in banks and banks' deleveraging process increased the liquidity needs of banks as well as their reluctance to lend to each other in money markets. During this crisis period, banks reportedly faced severe liquidity problems, in particular US-dollar funding shortages, prompting central banks around the world to adopt unprecedented policy measures to supply funds to the banks (see McGuire and von Peter, 2009).

What began as a dollar liquidity problem for European banks has turned into a global phenomenon. Given a structural mismatch in the maturity of US-dollar assets and liabilities, many non-US financial institutions relied heavily on foreign exchange (FX) swap markets to raise dollars using local currencies. FX swap-market premiums rose, as many financial institutions found themselves in a similar position. That is, heightened concerns over liquidity and counterparty risk rationed them out of the dollar cash market, and they all bid for dollars in the swap market. From the beginning of the financial turmoil in August 2007, there emerged a spread between the FX swap-implied dollar rate (across a range of funding currencies) and the corresponding dollar LIBOR rate (see Figure 2 in section II below). This unusual pricing behaviour revealed significant and persistent departure from covered interest parity (CIP). In normal times, this FX-swap spread is efficiently arbitraged and close to zero for most currency pairs, i.e. CIP holds. The differentials imply that the actual costs of dollar funding via the FX-swap market were significantly greater than the posted US-dollar LIBOR benchmark.

There exists a number of studies which report deviations from CIP (see Officer and Willett, 1979 for a survey). The studies attempted to rationalise these departures in terms of political risk, transactions costs, capital market imperfections and data imperfections. A recent study by Baba and Packer (2009a) finds that deviations from the CIP condition in terms of the US-dollar interest rate against the euro during the crisis period from August 2007 to mid-September 2008 are significantly associated with differences in the counterparty risk between European and US financial institutions. This finding is consistent with one possible rationalisation of CIP deviations in terms of the size and extent of credit limits (see Levich, 1985 and Taylor, 1989). According to this rationalisation, a bank determines which other banks it is willing to involve in transactions that entail credit risk, i.e. which banks it is willing to place deposits with and which it is willing to buy and sell foreign exchange with. By assessing the creditworthiness of other banks, the bank determines the maximum size of exposures it is willing to have outstanding with each of them at any point in time. This in effect can operate as a liquidity constraint on covered arbitrage operations.

The liquidity constraint can be tied to financial intermediaries' balance sheets. Adrian and Shin (2008) document that aggregate liquidity can be understood as the rate of growth of the aggregate financial sector balance sheet. When asset prices increase, financial intermediaries' balance sheets generally become stronger, and without adjusting asset holdings, their leverage tends to be too low. The financial intermediaries then hold surplus capital. To utilise such surplus capacity, the intermediaries must expand their balance sheets. On the liability side, they take on more short-term debt. On the asset side, they search for potential borrowers. Aggregate liquidity is intimately tied to how hard the financial intermediaries search for borrowers, including through the interbank market. Conversely, when asset prices decline during a financial crisis, the financial intermediaries' balance sheets contract and they are thus reluctant to lend. Such behaviour reduces their size of exposures to other financial intermediaries. The aggregate liquidity then declines.

When asset prices declined and the balance sheets of banks contracted during the crisis of 2007-2009, banks were reluctant to lend including in the interbank market. This reduced funding liquidity, and required higher risk premium (i.e. higher aggregate price of risk) for lending with longer maturity (say three months or beyond which is more illiquid). Their reluctance to lend to each other in the money market at longer maturity contributed to the substantial rise in spreads between LIBOR and the overnight index swap (OIS) rates in the US , euro area, UK and Japan in August 2007, with the spreads persisting at high levels during the financial crisis in 2007-2009.[1] Figure 1 shows the negative relationship between the leverage of US banks and the spread of three-month US-dollar LIBOR over OIS during 2007-2008.

The purpose of this paper is to investigate whether there has been any link between market-wide funding liquidity risk measured by the LIBOR-OIS spreads and the CIP deviations in terms of the US-dollar (USD) interest rate during the crisis. The currency pairs considered are those between the USD, on the one hand, and the euro (EUR), British pound (GBP), Hong Kong dollar (HKD), Japanese yen (JPY), Singapore dollar (SGD) and Swiss Franc (CHF) on the other. The existence of the linkage will provide evidence about how the funding liquidity conditions across economies determine the corresponding deviations from CIP. This evidence supports the rationalisation of the

[1] An OIS is an interest rate swap in which the floating leg is linked to an index of daily overnight rates. The two parties agree to exchange at maturity, on an agreed notional amount, the difference between interest rate accrued at the agreed fixed rate and interest accrued at the floating index rate over the life of the swap. The fixed rate is a proxy for expected future overnight interest rates. As overnight interest rates generally bear lower credit and liquidity risks, the credit risk and liquidity risk premiums contained in the OIS rates should be small. Therefore, the spread of the three-month interbank rate (LIBOR) relative to three-month OIS rate generally reflects the credit and liquidity risks of the interbank market.

deviations which relies on the existence and nature of credit limits (reluctance to lend) and implicit liquidity constraints as discussed in Taylor (1989).

A related study of deviations of CIP during this crisis is by Baba and Packer (2009a, b). They find that the deviation from CIP in the EUR FX-swap market was due to a reappraisal of counterparty risk based on the data obtained from August 2007 to September 2008. After the failure of Lehman Brothers in September 2008, the deviations from CIP in the EUR, GBP and CHF were negatively associated with the creditworthiness of US financial institutions and also the European institutions, which was consistent with the deepening of a dollar liquidity problem into a global phenomenon. European banks needed to secure USD funding to support their US conduits but US banks were also facing increased financing difficulties and had to preserve funds on hand. Thus, the US banks became cautious in lending to their European counterparts, forcing the latter to resort to converting the EUR, GBP and CHF into dollars in the swap market. In other words, the turmoil feeds through from the money to the swap market. As soon as European banks (borrowers) were perceived to be riskier by US banks (lenders), a risk premium quickly developed, adding to the dollar funding rates in the swap.[2] As distinct from the Baba and Packer's study which focuses on the role of counterparty risk in the CIP deviations, the objective of this paper is to identity how significant the market-wide funding liquidity condition is in explaining deviations from CIP during the crisis. In addition, the paper provides explanation for the deviations from CIP in HKD, JPY, and SGD which showed discounts on the dollar funding rates in the FX swaps after the Lehman default.

The remainder of this paper is organised as follows. The next section describes the derivations from CIP and changes in the LIBOR-OIS spreads during the crisis period. Section III and IV present the data used and model specification to study the impact of market-wide funding liquidity on the deviations and the estimation results. Section V and VI present the analysis of the impact of counterparty risk on the deviations, and the corresponding estimation results. Section VII concludes.

II. COVERED INTEREST PARITY AND LIQUIDITY IN FINANCIAL TURMOIL

The interest parity theory states that the equilibrium forward exchange rate F is:

$$F = \frac{S(1+r)}{(1+q)} \quad , \tag{1}$$

where S is the spot exchange rate (the foreign currency value of a unit of USD), r and q are, respectively, the foreign and USD rates of interest on securities that are identical in all

[2] Their estimations also show that the difference between the LIBOR-OIS (EUR-USD) spreads as a control variable is a significant determinant (with a large coefficient) of the deviation from CIP. This is consistent with the view that the demand for dollar liquidity in FX swap markets surged during the crisis.

respects except for the currency of denomination. The market forward exchange rate F^* gives a swap-implied USD interest rate q^*. Therefore, the return of investing a sum of money in a domestic interest-bearing asset for a certain period of time is the same as the return of investing in a similar foreign interest-bearing asset by converting the sum into a foreign currency while simultaneously purchasing a futures contract to convert the investment back at the end of the period. If the returns are different, an arbitrage transaction could, in theory, produce a risk-free return.

It is important to note that CIP assumes that assets denominated in domestic and foreign currencies are freely traded internationally (i.e. no capital controls) and have negligible transaction costs and similar risks. Given today's market structures and technology, these assumptions normally hold in the international financial markets, and so the parity condition is observed almost all the time (except for those countries where capital controls are still in place). However, there are times and situations in which the condition breaks down. Taylor (1989) finds that during the floating of the sterling in 1972 and the inception of the European Monetary System in 1979, significant departure had occurred from CIP for periods long enough to challenge the theory.[3]

McGuire and von Peter (2009) describe one of the distinct characteristics of this crisis is how the resulting increase in funding liquidity risk in particular USD funding shortages in European banks had paralysed the money market. Many non-US financial institutions relied heavily on FX-swap markets to raise dollars using local currencies. FX swap-market premiums rose as a result of heightened concerns over liquidity and counterparty risk. Figure 2 shows how much the three-month, six-month and 12-month USD funding rate implied from the FX swaps in the EUR, GBP, HKD, JPY, SGD and CHF deviates from the corresponding USD LIBOR – the risk premium ($q^* - q$) demanded by dollar lenders in the swap market or the departure from CIP during 9 August 2007 – 31 March 2009.[4] As can be seen, before Summer 2007 it oscillated around 0% but after then it started to follow an upward trend. Around the beginning of September 2008, it shot up and fluctuated widely. It is interesting to note that the deviations are positive for the EUR, GBP and CHF for most of the time the period, but negative for HKD, JPY and SGD after the Lehman's default in mid-September 2008.

Figure 3 shows how the three-month LIBOR-OIS spreads of the seven currencies studied in this paper have increased since August 2007 and surged with the Lehman default in mid-September 2008. The credit risk associated with OIS contracts is relatively small as they do not involve any principal payment. In addition, the liquidity premiums contained in OIS rates should be very small as these contracts do not involve any initial cash flows. Under normal market conditions, OIS rates tend to be slightly

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3 Other studies attempted to rationalise these departures in terms of transactions costs, e.g. Frenkel and Levich (1977) and Clinton (1988).

4 The data used in this paper are from Bloomberg.

below the corresponding LIBOR. Under a crisis period, the LIBOR-OIS spread is however a good indicator of risk premiums for credit risk and funding liquidity risk.

The LIBOR-OIS spreads indirectly measure the availability of funds in the interbank market. It is generally viewed as reflecting two types of risk. The first is related to liquidity. The spread reflects the different interbank funding costs (the liquidity premiums paid by banks) of term (say three-month) lending and overnight lending rolled over for three months. A second component of the spreads stems from counterparty default risk. Schwarz (2009) constructs new microstructure measures of credit and market liquidity and finds that liquidity effects explain more than two-thirds of the widening of the one- and three-month euro LIBOR-OIS spreads. The finding is consistent with that in McAndrews et al. (2008) who discover that there is a substantial and time-varying liquidity component in LIBOR-OIS spreads. Michaud and Upper (2008) also find a significant role for liquidity in explaining money market spreads. While Taylor and Williams (2009) find that counterparty risk is a key factor in the movements in the term-lending spreads including LIBOR-OIS spreads, they do not rule out that liquidity has been reduced by the increase in counterparty risk since the crisis began. The argument is that banks are reluctant to lend in the interbank market because of the uncertainty about their own future need for funds, perhaps because of concerns about risk in their own balance sheet. In view of these findings, the LIBOR-OIS spreads of an economy's currency should be an appropriate measure and broad representation of the funding liquidity risk in the financial system of the economy which is the main source of funding of its currency.[5]

III. MODEL SPECIFICATION – IMPACT OF MARKET-WIDE FUNDING LIQUIDITY

To test statistically whether the changes (i.e. the first differences) of the LIBOR-OIS spreads of the currencies concerned and the US dollar had effects on the changes of their CIP deviations, we estimate the following regression[6]:

$$\Delta FXdev_t = \alpha + \beta_1 \Delta LSS_t^{FC} + \beta_2 \Delta LSS_t^{USD} + \varepsilon_t , \qquad (2)$$

where

$$FXdev_t = \frac{S_t}{F_t}(1 + r_t) - (1 + q_t) \equiv q_t^* - q_t$$

is the FX-swap spread that represents the premium or discount as reflected in the swap-implied USD funding rate (i.e. the deviation from CIP), LSS_t^{FC} and LSS_t^{USD} are

5 Baba and Packer (2009a,b) use the LIBOR-OIS spread in level to control the funding liquidity conditions in the cash market.

6 The Augmented Dickey-Fuller test suggests that most of the variables are non-stationary in level but stationary in their first-difference form.

the LIBOR-OIS spreads for the foreign currency and USD respectively. If the funding liquidity risk of the banking systems of the economies concerned is a determinant of the FX swaps, the coefficients β_1 and β_2 in Equation (2) should be statistically significant.

Adrian and Shin (2008) propose that contraction of banks' balance sheets will be associated with the banks' reluctance to lend funds in the interbank market (which are unsecured loans) and tighten credit limits to their counterparties because of uncertainty about their own future need for funds, perhaps because of concerns about risk in their own balance sheet. The reluctance of the banks in an economy (say the UK) to lend will drive the funding liquidity down and the LIBOR-OIS spreads in currencies (in particular the GBP) in which the UK banks provide funding will surge.[7] The tightened liquidity in the money markets associated with high LIBORs force the banks to enter into the FX-swap markets to obtain currencies that they need. As the two counterparties in a FX-swap exchange the principals of the two underlying currencies at spot and maturity (see the cash flows in Figure 4), the loss due to default of the counterparty in the swap which is the potential mark-to-market profit is very small compared with an interbank loan.[8] Therefore, FX swaps consume very small amounts of credit limits. If the UK banks need USD funding, the GBP/USD swap market is their only channel. Such demand in USD will push down the forward exchange rate (i.e. its bid price in terms of GBP per USD as denoted in Equation (1)) in the FX swap such that the UK bank will receive less value of GBP at the swap maturity, compared with the value implied from the GBP LIBOR (which is very high due to the tightened or even paralyzed GBP money market). A decrease in the forward rate is equivalent to an increase in the swap-implied USD interest rate provided that the other variables in Equation (1) are kept unchanged. Therefore, the impact of the change in FC LIBOR-OIS spread (LSS_t^{FC}) is positive on the swap-implied USD interest rate spread *FXdev* (i.e. β_1 is positive).

Similarly, an increase in the USD LIBOR-OIS spread indicates that the US banks are reluctant to lend in the interbank market. If they need foreign currencies, they have to enter into FX swaps, that will push the forward exchange rate (i.e. the offer price) up such that their counterparties will receive more value of the foreign currency at the swap maturity, compared with the value implied from the USD LIBOR. An increase in the forward rate is equivalent to a decline in the swap-implied USD interest rate according to Equation (1). Therefore, the impact of the change in USD LIBOR-OIS spread (LSS_t^{USD}) is negative on the swap-implied USD interest rate spread, *FXdev* (i.e. β_2 is negative).

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7 Given the international nature of the main banks contributing to the daily LIBOR survey, increased LIBOR in GBP due to tightened liquidity ought to result in a very similar scale of increases in LIBOR in other currencies.

8 The settlement risk of an FX swap is very small in particular the foreign exchange transactions in the swap are settled on a payment-versus-payment (PvP) basis, which is a mechanism in a foreign exchange settlement system to ensure that a final transfer of one currency occurs only if a final transfer of the other currency or currencies also takes place.

IV. ESTIMATION RESULTS – IMPACT OF FUNDING LIQUIDITY

We use daily nominal exchange rates, interbank interest rates, OIS rates and FX-swap rates of the EUR, GBP, HKD, JPY, SGD and CHF against USD from 9 August 2007 to 31 March 2009 in the estimations.[9] The tenors of the LIBOR-OIS spreads and FX-swap contracts are three months, six months and 12 months. Using principal component analysis, we extract the common movements of the variables in the three tenors. This analysis reduces the observations to principal components that will account for most of the variance in the observed variables without much loss of information. The first principal component is then used for the analysis below.[10] Due to the increasing volatility and the wide-range of unprecedented policy measures after the failure of Lehman, the sample period is split into sub-periods with the first period from 9 August 2007 to 12 September 2008 (pre-Lehman-default period), and the second period from 15 September 2008 to 31 March 2009 (post-Lehman-default period).

Table 1a shows the estimation results for Equation (2) during the period before the Lehman default. The estimated coefficients are reported in bold and the corresponding *p*-values are reported beneath. In the first sample period, the estimated coefficients β_1 and β_2 are statistically significant with the expected signs for all the currencies. For the EUR, GBP, CHF and JPY, the funding liquidity measure explains more than 75% of the movements of the FX-swap spreads, suggesting funding liquidity risk was the major concern at the early stage of the crisis. This strong relationship is also consistent with the observation that many non-US financial institutions relied heavily on the FX-swap markets to raise dollars for their funding needs. Indeed, the estimated results reflect that the FX swaps in these four economies were close substitutes of interbank lending where the high LIBOR rates forced banks to obtain dollar funding from the FX-swap markets. Regarding HKD, the liquidity risk explains about one-half of the changes in its FX-swap spread. The relatively low explanatory power of the funding liquidity measure for the SGD is due to the small changes in its FX-swap spread.

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[9] Following Taylor and Williams (2009), we choose 9 August 2007 to mark the inception of the turmoil, when BNP Paribas frozen redemptions for three of its investment funds.

[10] The first principal component accounts for around 80% to 90% of the variations for the different variables used in the analysis.

During the post-Lehman-default period, Table 1b shows that funding liquidity risk remains an important factor driving the movements of the FX-swap spreads despite the significant fall in explanatory power, where the adjusted R-squared statistics of the estimations for the EUR, GBP, CHF and JPY fall by more than 50% compared with the estimations in Table 1a. The reduction in the explanatory power is partially attributed to the increasing idiosyncratic shocks as a result of the turbulence in the markets and the unprecedented policy measures (i.e. Federal Reserve dollar FX-swap lines that will be discussed below) introduced by central banks during the post-Lehman-default period, in particular the first month of the period.[11] As the Lehman default raised the concern with counterparty risk, the impact of counterparty risk on the CIP deviations is studied in the following two sections. Regarding the HKD and SGD which generally had negative FX-swap spreads after the Lehman default (see Figure 2), the reduction in the explanatory power of the liquidity measure is found to be small compared with those of the other four currencies. This implies that the tightened liquidity condition in USD (where β_2 is negative) was the main driving factor of the discounts on the swap-implied USD interest rate in the HKD and SGD.

As a dollar liquidity problem for European banks turned into a global phenomenon after the Lehman default, the Federal Reserve established dollar swap lines with the Bank of Japan, Bank of England and Bank of Canada on 18 September 2008. On 13 October, the Bank of England, European Central Bank and Swiss National Bank jointly announced that they conducted tenders of US dollar funding with 7-day, 28-day, and 84-day maturities at fixed interest rates for full allotment (i.e. unlimited Federal Reserve dollar FX-swap lines).[12] To capture the impact of these measures of liquidity injection on the FX-swap spreads for the three European currencies and JPY, we re-estimate Equation (2) with a dummy variable "commitment" set to be 1 (and 0 otherwise) at the two announcement dates. As shown in Table 1c, the estimated coefficients are significantly negative with notable additional explanatory power from 6.6% to 24.9% (in terms of the adjusted R-squared). This suggests that Federal Reserve Swap lines with other central banks significantly reduced the FX-swap spreads (i.e. the dollar shortage-related dislocations in the FX-swap markets) in the three European economies and Japan after the Lehman failure.[13]

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[11] Melvin and Taylor (2009) find that measurement errors rose significantly after the Lehman default in terms of the "inside" bid-ask spread in the foreign exchange market. Regarding central banks' policy measures, Baba and Packer (2009b) find that the US dollar term-funding auctions provided by different central banks and the unlimited dollar swap lines committed by the US Federal Reserve have stabilising effect on the CIP deviations.

[12] A timeline of events and policy actions during the financial crisis is documented by the Federal Reserve Bank of St. Louis at http://timeline.stlouisfed.org/.

[13] The impact of the Federal Reserve dollar swap lines with the European Central Bank and Swiss National Bank on the corresponding FX-swap spreads before the Lehman default is found to be insignificant.

V. MODEL SPECIFICATION – IMPACT OF COUNTERPARTY RISK

To identify the attribution of counterparty risk to the deviations from CIP, credit default swap (CDS) spreads are used to measure the default risk of the banks in the US, the euro area, Japan, Switzerland and the UK. The sample of banks with the CDS spreads is given in Appendix A. It is noted that the Hong Kong banks in the sample are international active banks with major market shares in the Hong Kong banking sector and there is only one Singapore bank in the sample. In order to increase the sample of banks for which a counterparty risk measure can be calculated, an alternative default risk measure based on the distance-to-default (DTD) as described in Bharath and Shumway (2008) is used for these two economies. The DTD measure is based on the structural models of credit risk in which default risk of a firm is determined by the firm's asset value and the volatility which can be measured using the firm's stock price.[14] The smaller DTD means higher default risk and the derivation of the DTD is in Appendix B. The financial stock indexes in Hong Kong and Singapore which consist of more financial institutions than those in the CDS market are used for the estimations.

We then estimate the following specification:

$$\Delta FXdev_t = \alpha + \beta_1 \Delta LSS_t^{FC} + \beta_2 \Delta LSS_t^{USD} + \beta_3 \Delta DEF_t^{FC} + \beta_4 \Delta DEF_t^{US} + \beta_5 \Delta VOL_t + \varepsilon_t , \quad (3)$$

where DEF_t^{FC} and DEF_t^{US} are the default risks of foreign banks and US banks respectively, which are the simple averages of the CDS spreads, while VOL_t is the at-the-money foreign exchange option-implied volatility. This variable is included in order to control for the effect of volatility on mark-to-market profits or losses as explained below. These three additional variables are considered to form the counterparty risk as a whole.[15]

It is difficult for a bank with high default risk to borrow in the interbank market. The bank must switch to the FX-swap market in order to obtain the currencies needed. Demand for USD by a non-US (say UK) bank with increased default risk will push down the forward exchange rate (i.e. its bid price in terms of GBP per USD as denoted in Equation (1)) in the FX swap, such that the UK bank will receive less value of GBP at the swap maturity compared with the value implied from the GBP LIBOR. A decrease in the forward rate is equivalent to an increase in the swap-implied USD interest rate provided that the other variables in Equation (1) are kept unchanged. Therefore, the impact of the change in the default risk of a non-US bank is positive on the swap-implied

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[14] Merton (1974) has been the pioneers in the development of the structural models for credit risk of firms using a contingent-claims framework. Default risk is equivalent to a European put option on a firm's asset value and the firm's liability is the option strike. Covrig et al. (2004) use the framework of the structure models to determine the default risk of Japanese banks for the analysis of the Japan premium from 1995 to 2001.

[15] The option data are from JPMorgan Chase.

USD interest rate spread, *FXdev* (i.e. β_3 is positive).

Conversely, demand for foreign currencies by a US bank with increased default risk will push up the forward exchange rate (i.e. its offer price in terms of GBP per USD as denoted in Equation (1)) in the FX swap. Therefore, the impact of the change in the default risk of a US bank is negative on the swap-implied USD interest rate spread *FXdev* (i.e. β_4 is negative). However, in the period of shortage in the dollar, some US banks with high default risk might also need to raise dollar funding through FX swaps. Under the circumstances, the impact of the change in the default risk of a US bank is positive on the swap-implied USD interest rate spread, *FXdev* (i.e. β_4 is positive). The size of the two opposing forces will hence determine the sign of β_4.

In a FX-swap contract, higher volatility of the exchange rate increases the potential mark-to-market profit/loss of the two counterparties in the contract. Therefore, the expected loss due to the default of a counterparty in the FX swap is an increasing function of the volatility of the exchange rate. As the volatility implied from foreign-exchange options captures the size of the expected loss given the default of a counterparty, the impact of ΔVOL_t on the swap-implied USD interest rate spread, *FXdev*, is positive (i.e. β_5 is positive).[16]

VI. Estimation Results – Impact of Counterparty Risk

The attribution of counterparty risk to the FX-swap spreads is studied by comparing the explanatory power of the models in Equations (2) and (3) using their log-likelihood statistics based upon the log-likelihood ratio (LR) test.[17] During the pre-Lehman-default period, the estimation results in Table 2a show that while the counterparty risk is a statistically significant factor driving the FX-swap spreads for the three European currencies, the EUR, GBP and CHF, according to the LR test, its explanatory power is very small.[18] For the other three Asian currencies, counterparty risk was not a significant factor in driving the FX-swap spreads. The estimations based on the

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[16] The expected loss of a forward transaction with expiry at time *t* can be formulated as $q_t \mathrm{E}[\max(f_t,0)]$, where q_t is the default probability of the counterparty, f_t is the value of the forward position at expiry and $\mathrm{E}[\max(f_t,0)]$ is the expected loss given default.

[17] The LR test makes a decision between two hypotheses (H_0 versus H_1) based on the likelihood ratios of the maximum probabilities under these two hypotheses. The LR-test statistic is denoted by: LR = - 2 [log(L_R) - log(L_U)], where L_R and L_U are the likelihood for the restricted and unrestricted specifications. The LR statistic has an asymptotic chi-square distribution with degrees of freedom equal to the number of restrictions (the number of added variables). The 5% and 1% confidence intervals for the chi-square distribution with degree of freedom 3 are 7.82 and 11.35 respectively.

[18] The results are estimated from the changes in the variables. Therefore, they are different from the finding in Baba and Packer (2009a) that the level of the FX-swap dislocation represented the risk premium added amid the reappraisal of counterparty risk of European financial institutions during the crisis.

DTD as a measure of banks' default risk for HKD and SGD in Table 4 give the consistent results.

After the Lehman default, the rising concern about counterparty risk in addition to funding liquidity risk led to further dislocations in the FX-swap market. As suggested by the LR test statistics in Table 2b, the counterparty risk factor is an important determinant of the FX-swap spreads for the three European currencies and JPY during the post-Lehman-default period. In particular, the counterparty risk factor explains the sharp rise in the FX-swap spreads for the three European currencies, with additional explanatory power (in terms of the adjusted R-squared) of 24.9%, 22.3% and 23.6% for the EUR, GBP and CHF respectively. This suggests that after the Lehman default, the deterioration of the creditworthiness of the European banks drove the surge of premiums on their FX-swap implied US-dollar funding costs (see Figure 2). The finding is consistent with that in Baba and Packer (2009b). The impact of counterparty risk is also significant for the JPY with an increase in the explanatory power of 20.9%. However, the impact declined substantially and became insignificant after mid-October 2008 (i.e. a month after the Lehman default). This implies that the effect of default risk of the Japanese banks appeared in a short period time and caused the short-term surge of the FX-swap spread. For the HKD and SGD, the impact of counterparty risk is however very small and similar result is reported in Table 4.

Alternative specifications of Equation (3) are used to analyse the attribution of the individual counterparty risk variables during the post-Lehman-default period and the estimation results are reported in Tables 3a-f.[19] Among the EUR, GBP and CHF, the estimated coefficients of the default risk variables of foreign banks and US banks are significantly positive. This is consistent with the observation that the global US dollar shortage amid the counterparty risk concern forced banks, including US banks (i.e. β_4 is positive), to raise US-dollar funding through the FX-swap markets. In particular, the default risk variables of foreign banks for the three European currencies have significantly larger impact on the FX-swap spreads than that of the US banks (where $\beta_3 > \beta_4$ in Tables 3a-c and the explanatory power is higher by including the foreign bank default risk), indicating that the default risk of the European banks became a determinant of the FX-swap spreads in addition to the funding liquidity risk.

Tables 3d-f show that the tightened liquidity condition in USD was the main driving factor of the discounts on the swap-implied USD interest rate (i.e. negative FX-swap spreads) in the HKD, JPY and SGD after the Lehman default. The impact of the default risk of US banks for the FX-swap spreads in the HKD and JPY is significantly positive but relatively small. This implies that some US banks may raise US-dollar funding through the FX-swap market in the JPY and HKD. Regarding SGD, the default

[19] This exercise can isolate the effects of the potential multi-collinearity among the counterparty risk variables on the estimations.

risk of banks shows insignificant impact on the FX-swap spread.[20]

In summary, counterparty risk did not have any significant effect on the changes in the deviations from CIP before the Lehman default. After the failure of Lehman, the deviations in the EUR, GBP and CHF tended to widen upward when counterparty risk was heightened for the financial institutions in these economies. On the other hand, the deviations in the JPY, HKD and SGD tended to go downward one month after the Lehman default as the funding liquidity in the USD was the main determinant while the attribution of counterparty risk of the financial institutions in these economies were perceived to be low.

VII. CONCLUSION

This paper analyses the impact of the market-wide funding liquidity risk during the financial crisis of 2007-2009 on the money and FX-swap markets. Uncertainty about losses incurred in banks and banks' deleveraging process increased the liquidity needs of banks as well as their reluctance to lend to each other in the money market. This paper finds that before the Lehman default the funding liquidity risk measured by the LIBOR-OIS spreads, which was the main determinant of the changes in the CIP deviations for the EUR, GBP, HKD, JPY, SGD and CHF, could explain for 75% to 80% of the changes. The contraction of non-US banks' balance sheets during their deleveraging process that drove the liquidity down added premiums on the swap-implied USD interest rate. This linkage provides evidence about how the funding liquidity conditions across economies determine the corresponding CIP deviations, which supports the rationalisation of CIP deviations offered in terms of the existence and nature of liquidity constraints.

After the Lehman default, both the counterparty risk and funding liquidity risk in the European economies were significant determinants of the changes in the CIP deviations for the EUR, GBP and CHF, that drove up the premiums on the swap-implied USD interest rate. This shows that the turbulence in money markets had spilled over to FX-swap markets amid a reappraisal of counterparty risks of the US and European banks, resulting in substantial deviations from CIP during this period of the crisis. As European banks needed to secure US dollar funding to support their US conduits while US banks were cautious in lending to them, forcing the European banks to resort to converting their EUR, GBP and CHF into dollars in the swap market, resulting in a rise in risk premiums on the dollar-funding rates for swaps. However, the liquidity injected through Federal Reserve Swap lines with other central banks significantly reduced the premiums. On the other hand, the tightened liquidity condition in USD was the main driving factor of the

[20] We have also employed the DTD measure as the default risk proxy for the EUR, GBP, CHF and JPY instead of the CDS spreads of the selected banks. The estimation results are qualitatively the same as those reported in Tables 3a-d, suggesting the measure is useful in gauging default risk. The estimation results are available upon request.

discounts on the swap-implied USD interest rates in the HKD, JPY and SGD. This means that the funding liquidity risk was lower in these three Asian economies compared with that in the US. Counterparty risk was not considered a concern in the money and FX-swap markets of these economies.

Appendix A: Sample of banks of CDS spreads

Region	Banks
US	Bank of America Corp.
	Citigroup Inc.
	JPMorgan Chase & Co
Eurozone	Deutsche Bank AG
	Rabobank Nederland NV
	WestLB AG
UK	Barclays Bank PLC
	Lloyds TSB Bank PLC
Switzerland	UBS AG
	Credit Suisse Group AG
Japan	Norinchukin Bank
	Bank of Tokyo-Mitsubishi UFJ
	Nomura Holdings Inc.
	Mizuho Financial Group Inc.
Hong Kong	Bank of China Ltd.
	HSBC Bank PLC
	Standard Chartered PLC
Singapore	DBS Bank Ltd.

Note: The sample of banks for the US, the euro area, Switzerland and the UK are the same as that in Baba and Packer (2009b). The tenor of the CDS contracts is five years and the type of protection is senior debt. The data are from Bloomberg.

Appendix B: Derivation of distance-to-default (DTD) measure

In the structural models of credit risk, a firm's asset value V_A is assumed to be governed by the following dynamics:

$$\frac{dV_A}{V_A} = \mu dt + \sigma_A dW_t, \tag{B1}$$

where μ is the expected return of the firm's asset, σ_A is the volatility of the firm's asset value and W_t is a standard Brownian process. The Merton type DTD measure is defined as

$$DTD_t = \frac{\ln\left(\frac{V_A}{D}\right) + \left(\mu - \frac{1}{2}\sigma_A{}^2\right)T}{\sigma_A \sqrt{T}} \quad , \tag{B2}$$

where D is the face value of the firm's debt and T is the time horizon. The DTD measures the difference between the firm's asset value and default threshold D in terms of its volatility. In other words, the lower the DTD, the higher the default risk of the firm is. Following the derivation in Bharath and Shumway (2008), the measure of the DTD is:

$$DTD_t = \frac{\ln\left(\frac{V_E + D}{D}\right) + \left(\mu - \frac{1}{2}\sigma_A{}^2\right)T}{\sigma_A \sqrt{T}}. \tag{B3}$$

where V_E is the firm's equity value. Assuming $V_E < D$ and using the time horizon of one year, Equation (B3) can be expressed according to Taylor expansion as

$$DTD_t = \frac{V_E}{D\sigma_A} + \left(\frac{\mu}{\sigma_A} - \frac{1}{2}\sigma_A\right). \tag{B4}$$

The change in the DTD can then be approximated by

$$\Delta DTD_t \cong \frac{\Delta V_E}{D\sigma_E} \propto \frac{\Delta V_E}{\sigma_E}, \tag{B5}$$

where the changes in D, μ and σ_A are assumed to be relatively slow and the firm's asset volatility can be proxied by its equity volatility. A similar approach was adopted by Corvig et al. (2004) who proxied the aggregate default risk of Japanese banks by using the bank stock index return (ΔV_E) and its volatility (σ_E). The volatility was measured by the conditional variance of the index using a GARCH(1,1) model with a rolling window.

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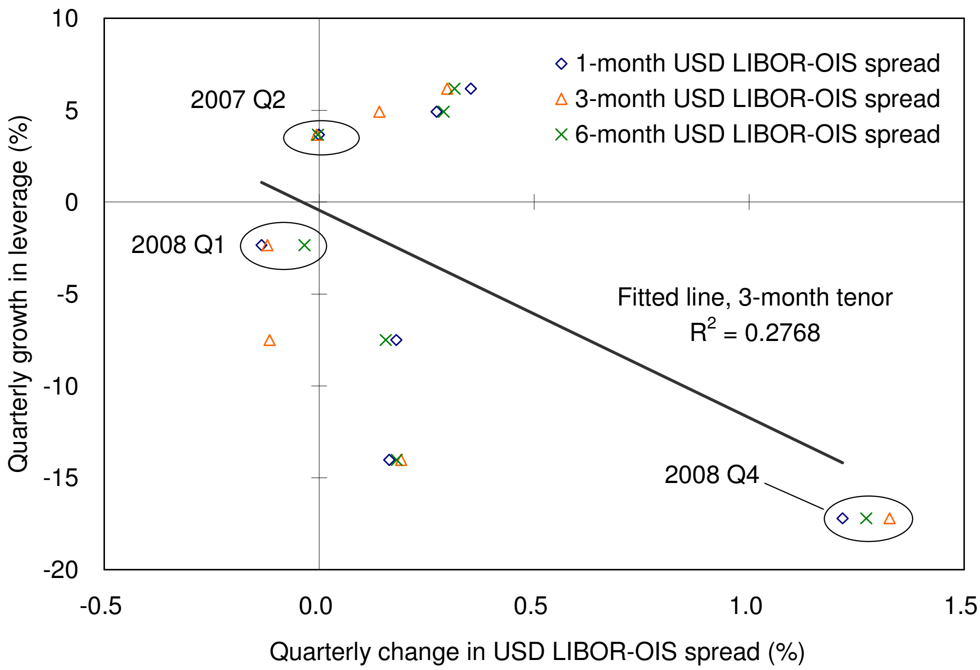
Figure 1: Relationship between leverage of US banks and US dollar LIBOR-OIS spread during 2007 Q2 – 2008 Q4

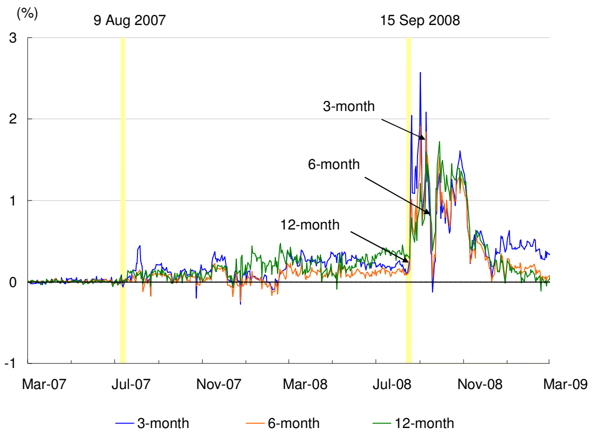


Notes:

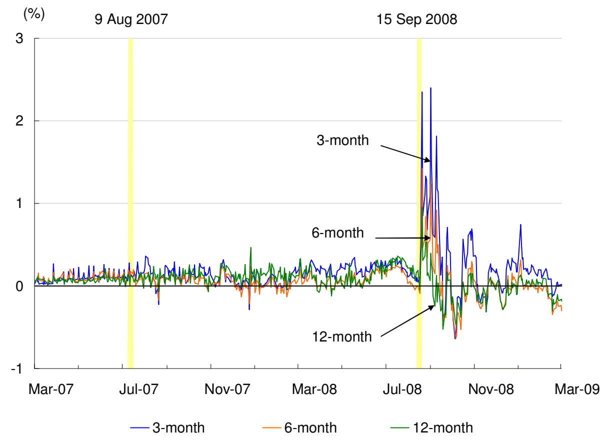
1. The leverage is measured as the average asset-to-equity (book value) ratio of the following banks: Goldman Sachs, Morgan Stanley, Citigroup, Merrill Lynch, Bear Sterns (until 2008 Q1) and Lehman Brothers (until 2008 Q2). The sample of banks is the same as in Adrian and Shin (2008). The data are from Bloomberg.
2. The LIBOR-OIS spread in the chart is the quarterly average figure.

Figure 2: Deviation of FX swap-implied USD funding rate from USD LIBOR

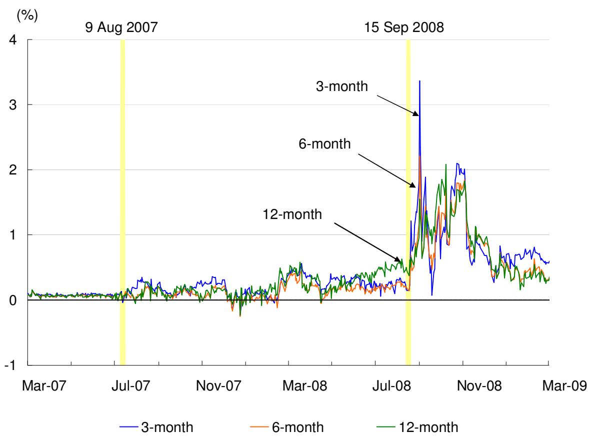
EUR



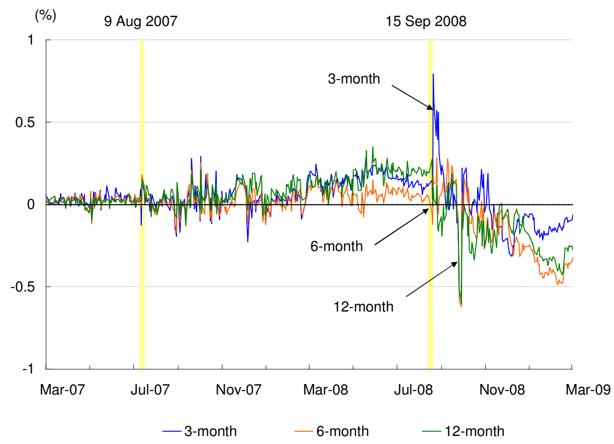
JPY



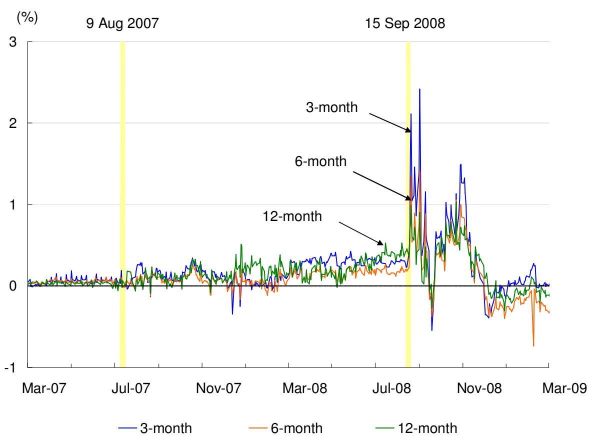
GBP



HKD



CHF



SGD

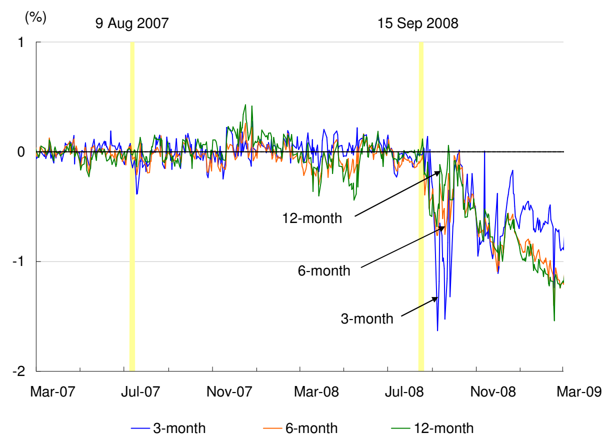
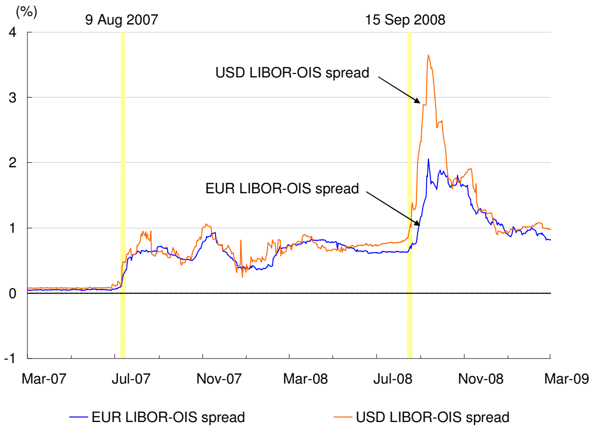
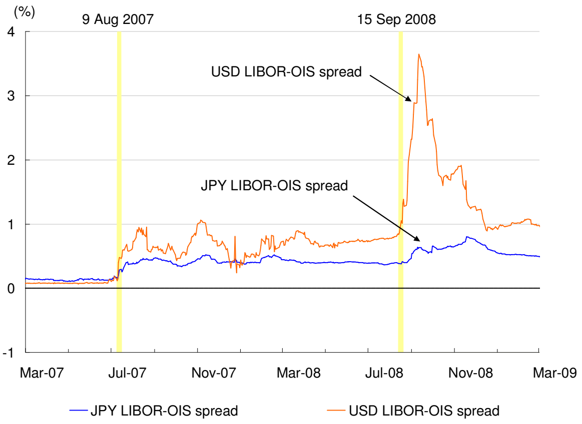


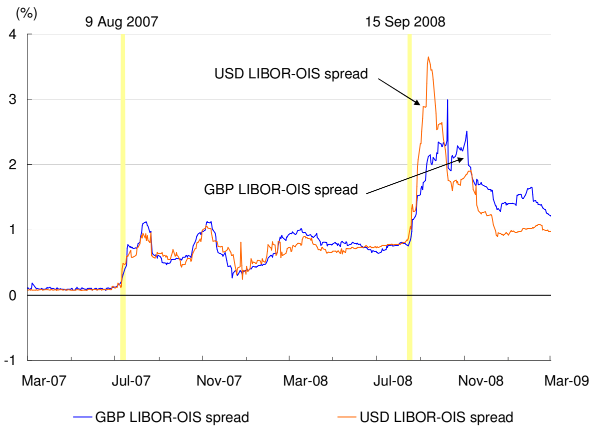
Figure 3: Three-month LIBOR-OIS spreads of different economies

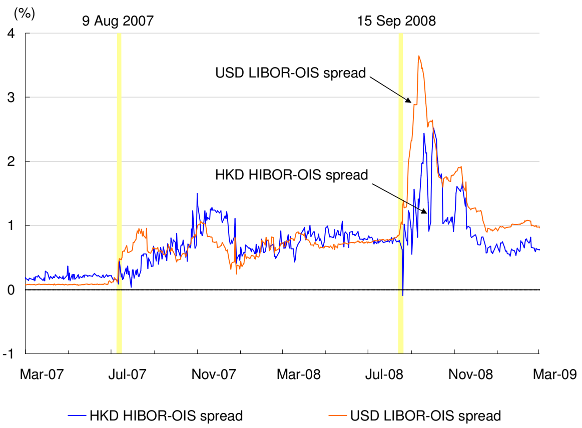
EUR	JPY



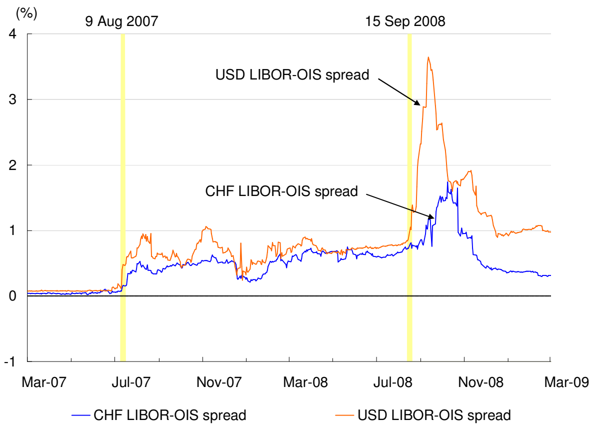


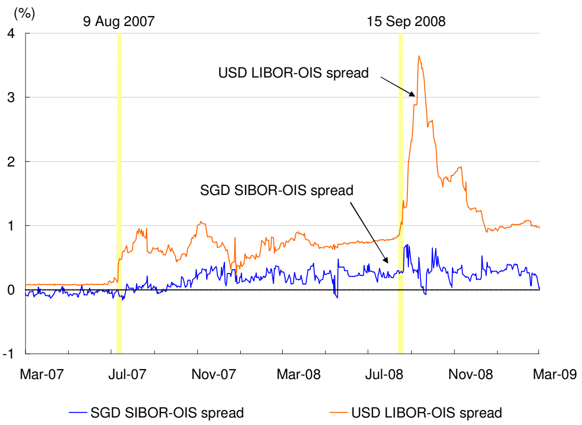
GBP	HKD[1]





CHF	SGD[1]

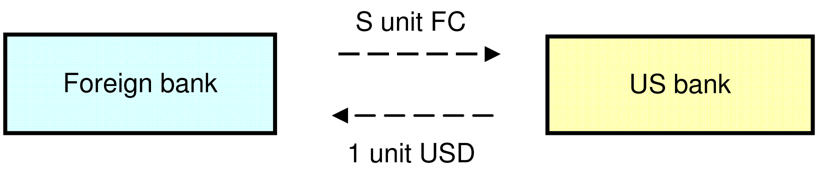




[1] For Hong Kong and Singapore, the interbank rates are Hong Kong Interbank Offered Rate (HIBOR) and Singapore interbank offered rate (SIBOR) respectively.

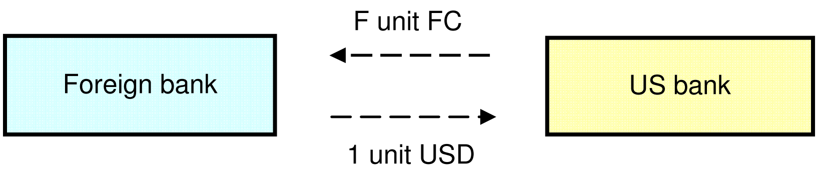
Figure 4: Cash flows of FX-swap transaction

- At initiation of the FX swap contract (t = 0)



S = spot exchange rate (FC/USD)

- At maturity of the FX swap contract (t = T)



F = forward exchange rate (FC/USD)

Table 1a: Relationship between FX-swap spread and funding liquidity measure -
Sample period: 9 August 2007 to 12 September 2008 (before Lehman default)

	EUR	GBP	CHF	JPY	HKD	SGD
FC LIBOR-OIS spread (β_1)	**0.767****	**0.702****	**0.432****	**0.484****	**0.533****	**0.328****
	0.000	0.000	0.000	0.008	0.000	0.001
US LIBOR-OIS spread (β_2)	**-0.773****	**-0.822****	**-0.768****	**-0.771****	**-0.435****	**-0.211****
	0.000	0.000	0.000	0.000	0.000	0.003
Constant (α)	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
	1.000	1.000	1.000	1.000	1.000	1.000
R-squared	75.63%	80.19%	77.74%	75.13%	48.66%	16.65%
Adjusted R-squared	75.44%	80.04%	77.57%	74.94%	48.26%	16.01%
Log likelihood	406.295	417.433	392.917	386.475	285.000	213.566

Table 1b: Relationship between FX-swap spread and funding liquidity measure -
Sample period: 15 September 2008 to 31 March 2009 (after Lehman default)

	EUR	GBP	CHF	JPY(3)		HKD	SGD
				(a)	(b)		
FC LIBOR-OIS spread (β_1)	**1.388****	**1.011****	**1.037****	**1.822**	**-0.782**	**0.289****	**0.455****
	0.000	0.000	0.000	0.399	0.444	0.003	0.003
US LIBOR-OIS spread (β_2)	**-0.591***	**-0.725****	**-0.386**	**-0.171**	**-0.542****	**-0.259****	**-0.238****
	0.076	0.002	0.239	0.632	0.009	0.007	0.024
Constant (α)	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
	1.000	1.000	1.000	1.000	1.000	1.000	1.000
R-squared	19.33%	37.63%	20.54%	1.93%	9.97%	33.11%	14.83%
Adjusted R-squared	18.08%	36.68%	19.30%	0.31%	8.20%	32.04%	13.43%
Log likelihood	-28.759	-30.134	-37.315	-61.043	13.949	66.833	27.356

Notes:
1. The p-value is computed using the White heteroskedasticity-consistent standard error.
2. * and ** indicate significant at 10% and 5% levels respectively.
3. For the JPY, we estimate using two sample periods: (a) 15 September 2008 to 31 March 2009 and, (b) 15 October 2008 to 31 March 2009.

Table 1c: Impact of the US dollar swap-line commitment on the FX-swap spread

Sample period: 15 September 2008 to 31 March 2009 (after Lehman default)

	EUR	GBP	CHF	JPY
FC LIBOR-OIS spread (β_1)	**1.092****	**0.9995****	**0.881****	**0.460**
	0.001	0.000	0.000	0.826
US LIBOR-OIS spread (β_2)	**-0.614***	**-0.838****	**-0.528**	**-0.352**
	0.065	0.000	0.103	0.316
Commitment (dummy variable)	**-0.795****	**-0.845****	**-1.134****	**-1.650****
	0.000	0.000	0.000	0.000
Constant (α)	**0.012**	**0.013**	**0.017**	**0.027**
	0.629	0.616	0.498	0.385
Adjusted R-squared	24.88%	43.24%	32.88%	25.24%
Additional explanatory power	6.80%	6.56%	13.58%	24.93%
Log likelihood	-22.526	-22.298	-24.731	-42.686

Note: As the analysis considers the changes in the FX-swap spreads, the dummy variable commitment is set to be 1 on the dates 19 September 2008 and 14 October 2008, i.e. one day after the announcements of FX-swap facilities with the central banks.

Table 2: Relationship between FX-swap spread with funding liquidity and counterparty risk measures

a.) Sample period: 9 August 2007 to 12 September 2008

	EUR	GBP	CHF	JPY	HKD	SGD
FC LIBOR-OIS spread (β_1)	**0.753****	**0.712****	**0.402****	**0.504****	**0.538****	**0.325****
	0.000	0.000	0.000	0.011	0.000	0.000
US LIBOR-OIS spread (β_2)	**-0.780****	**-0.834****	**-0.767****	**-0.782****	**-0.452****	**-0.216****
	0.000	0.000	0.000	0.000	0.000	0.002
Foreign bank default risk (β_3)	**0.007**	**-0.105**	**-0.040**	**-0.117**	**0.279**	**0.000**
	0.918	0.299	0.500	0.260	0.115	0.811
US bank default risk (β_4)	**-0.178****	**-0.093**	**-0.070**	**-0.042**	**-0.256****	**0.000**
	0.040	0.228	0.406	0.550	0.035	0.829
FX implied volatility (β_5)	**0.017***	**0.004**	**0.032****	**0.007**	**0.033**	**-0.052****
	0.096	0.555	0.000	0.156	0.723	0.020
Constant (α)	**0.001**	**0.001**	**0.000**	**0.000**	**0.000**	**0.000**
	0.846	0.829	0.908	0.906	0.963	0.994
Adjusted R-squared	76.18%	80.44%	78.89%	75.16%	48.91%	16.81%
Additional explanatory power	0.74%	0.39%	1.31%	0.22%	0.66%	0.80%
Log likelihood	411.91	421.64	402.41	389.19	288.18	216.35
LR test	11.23*	8.42*	18.98**	5.44	6.35	5.56

b.) Sample period: 15 September 2008 to 31 March 2009

	EUR	GBP	CHF	JPY(1)		HKD	SGD
FC LIBOR-OIS spread (β_1)	**0.832****	**0.905****	**0.873****	**-0.543**	**-1.562***	**0.297***	**0.458****
	0.009	0.000	0.000	0.785	0.079	0.001	0.004
US LIBOR-OIS spread (β_2)	**-0.468***	**-0.707****	**-0.422***	**-0.242**	**-0.542****	**-0.273****	**-0.181***
	0.072	0.000	0.094	0.406	0.005	0.009	0.078
Foreign bank default risk (β_3)	**0.783****	**1.092****	**1.284****	**1.496****	**0.307**	**-0.056**	**-0.261**
	0.007	0.003	0.001	0.014	0.300	0.803	0.350
US bank default risk (β_4)	**0.149**	**0.083**	**0.074**	**0.449**	**0.023**	**0.128****	**0.109***
	0.174	0.386	0.632	0.112	0.789	0.037	0.092
FX implied volatility (β_5)	**0.067****	**0.046****	**0.026**	**0.030**	**0.039****	**0.218**	**-0.038**
	0.000	0.020	0.169	0.254	0.036	0.153	0.139
Constant (α)	**-0.009**	**-0.008**	**-0.011**	**-0.025**	**-0.002**	**-0.002**	**-0.001**
	0.692	0.695	0.658	0.459	0.903	0.869	0.973
Adjusted R-squared	42.93%	58.93%	42.86%	21.24%	15.16%	38.26%	16.29%
Additional explanatory power	24.85%	22.25%	23.56%	20.93%	6.95%	6.22%	2.86%
Log likelihood	-3.350	0.422	-13.153	-44.879	19.652	74.531	31.013
LR-test	50.82**	61.11**	48.32**	32.33**	11.41**	15.40**	7.31

Notes:

1. For JPY, the two sample periods adopted are: (a) 15 September 2008 to 31 March 2009 and, (b) 15 October 2008 to 31 March 2009.
2. The LR test compares the extended specification of Equation (3) with Equation (2).

Table 3a: Estimation result for the EUR (after Lehman default)

	(i)	(ii)	(iii)	(iv)	(v)
FC LIBOR-OIS spread (β_1)	**0.832****	**1.225****	**1.225****	**1.333****	**1.388****
	0.009	0.000	0.000	0.000	0.000
US LIBOR-OIS spread (β_2)	**-0.468***	**-0.615****	**-0.630****	**-0.558***	**-0.591***
	0.072	0.015	0.012	0.088	0.076
Foreign bank default risk (β_3)	**0.783****	**0.841****	**0.946****		
	0.007	0.003	0.000		
US bank default risk (β_4)	**0.149**	**0.151**		**0.474****	
	0.174	0.185		0.000	
FX implied volatility (β_5)	**0.067****				
	0.000				
Constant (α)	**-0.009**	**-0.009**	**-0.007**	**-0.009**	**0.000**
	0.692	0.688	0.763	0.711	1.000
R-squared	45.11%	40.12%	39.44%	28.45%	19.33%
Adjusted R-squared	42.93%	38.24%	38.02%	26.77%	18.08%
Log likelihood	-3.350	-9.087	-9.834	-20.841	-28.759
LR test	50.82**	39.34**	37.85**	15.84**	

Table 3b: Estimation result for the GBP (after Lehman default)

	(i)	(ii)	(iii)	(iv)	(v)
FC LIBOR-OIS spread (β_1)	**0.905****	**0.987****	**0.986****	**1.015****	**1.011****
	0.000	0.000	0.000	0.000	0.000
US LIBOR-OIS spread (β_2)	**-0.707****	**-0.707****	**-0.708****	**-0.710****	**-0.725****
	0.000	0.000	0.000	0.002	0.002
Foreign bank default risk (β_3)	**1.092****	**1.218****	**1.266****		
	0.003	0.000	0.000		
US bank default risk (β_4)	**0.083**	**0.066**		**0.446****	
	0.386	0.487		0.001	
FX implied volatility (β_5)	**0.046****				
	0.020				
Constant (α)	**-0.008**	**-0.009**	**-0.008**	**-0.009**	**0.000**
	0.695	0.686	0.720	0.728	1.000
R-squared	60.47%	58.32%	58.22%	43.69%	37.63%
Adjusted R-squared	58.93%	57.03%	57.26%	42.39%	36.68%
Log likelihood	0.422	-3.124	-3.287	-23.288	-30.134
LR test	61.11**	54.02**	53.69**	13.69**	

Table 3c: Estimation result for the CHF (after Lehman default)

	(i)	(ii)	(iii)	(iv)	(v)
FC LIBOR-OIS spread (β_1)	**0.873****	**0.935****	**0.926****	**1.066****	**1.037****
	0.000	0.000	0.000	0.000	0.000
US LIBOR-OIS spread (β_2)	**-0.422***	**-0.441***	**-0.446***	**-0.369**	**-0.386**
	0.094	0.077	0.071	0.249	0.239
Foreign bank default risk (β_3)	**1.284****	**1.331****	**1.400****		
	0.001	0.000	0.000		
US bank default risk (β_4)	**0.074**	**0.073**		**0.499****	
	0.632	0.643		0.022	
FX implied volatility (β_5)	**0.026**				
	0.169				
Constant (α)	**-0.011**	**-0.011**	**-0.010**	**-0.010**	**0.000**
	0.658	0.648	0.673	0.727	1.000
R-squared	45.05%	44.29%	44.16%	29.32%	20.54%
Adjusted R-squared	42.86%	42.52%	42.84%	27.65%	19.30%
Log likelihood	-13.153	-14.057	-14.214	-29.649	-37.315
LR test	48.32**	46.52**	46.20**	15.33**	

Table 3d: Estimation result for the JPY (after Lehman default)[1]

	(i)	(ii)	(iii)	(iv)	(v)
FC LIBOR-OIS spread (β_1)	**-1.562***	**-0.931**	**-0.934**	**-0.796**	**-0.782**
	0.079	0.363	0.360	0.432	0.444
US LIBOR-OIS spread (β_2)	**-0.542****	**-0.541****	**-0.548****	**-0.527****	**-0.542****
	0.005	0.011	0.008	0.011	0.009
Foreign bank default risk (β_3)	**0.307**	**0.479**	**0.512***		
	0.300	0.148	0.091		
US bank default risk (β_4)	**0.023**	**0.037**		**0.079**	
	0.789	0.692		0.379	
FX implied volatility (β_5)	**0.039****				
	0.036				
Constant (α)	**-0.002**	**-0.004**	**-0.003**	**-0.001**	**0.000**
	0.903	0.854	0.869	0.946	1.000
R-squared	19.24%	12.19%	12.09%	10.49%	9.97%
Adjusted R-squared	15.16%	8.68%	9.48%	7.83%	8.20%
Log likelihood	19.652	15.263	15.198	14.252	13.949
LR test	11.41**	2.63	2.50	0.61	

[1] The sample period for JPY in the Table 3d is from 15 October 2008 to 31 March 2009.

Table 3e: Estimation result for the HKD (after Lehman default)

	(i)	(ii)	(iii)	(iv)	(v)
FC LIBOR-OIS spread (β_1)	**0.297****	**0.309****	**0.307****	**0.305****	**0.289****
	0.001	0.002	0.003	0.002	0.003
US LIBOR-OIS spread (β_2)	**-0.273****	**-0.280****	**-0.288****	**-0.273****	**-0.259****
	0.009	0.006	0.006	0.003	0.007
Foreign bank default risk (β_3)	**-0.056**	**0.067**	**0.225**		
	0.803	0.762	0.305		
US bank default risk (β_4)	**0.128****	**0.140****		**0.150****	
	0.037	0.024		0.015	
FX implied volatility (β_5)	**0.218**				
	0.153				
Constant (α)	**-0.002**	**-0.004**	**-0.003**	**-0.003**	**0.000**
	0.869	0.764	0.830	0.806	1.000
R-squared	40.69%	36.58%	34.14%	36.50%	33.11%
Adjusted R-squared	38.26%	34.52%	32.55%	34.97%	32.04%
Log likelihood	74.531	70.246	67.832	70.170	66.833
LR test	15.40**	6.82*	2.00	6.67**	

Table 3f: Estimation result for the SGD (after Lehman default)

	(i)	(ii)	(iii)	(iv)	(v)
FC LIBOR-OIS spread (β_1)	**0.458****	**0.484****	**0.485****	**0.451****	**0.455****
	0.004	0.001	0.001	0.003	0.003
US LIBOR-OIS spread (β_2)	**-0.181***	**-0.193***	**-0.199****	**-0.236****	**-0.238****
	0.078	0.050	0.045	0.025	0.024
Foreign bank default risk (β_3)	**-0.261**	**-0.525****	**-0.478****		
	0.350	0.004	0.008		
US bank default risk (β_4)	**0.109***	**0.086**		**0.060**	
	0.092	0.186		0.350	
FX implied volatility (β_5)	**-0.038**				
	0.139				
Constant (α)	**-0.001**	**0.002**	**0.003**	**-0.001**	**0.000**
	0.973	0.931	0.863	0.945	1.000
R-squared	19.67%	17.85%	17.07%	15.22%	14.83%
Adjusted R-squared	16.29%	15.12%	15.01%	13.12%	13.43%
Log likelihood	31.013	29.618	29.023	27.649	27.356
LR test	7.31	4.52	3.33	0.59	

Table 4: Estimation results for the HKD and SGD using DTD as default risk measure for Hong Kong banks and Singapore banks

	Before Lehman default		After Lehman default	
	HKD	SGD	HKD	SGD
FC LIBOR-OIS spread (β_1)	**0.534****	**0.324****	**0.300****	**0.428****
	0.000	0.000	0.000	0.003
US LIBOR-OIS spread (β_2)	**-0.440****	**-0.216****	**-0.278****	**-0.203***
	0.000	0.002	0.002	0.058
Foreign bank default risk (β_3)	**0.009**	**-0.010**	**0.002**	**-0.182**
	0.715	0.851	0.977	0.352
US bank default risk (β_4)	**-0.120**	**0.015**	**0.121****	**0.087**
	0.198	0.890	0.042	0.161
FX implied volatility (β_5)	**0.055**	**-0.054****	**0.213**	**-0.058****
	0.552	0.019	0.179	0.001
Constant (α)	**0.000**	**0.000**	**-0.002**	**-0.006**
	0.923	0.981	0.845	0.742
R-squared	49.22%	18.39%	40.64%	20.39%
Adjusted R-squared	48.21%	16.80%	38.21%	17.05%
Log likelihood	286.408	216.338	74.479	31.582
LR test	2.82	5.54	15.29**	8.45*