Dynamic Cross-currency Linkages of the LIBOR-OIS Spreads

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Abstract

This article examines the dynamic linkages of the LIBOR-OIS spreads in major currencies. We consider daily data for the period of March 1, 2006 to Nov 12, 2008. The Dynamic Conditional Correlation model is employed to study the impact of the global financial crisis on the cross-currency correlations of the spreads. The overall evidence suggests that the crisis has changed the degree of money market integration of the Euro and the Sterling with the US dollar, but exercised a limited impact for the Australian dollar. Japanese Yen appears to be insulated from the US dollar shortage shocks throughout the periods. In addition, the FX swap market liquidity plays an important role in explaining the market integration, while the credit worthiness difference between the LIBOR panel banks is a less significant factor.

JEL classifications: G15; C32
Key Words: Global financial crisis, LIBOR-OIS spreads, Dynamic conditional correlation model

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1. Introduction

The Global Financial Crisis has exerted an immense impact on financial sectors as well as real economies around the world. Governments have taken unprecedented interest rate cuts and implemented various individual and/or joint financial facilities in response to the turbulence in financial markets. For example, the Federal Reserve established the Term Auction Facility (TAF) to inject liquidity into the interbank markets and facilitated the Dollar Liquidity Swap Lines and Foreign-Currency Liquidity Swap Lines with other international monetary authorities.[1] A primary policy objective of these facilities is to mitigate financial stress in the US interbank markets and often the stress is measured by the spread between the London Interbank Offer Rate and the Overnight Indexed Swap (LIBOR-OIS, henceforth). Consequently, the spread has received a great deal of attention from academic literature and practitioners.

An issue to note is that in the literature there has been an ongoing debate over whether the spread should be regarded as the measure of credit risk or liquidity stress. A number of authors have put forward competing arguments and evidence. Bank of England (2007) reported that the estimate of credit risk based on the Credit Default Swaps (CDS) prices explicates a considerable portion of the persistence in the spread data for the recent periods since October 2007. Also Brunnermeier (2009) advocates credit risk reasoning that the LIBOR-OIS has the same structure as a widely adopted credit risk measure, TED spread, because a relatively secured lending cost (OIS) is subtracted from an unsecured one (LIBOR) in its construction. Taylor and Williams (2008, 2009) agree to support the credit risk in a series of articles. Regression results from Taylor (2009) show that an interbank market credit

[1] See, for details, Credit and Liquidity Programs and the Balance Sheet, Board of Governors of the Federal Reserve System at http://www.federalreserve.gov/monetarypolicy/bst.htm.

risk measure, the LIBOR-REPO (government-backed repurchase agreements) spread, accounts for a large proportion of deviations in the LIBOR-OIS spread. Some of these arguments are clearly defensible but deserve further considerations nevertheless. For example, it is not entirely compelling that the LIBOR-OIS spread is the sole measure of credit risk because its movement is well explained by the LIBOR-REPO. Both spreads share the LIBOR which is an interbank unsecured rate; hence may contain either credit, liquidity, or both risks. The OIS and the REPO, as secured lending exposed to minimal risk, would be expected to behave in a similar way due to their inherent nature.[2] Figure 1 depicts times series data for the OIS and the REPO in the past few years. Both track each other very closely and their correlation is 0.99. In other words, both measures, the LIBOR-OIS and the LIBOR-REPO, seem to have almost the same risk components so that one should easily explain the other. The high correlation between the two risk measures simply originates from the comovement of the OIS and REPO.

In fact there is a stream of literature which studied the role of the LIBOR-OIS as liquidity stress measure. Imakubo et al (2008) documented that the widening of the LIBOR-OIS spread during the global financial crisis is mainly driven by liquidity stress based on decomposition estimates from the Credit Default Swap (CDS) data. McAndrews et al. (2008) and Sarkar (2009) also note that the spread contains both credit and non-credit risk components. Similarly, Kwan (2009) conducted a regression analysis of the LIBOR-OIS spread on the CDS and found that more than fifty percent of the variation in the spread is not explained by the credit risk proxy, which means that other factors, most likely the liquidity premium, are certainly at work. In principle these liquidity favouring results are not immune

[2] Both the REPO and OIS are hardly viewed to contain credit and liquidity risks due to its collateralizing aspects.

to criticism because credit and liquidity risk are entwined (von Thadden, 1999).[3] For instance, credit risk can cause liquidity risk through adverse selection in the money market. In the context of the financial crisis, McAndrews et al. (2008) raised an issue that the CDS may have been subject to liquidity stress in early 2008 when the CDS market became highly illiquid. The CDS prices of the LIBOR panel banks' may have been affected by liquidity risk or *vice versa*. To address this issue more formally, Schwarz (2009) proposed to use alternative credit and liquidity measures based on microstructure data and concludes that liquidity plays a major role in explaining the soaring of the spread. In short, given that there is no hard evidence for one measure against the other, these previous studies would suggest that the spread certainly contains both forms of financial stress in the interbank market.

Another avenue of academic research surrounding the spread is the cross-currency linkages of financial stress over the course of the financial crisis. Imakubo et al. (2008) offered summary evidence on the cross-currency interdependence between the spreads in the US dollar, Euro and Yen in a Vector-Autoregressive (VAR) framework. Ji and In (2010) took a more formal estimation approach to the issue using bias-corrected bootstrap in the VAR and Vector Error Correction (VEC) models, and cointegration test for the LIBOR-OIS spreads in a wider range of currencies; namely, the US dollar, Euro, Sterling, Yen and the Australian dollar. The empirical findings from these articles can be summarised as the following: (1) financial stress shocks due to the US dollar shortage ignited stress in other major currencies throughout global money markets, resulting in increased market integration. (2) It appears that Japanese Yen played a significant role of liquidity provider in money markets. (3) The liquidity search via Yen involved transactions between the interbank money markets and

[3] Nonetheless, Schwarz (2009) notes that there exist possible cases of liquidity shock which do not incur the credit tiering or easing.

Foreign Exchange (FX) swap markets.

However, the estimates from the VAR and VEC models are essentially time-invariant and would deliver rather limited information about the dependence structure when the structure change over time as is the case with the global financial crisis. Since Aug 2008, a number of episodes have occurred; the collapses of Lehman brothers and Bear Sterns, just to name a few, subsequently followed by various policy responses. It is plausible that the impact of the market events and policy shocks on the cross-currency correlations of the money market stress differs depending on the nature of the shocks. Also the VAR and VEC models are useful in examining the interactions between the level data but ignore the volatility spillover effects.

In the present article we employ the Dynamic Conditional Correlation (DCC) model[4] to examine the impact of the global financial crisis on time-varying correlations of the LIBOR-OIS spreads in the Euro (EUR), Sterling (GBP), Yen (JPY) and the Australian dollar (AUD) with the US dollar (USD). That is, we consider the correlations between each non-USD and USD LIBOR-OIS spreads since the turbulence in money markets largely stems from the US dollar shortage. The higher the correlation is, the stronger market integration ought to be. In addition, we test the correlations to ascertain whether the crisis brought permanent effects to the degree of integration. To this end, a unit root test with structural breaks is conducted on the correlations to account for the shocks from the commencement of the crisis and Lehman Brothers default.

In the following part of the article, we extend the scope of our study to the FX swap markets.

[4] See, for details of the model, Engle (2002)

If a bank is confronted with the US dollar shortage, there would be two main funding channels; borrowing directly from the money market or borrowing foreign currencies and then converting them into the US dollar through FX swap contracts. As mentioned above, one of the findings from Imakubo et al. (2008) is the relevance of the FX swap markets to the cross-currency linkages of the LIBOR-OIS spreads because their evidence suggests that the dollar funding was sought via Yen through the FX swap contracts.[5] We relate to the time-varying correlations the FX swap market liquidity condition and the credit worthiness difference between LIBOR penal banks. We attempt to enlighten on the contributions of these two liquidity and credit variables to the explanation of the cross-currency market integration.

We offer several findings in the present article. The LIBOR-OIS correlations of the Euro, Sterling and the Australian dollar with the US dollar became stronger and more volatile as the crisis unfolded; the degree of integration increased between the US dollar and the other currencies. In a stark contrast, the correlation between the Yen and the US dollar stayed relatively stable throughout the sample periods, which indicates that the Yen was independent of the US dollar shocks. This is consistent with the past findings from Imakubo et al. (2008), and Ji and In (2010). Also having accounted for structural changes in the sample periods, we find that the Australian dollar received a limited impact from the US dollar shocks, which supports the generally accepted view that the Australian market fared better the financial

[5] In fact the interaction between the FX swap and money market transactions have been of interest to several other authors.[5] For example, Baba et al. (2008) noted that FX swap market became quite volatile as money market turbulence commenced at the beginning of the crisis. Baba and Packer (2009a; 2009b) found the pre and post crisis spillover effects from money markets on the FX swap deviation from the Covered Interest Rate Parity for the Euro against the dollar. The same authors (2009b) argued that the USD LIBOR-OIS spread is a determinant of the common factor of the deviations in the Euro, Franc and Sterling when they studied the impact of Lehman Brothers default in an Exponential General Autoregressive Conditional Heteroskedasticity (EGARCH) framework. Genberg et al. (2009) is another example where the FX swap market is introduced as a relevant funding source to study the effect of LIBOR-OIS difference between currencies on the deviation.

crisis.[6] Lastly, liquidity condition in the FX swap markets is a significant factor for the money market integration for the US dollar during the crisis, Euro and Sterling, whereas credit factor plays a less evident role.

The article proceeds as follows: Section 2 describes the methodologies. Section 3 presents the data and findings. Concluding remarks are made in Section 4.

2. Methodologies

The DCC model assumes that a vector of series is conditionally multivariate normally distributed with zero expected value and covariance matrix H_t.[7] We employ auto-regressive (AR) filter to demean the LIBOR-OIS spreads as follows:

$$R_{i,t} = \mu_i + \gamma_i R_{i,t-1} + \varepsilon_{i,t} \qquad \varepsilon_{i,t} \sim N(O, H_t) \tag{3}$$

where $R_{i,t}$ is the LIBOR-OIS spread in each currency and μ_i is the unconditional mean. The AR filter is used to extract zero mean residuals and the lag order is selected as unity for the parsimonious reason. $\varepsilon_{i,t}$ is a residual for the spread *i*, which follows the normal distribution. The zero-mean residuals are then modelled by bivariate DCC-GARCH (1,1).

$$H_t = Q_t^* P_t Q_t^* \tag{4}$$

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[6] See, for example, Rozhkov (2008) has reported that Australian banks were mildly exposed to the US subprime related assets and the securitization of mortgage-related assets was not popular in Australia. D'Aloisio (2009) also points out that a combination of factors such as resource boom, policy coordination and stringent prudential regulations, played a role against the crisis.

[7] Engle and Sheppard (2001) note that the residuals from the AR filter do not have to follow multivariate normal distribution for consistent and asymptotic normal estimators.

where Q_t^* is a diagonal matrix of time-varying standard deviations and P_t is the conditional correlation matrix. The log-likelihood of this estimator is the following

$$\mathrm{L} = \left[-\frac{1}{2} \sum_{\mathrm{t}=1}^{\mathrm{n}} \{ \mathrm{k} \log(2\pi) + \log(|H_t|) + \varepsilon_t' H_t^{-1} \varepsilon_t \} \right] + \left[-\frac{1}{2} \sum_{t=1}^{n} \{ \log|P_t| + \overline{\varepsilon}_t' P^{-1} \overline{\varepsilon}_t - \overline{\varepsilon}_t' \overline{\varepsilon}_t \} \right]$$

$$\overline{\varepsilon}_{i,t} = \frac{\varepsilon_{i,t}}{\sqrt{h_{i,t}}} \text{ , } h_{i,t} = w_i + \sum_{j=1}^{p} \alpha_{i,j} \varepsilon_{i,t-j}^2 + \sum_{j=1}^{q} \beta_{i,j} h_{i,t-j}$$

where $\overline{\varepsilon}_{i,t}$ is a standardized residual and $h_{i,t}$ is a time-varying conditional variance. To ensure the stationary condition for the GARCH process, we impose the non-negativity restriction on coefficients and $\sum_{j=1}^{p} \alpha_{i,j} + \sum_{j=1}^{q} \beta_{i,j} < 1$. For the DCC modelling, the following structure is suggested by Engle (2002).

$$Q_t = \left(1 - \sum_{j=1}^{s} a_j - \sum_{i=1}^{u} b_i \right) \overline{P} - \sum_{i=1}^{u} b_i Q_{t-i} + \sum_{j=1}^{s} a_j (\overline{\varepsilon}_{t-j} \overline{\varepsilon}_{t-j}') \tag{5}$$

$$P_t = Q_t^{*-1} Q_t Q_t^{*-1} \tag{6}$$

where $\overline{P}$ is the unconditional covariance matrix from the standardized residuals and P_t is the conditional correlation matrix.

3. Data and the Empirical Findings

We use three-month maturity LIBOR-OIS spreads and the FX swap rates from Bloomberg in daily frequency for the period of March 1, 2006, to November 12, 2008. The currencies of our interest are the Australian dollar (AUD), Sterling (GBP), Euro (EUR), Japanese Yen (JPY), and the US dollar (USD). These currencies represent a variety of funding sources, from major currencies for international financial institutions to less traded ones.

[Insert Figure 2 about here]

[Insert Table 1 about here]

Since August 9, 2007, the LIBOR-OIS spreads have become exceedingly volatile and shown a strong sign of comovement. (See Figure 2) It is also noteworthy that the Yen hiked less than the others after the Lehman Brothers bankruptcy September 2008. Table 1 reports summary statistics of the spreads. Panel A is for the pre-crisis period and Panel B for the crisis period. The Yen exhibits the largest mean and variance in the pre-crisis period; however, this is reversed in the crisis period, meaning that the Yen money market underwent less stress in the crisis. The Australian dollar shows similar resilience with the lowest mean and median in the pre-crisis period and the second lowest in the crisis period. According to the Jarque-Bera and ARCH tests, the AR filter residuals appear non normal and conditionally heteroskedastistic, which justifies the DCC model.

[Insert Table 2 about here]

The DCC Model

Table 2 presents the estimates from the DCC-GARCH (1,1) model where we examined pairs of the LIBOR-OIS spreads in the US dollar and every other currency. Looking at the first two rows, all the individual series shows persistence in variance but the conditional covariance structures of the examined pairs are not entirely the same. From the large size of b over 0.9, the covariances of EUR-USD, GBP-USD and AUD-USD are quite significantly dependent on their own past covariance, whereas the coefficient on the past covariance is smaller at 0.6 and relatively less significant for the JPY-USD pair. This evidence of the Yen's weaker persistence coincides with what Imakubo et al. (2008), and Ji and In (2010) documented on the Yen.

[Insert Figure 3 about here]

Figure 3 depicts the time-varying conditional correlations of the non-US LIBOR-OIS spreads with the US dollar spread. In each graph, the first vertical line corresponds to Aug 9 2007, the beginning of the crisis, and the second to September 15 2008, the bankruptcy of Lehman Brothers.[8] Clearly, the crisis period appears more volatile than the pre-crisis period for all spreads except the Yen. The crisis period correlations of the Euro and the Sterling with the US dollar are noticeably higher than pre-crisis, suggesting that the linkage in financial stress between these currencies became stronger in the crisis. Although this phenomenon seems less evident for the AUD-USD pair, their correlation is still of higher and persistent degree during the crisis period. Despite the occasional abrupt peaks, however, the Yen and US dollar pair is markedly tranquil as well as low around 0.1 throughout. This evidences the isolation of the Yen. The yen money market, unlike the other currencies, effectively absorbed the shocks from the dollar money market.

[8] The shaded area is the interval between the first and second structural breaks detected by a unit root test with structural breaks (See, for details, Lumsdaine and Papell, 1997). More discussions on the test results are provided subsequently.

The Unit Root Test with Structural Breaks for the Correlations

To examine further the impact of the crisis on the integration of the money markets, we conduct unit root tests on the time-varying correlations.[9] Under the normal market condition where money markets assimilate external shocks effectively, the impact would not significantly alter its relation with other money markets sustaining the correlation stationary. On the other hand, as the integration heightens under distressed operation, the correlation would exhibit non-stationarity averting from the mean. However, unit root tests could misleadingly diagnose the correlation as non-stationary when the data is in fact regime-wise stationary with the crisis-induced breaks. Further, if the correlation is tested regime-wise stationary rather than stationary, it would indicate that the crisis had a limited force on the stress linkage.

We adopt Lumsdaine and Papell test (LP test, hereafter) which allows for two data-dependent breaks; possibly associated with the onset of the crisis and Lehman Brothers default in our case.[10] The LP test specification is presented as follows:

$$\Delta y_t = c + \pi t + \theta T_1 + \omega T_2 + \varphi y_{t-1} + \sum_{i=1}^{k} \delta_i \Delta y_{t-i} + \varepsilon_t \tag{7}$$

where y_t is the correlation of the LIBOR-OIS spreads, c a constant and t the trend in a series. T_1 and T_2 are dummy variables for the mean shift at the first break point and the second break point, respectively.

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[9] Some may argue it may be inappropriate to examine the stationarity of the correlation series given that they are bounded between negative unity and positive unity. However, the data is not a historical series and may temporarily behave non-stationary.

[10] See, for further details, Lumsdaine and Papell (1997)

[Insert Table 3 about here]

[Insert Table 4 about here]

Before proceeding to the LP test, we conduct the Kwiatkowski-Phillips-Schmidt-Shin test[11] for the full sample periods to obtain an overview of the data.[12] Table 3 shows that the null of stationarity is rejected at the 5% significance level for all the correlations except the JPY-USD. The full sample period stationarity of JPY-USD provides a confirming result for the insulation of the Yen.

The LP test results are reported in Table 4 where the test statistics, denoted by φ, indicate that the EUR-USD and GBP-USD are non-stationary but AUD-USD and JPY-USD stationary when the structural breaks are allowed. The crisis stroke the Euro and Sterling averting their integrations with the US dollar from the mean. Contrarily, it appears that market integration between the Australian and US dollars has been moderately affected as well as the JPY-USD pair. However, the fact that the test statistic for the AUD-USD is less significant than the JPY-USD pair implies the Yen's stronger isolation. As Imakubo et al (2008), and Ji and In (2010) observed, the shielding effect of the Yen may be due to its better liquidity position. Mild exposure to subprime-related assets is another strength of the Yen. It has been widely reported that Japanese financial institutions held less toxic US assets.[13]

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[11] See Kwiatkowski et al. (1992)

[12] Our preliminary analysis has included the Augmented Dickey-Fuller and Phillip-Perron tests, and they show quantitatively similar results.

[13] The International Monetary Fund Survey Magazine (2009), among many references, notes that Japan's limited international financial integration stems from no direct exposure to toxic US assets. The Bank of Japan (2010) also reports that the Asia-Pacific banks held less the US and European financial assets.

The structural breaks are identified close to the actual events. The shaded area in Figure 3 is the interval between the first and second breaks estimated by the LP test. The first break for the EUR-USD, GBP-USD, and AUD-USD is all detected near the eruption of the financial crisis, 9 August 2007, while the second comes near the Lehman Brothers default. In particular, the demise of the major head figure institution in global banking concurs with the sudden rise of the correlation. For the Euro, the correlation for EUR-USD jumps as high as Aug 2007. The Lehman incident brought the integration between the Euro and the US dollar a shock as powerful as the outbreak of the crisis in 2007. The Sterling and Australian dollar even encountered the most intense integration with the US dollar at the collapse. On the other hand, a closer look at the JPY-USD pair tells that the Yen took a distinctive path again with the structural breaks. The first break is right before the onset of the crisis but the second occurs immediately after the Black Monday, 21 January 2008, when most stock markets around the world suffered a drastic plunge. The JPY-USD correlation was accelerated by the stock market crash, while a sharp decline is observed for the other currencies at the same point of time in the figure.[14] On the other hand, it seems that the JPY-USD experiences a drop and the others pairs vertically soar at the fall of Lehman Brothers, corroborating the negative association between the Yen and the other currencies. Ji and In (2010) have previously attested to the easing of the US dollar, Euro, Sterling and the Australian dollar money markets accompanied by a rise in tension of the Yen market, which coincides with this observation. Based on the impulse response estimates these authors argue that the negative association between the Yen and the other currencies signifies the conversion of the Yen borrowing to the counterpart currencies through the FX swap contracts. Our findings lend support to Ji and In (2010) in that the Yen liquidity alleviated the stress in the other currencies in the face of the

[14] Jan 21, 2008 is unmarked except for the Yen in Figure 3 to avoid confusion, but scrolling up to the other currencies in the figure it is manifestly clear to see the Euro, Sterling and Australian dollars dived on the day.

major episodes during the crisis.

Credit deterioration, liquidity impairment and the FX swap markets

As mentioned in the foregoing discussions, which risk between credit and liquidity risk or to what extent a risk as opposed to the other, is manifested in the LIBOR-OIS spread is an unsettled issue. It is fair to pose the analogous question to the cross-currency time-varying correlations of the LIBOR-OIS as well. To gain insight into this we regress the correlations on the quoted bid-ask spreads of the FX forward discount rates and the CDS spread differentials between the USD and non-USD LIBOR penal banks for each currency.[15] The forward discount bid-ask spread measures the liquidity condition in the FX swap market,[16] while the CDS spread differential gauges the difference in the credit worthiness perceptions of the major participating financial institutions between the USD money market and non-USD market.[17]

The latter can be a good proxy for credit deterioration in the non-USD market relative to the USD market. We hypothesise that the CDS differentials ought to have explanatory power of the correlations of the LIBOS-OIS spreads if the correlation is the indicator of the credit risk integration between the USD market and the non-USD. This is because, faced with the difficulties in borrowing the US dollar due to the credit deterioration in the US dollar money market, the institutions will switch to borrow the non-USD currency and convert it to the US dollar through the FX swap contracts. Subsequently, although the total demand for and

[15] Because our preliminary analysis suggests that these regressors are I(0), we do not have an issue of the spurious regression.
[16] Bid-Ask spread = $2(P_{ask,i} - P_{bid,i})/(P_{ask,i} + P_{bid,i})$ where P is the price of the contract, which is used as the standard price metric for the FX swaps. See, for example, Baba et al. (2008).
[17] CDS spread differential is the difference between the average CDS prices of USD and non-USD LIBOR penals.

supply of the non-USD currency will be eventually cleared in the entire markets, the supply of the non-USD currency will contract in the non-USD money market at least in the short-term.[18] In short, the strain in the US dollar money market reaches the non-USD markets through a credit risk channel. An increase in the CDS differentials would lead to higher correlations.

The forward discount bid-ask spread is used as a regressor to account for the effects of the liquidity hoarding in the FX swap markets on the correlations.[19] Since the FX swap market is one of the most closely linked funding outlets to the money market, the liquidity measure of the FX swap market may help examine how the liquidity condition affected the market integration between the USD and non-USD money markets. Imakubo et al (2008) found from the impulse response estimates in a VAR estimation of the FX implied rate and LIBOR that not only spillover effects from the USD money market to the Euro and Yen FX swap markets but the reverse causality existed in the converse direction during the crisis.[20] In their exposition of the reverse causality, the authors argued that once the FX swap market has become impaired in liquidity by the liquidity seeking banks who resorted to the FX swap contracts borrowers would increase the direct US dollar funding in the money market by paying additional premium and lenders would shift the loans from the US dollar market to the

[18] Imakubo et al. (2008) argue that such upward pressure on the non-USD market can be caused by the mismatch of the terms and instruments. For example, when the borrowing institutions are eagerly seeking a non-USD currency in the money market, their counterparties of 3 month FX transactions may want to lend in the overnight repo market to avoid credit and liquidity risk.

[19] Some may argue that the forward discount bid-ask spread is not the perfect measure of the liquidity shock to the money markets because it does not directly measure the liquidity in the money markets. While we agree with this argument, we also contend that the past finding from Imakubo et al (2008) that the liquidity impairment of the FX swap market affected the US dollar money market provides some endorsement of the bid-ask spread as a, though not entirely satisfactory, useful measure of the liquidity shock relevant to the money markets in the context of the crisis.

[20] A preliminary analysis of our data confirmed the strong reverse causality for the Euro and Yen, and weaker degree of the reversal for the Sterling. The Australian dollar failed to show statistically significant reverse causality. However, the statistical insignificance was not robust to the alternative lag choices. Cholesky ordering (from USD LIBOR, JPY FX implied rate, EUR FX implied rate, GBP FX implied rate, through to AUD FX implied rate) was used. The overall results of the impulse response were robust to other orderings.

FX swap market. They also note that the reverse course of the liquidity shock from the FX swap market to the USD money market may signal non-US banks liquidity shortage. Consequently, the more this USD liquidity shock is propagated through to the non-USD market, the higher the correlation will be. Positive coefficient on the forward discount bid-ask spreads would suggest that the market integration is intensified by the liquidity shock.

Before running the regression, we conducted the subsampling version of the penal unit root test (Im, Peseran and Shin test, 2003) that takes explicit account of cross-sectional dependence to ensure that all the variables as a penal are stationary. This version of the test has been proposed by Choi and Chue (2007) to better suit cross-sectionally dependent data. Since the correlation, the FX forward discount bid-ask spread and the CDS differential are likely to be contemporaneously correlated, the subsampling version was adopted. As reported in Table 5, the null of unit root is rejected for all cases.

The regression is then run and Table 6 reveals that the liquidity impairment in the FX swap markets was more influential on the cross-currency linkage in the crisis than the prior period except for the Yen. Forward bid-ask spread is significant only for AUD-USD in the pre-crisis period, while it becomes strongly significant for EUR-USD and GBP-USD as well in the crisis. Positive signs on the bid-ask spreads entail that the liquidity shocks drove up the degree of integration between USD and non-USD money markets as the market situation escalated.

The CDS differentials tell a somewhat different story. For the Euro, the creditworthiness difference shows up as a significant factor in the crisis period, which may indicate that the credit deterioration in the USD market relative to the Euro market hastened the integration between the dollar and Euro markets. However, the CDS differential became less significant in the crisis for the Sterling and the Australian dollar than the pre-crisis period. These results downplay the credit factor for these two currencies. The JPY-USD correlation appears independent of the liquidity and credit variables, except that the credit factor is weakly significant and is in minor magnitude of the coefficient size before the crisis. Also R^2 is negligibly small for both periods, which suggests that the Yen was insulated; therefore, the currency was not subject to the same factors as the other currencies.

Some caution may be necessary to interpret the results for the pre-crisis period because R^2 is quite low for the period. However, the explanatory power of the dependent variables substantially increases for the crisis period. Also we calculated the marginal contributions of the CDS differential to R^2 for each equation to measure the explanatory power of the variable. They only amount to 0.020, 0.012, 0.016 and 0.002 for the Euro, Sterling, Australian dollar and the Yen, respectively, confirming the more pronounced role of the bid-ask spread as an explanatory variable.

For the sign of the coefficients, most of the other liquidity and credit factors are positive but the sign of the credit factor for the Australian dollar is negative. However, the negative coefficients for AUD-USD are small-scale for both periods compared to the others.

In summary, we learned that the liquidity factor played an important role in driving up the cross-currency market integration and the credit factor shows a weaker capacity in explaining the integration during the crisis. The results for the Yen provide little support for these factors.

4. Conclusion

This article examines the impact of the global financial crisis on the Dynamic Conditional Correlation (DCC) by studying the time-varying correlations between each non-USD and USD LIBOR-OIS spreads; viz, the Euro, Sterling, Yen and the Australian dollar with the US dollar. The high the correlation estimates indicate that the crisis has induced stronger market integration. Further, the correlations are tested by a unit root test with structural breaks to take account of the shocks from the commencement of the crisis and Lehman Brothers default. As the past findings suggested that financial intuitions attempted to secure the US dollar funding through the FX swap transactions as an alternative to the money market during the crisis, we resort to the FX swap market liquidity condition and the credit worthiness difference between LIBOR penal banks as explanatory source of the correlation movements.

The following findings are offered in the article. The LIBOR-OIS correlations of the Euro, Sterling and the Australian dollar with the US dollar became stronger and more volatile as the crisis unfolded; the degree of integration increased between the US dollar and the other currencies. By contrast, the correlation between the Yen and the US dollar stayed relatively stable, which is indicative of the Yen's independence of the US dollar shocks. Also the Australian dollar apparently received a moderate impact from the US dollar shocks, supporting the view that the Australian market was relatively resilient to the financial crisis. Lastly, liquidity condition in the FX swap markets is a significant factor for the money market integration for the US dollar during the crisis, Euro and Sterling, whereas credit factor played a less evident role.

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Table 1 Summary Statistics of LIBOR-OIS Spreads

Table 1: Summary Statistics of LIBOR-OIS Spreads

	USD	EUR	GBP	AUD	JPY
Panel A. Pre-crisis period					
Mean	0.08	0.05	0.09	0.01	0.12
Median	0.08	0.05	0.09	0.01	0.13
Maximum	0.18	0.12	0.20	0.08	0.19
Minimum	0.01	0.03	-0.07	-0.08	0.03
Std. Dev.	0.01	0.01	0.02	0.02	0.03
Skewness	1.09	2.17	-1.86	-1.04	-0.62
Kurtosis	9.27	14.19	27.69	5.68	3.25
Jarque-Bera	670.68*	2186.88*	9461.87*	175.486*	24.53*
Panel B. Crisis period					
Mean	0.91	0.73	0.86	0.54	0.43
Median	0.73	0.64	0.76	0.43	0.4
Maximum	3.64	2.05	2.98	2.42	0.66
Minimum	0.24	0.18	0.25	0.09	0.19
Std. Dev.	0.64	0.34	0.46	0.41	0.06
Skewness	2.6	2.04	1.9	2.46	1.21
Kurtosis	9.14	6.84	6.47	8.67	5.13
Jarque-Bera	868.99*	421.63*	356.03*	755.04*	140.67*
Residual Diagnostics from AR estimation : Entire period					
Normality	8611.529*	40226.770*	745129.400*	19321.710*	6286.414*
ARCH	28.506*	52.593*	21.963*	171.764*	8.168*
Auto	57.634*	48.444*	45.549*	35.911*	2.857
Adjusted R^2	0.990	0.994	0.986	0.986	0.994

- “*” indicates the significance of the coefficients (or rejection of the null hypothesis) at 5% level.
- Normality is the Jarque-Bera test for the normality of residuals
- ARCH is the Lagrange multiplier test for ARCH(4) model applied to residuals
- Auto is the Ljung-Box test for no serial correlation applied to the residuals with lag 4

Table 2 AR (1) – DCC (1,1) – GARCH (1,1)© model

$$R_{i,t} = \mu_i + \gamma_i R_{i,t-1} + \varepsilon_{i,t}$$

$$h_{i,t} = w_i + \alpha_i \varepsilon^2_{i,t-1} + \beta_i h_{i,t-1}$$

$$Q_t = \left(1 - a - b\right)\overline{P} - bQ_{t-1} + a(\overline{\varepsilon}_{t-1}\overline{\varepsilon}'_{t-1})$$

	EUR	GBP	AUD	JPY
a	0.028***	0.033***	0.003	0.016
	(2.806)	(2.891)	(1.118)	(0.940)
b	0.961***	0.911***	0.995***	0.601*
	(61.599)	(36.328)	(200.28)	(1.778)
μ	0.001***	0.001*	0.000	0.000
	(3.118)	(1.774)	(0.575)	(0.815)
γ	0.979***	0.986***	0.991***	0.998***
	(627.869)	(351.141)	(214.587)	(439.013)
α	0.135***	0.462***	0.863***	0.160***
	(7.114)	(7.923)	(59.149)	(6.597)
β	0.864***	0.537***	0.137***	0.839***
	(45.499)	(9.201)	(9.358)	(34.503)
μ_{USD}	0.001***	0.001***	0.001***	0.001**
	(3.569)	(2.826)	(2.368)	(2.432)
γ_{USD}	0.985***	0.99***	0.993***	0.993***
	(322.793)	(346.833)	(381.579)	(391.196)
α_{USD}	0.743***	0.728***	0.730***	0.722***
	(42.857)	(39.953)	(39.429)	(38.171)
β_{USD}	0.256***	0.270***	0.270***	0.277***
	(14.82)	(14.851)	(14.611)	(14.688)

- "*", "**" and "***" indicate the significance of the coefficients (or rejection of the null hypothesis) at 10%, 5% and 1% level respectively.
- The t-statistics are in parentheses.

Table 3 Kwiatkowski-Phillips-Schmidt-Shin Test

	KPSS test statistic			
	Intercept only		Intercept and trend	
	Level	First Difference	Level	First Difference
EUR	1.366***	0.048	0.115	0.048
GBP	0.736**	0.048	0.092	0.033
AUD	1.162***	0.404*	0.447***	0.062
JPY	0.280	0.070	0.088	0.070

- The sample period is from March 1, 2006 to Nov 12, 2008.
- "*", "**" and "***" indicate the significance of the coefficients (or rejection of the null hypothesis) at 10%, 5% and 1% level respectively.

Table 4 Lumsdaine and Papell Test

$$\Delta y_t = c + \pi t + \theta T_1 + \omega T_2 + \varphi y_{t-1} + \sum_{i=1}^{k} \delta_i \Delta y_{t-i} + \varepsilon_t$$

	EUR-USD	GBP-USD	AUD-USD	JPY-USD
TB1	19-Jul-07	29-Jun-07	25-Jul-07	9-Aug-07
TB2	22-Aug-08	12-Sep-08	12-Sep-08	22-Jan-08
φ	-0.048	-0.073	-0.070**	-0.320***
	(-4.706)	(-4.817)	(-6.511)	(-15.947)
θ	-0.025	-0.026	0.000	0.349
	(-0.756)	(-0.773)	(0.952)	(23.964)
ω	0.023	0.013	-0.000*	-0.001
	(-3.420)	(1.882)	(-6.089)	(-0.590)
lag order	6	1	7	0

- The critical values are -6.94 (1%), -6.24 (5%) and -5.96 (10%).
- The t-statistics are in parentheses.
- "*", "**" and "***" indicate the significance of the coefficients (or rejection of the null hypothesis) at 10%, 5% and 1% level respectively.

Table 5 The Supsampling Version of the Im-Pesaran-Shin Test

	Test Statistics	Critical Values
EUR	-3.91**	-3.82
GBP	-5.65**	-4.92
AUD	-5.11**	-4.60
JPY	-6.45**	-4.90

- The sample period is from March 1, 2006 to Nov 12, 2008.

Table 6 Regression of Time-Varying Correlation on Forward Discount Bid-Ask Spread and CDS Differential

Dependent Variables	EUR-USD	GBP-USD	AUD-USD	JPY-USD
Pre-crisis period: 2 Mar 2006 - 8 Aug 2007				
C	0.002	0.080***	0.159***	0.106***
	(0.023)	(10.733)	(41.931)	(56.415)
Forward Bid-Ask Spread	-79.616	21.900	79.656***	18.063
	(-0.887)	(0.595)	(8.130)	(1.646)
CDS Differential	0.047	0.027***	-0.006**	-0.007*
	(1.031)	(2.725)	(-2.194)	(-1.755)
R^2	0.005	0.027	0.154	0.027
In-crisis period: 9 Aug 2007 - 12 Nov 2008				
C	0.257***	0.132***	0.239***	0.116***
	(14.191)	(9.852)	(97.183)	(35.514)
Forward Bid-Ask Spread	527.317***	380.926***	27.121***	-3.464
	(5.790)	(6.194)	(4.781)	(-0.446)
CDS Differential	0.025***	0.007*	-0.000*	-0.000
	(3.741)	(1.957)	(-1.838)	(-0.896)
R^2	0.353	0.144	0.228	0.003

- The t-statistics are in parentheses.
- "*", "**" and "***" indicate the significance of the coefficients (or rejection of the null hypothesis) at 10%, 5% and 1% level respectively.

Figure 1 Three Month Maturity OIS and REPO

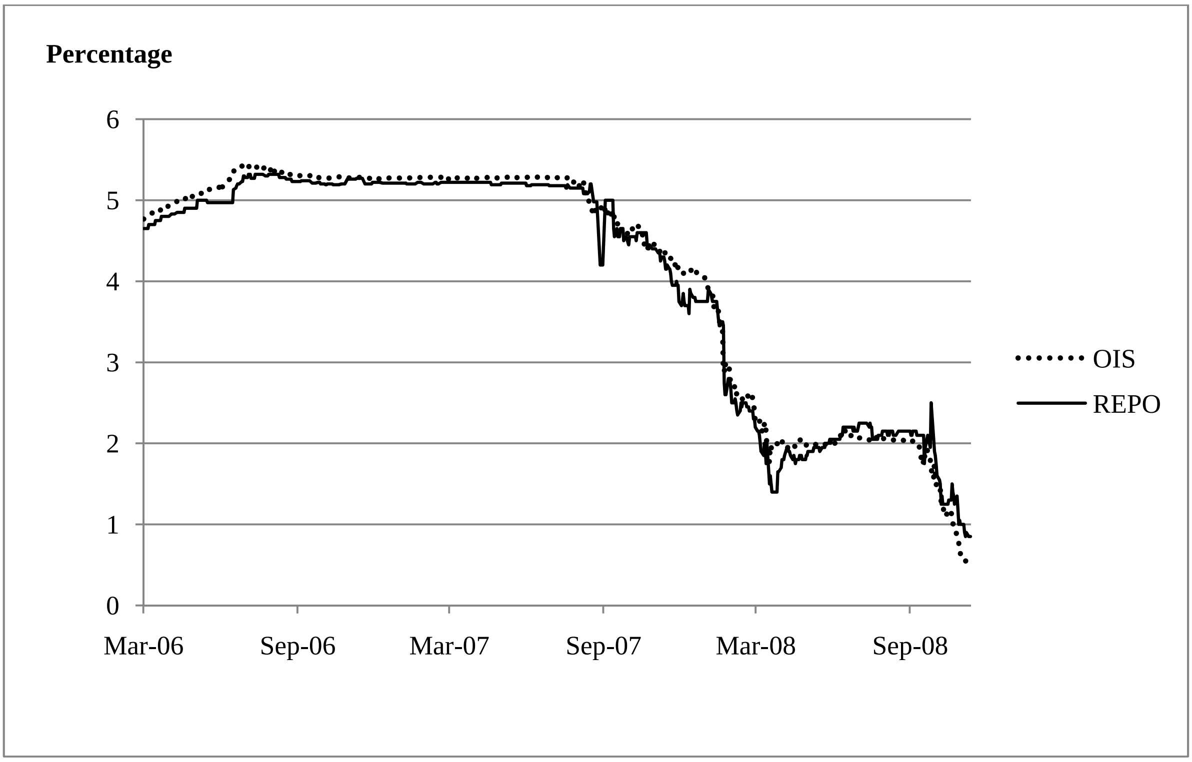

Figure 2 LIBOR-OIS spreads

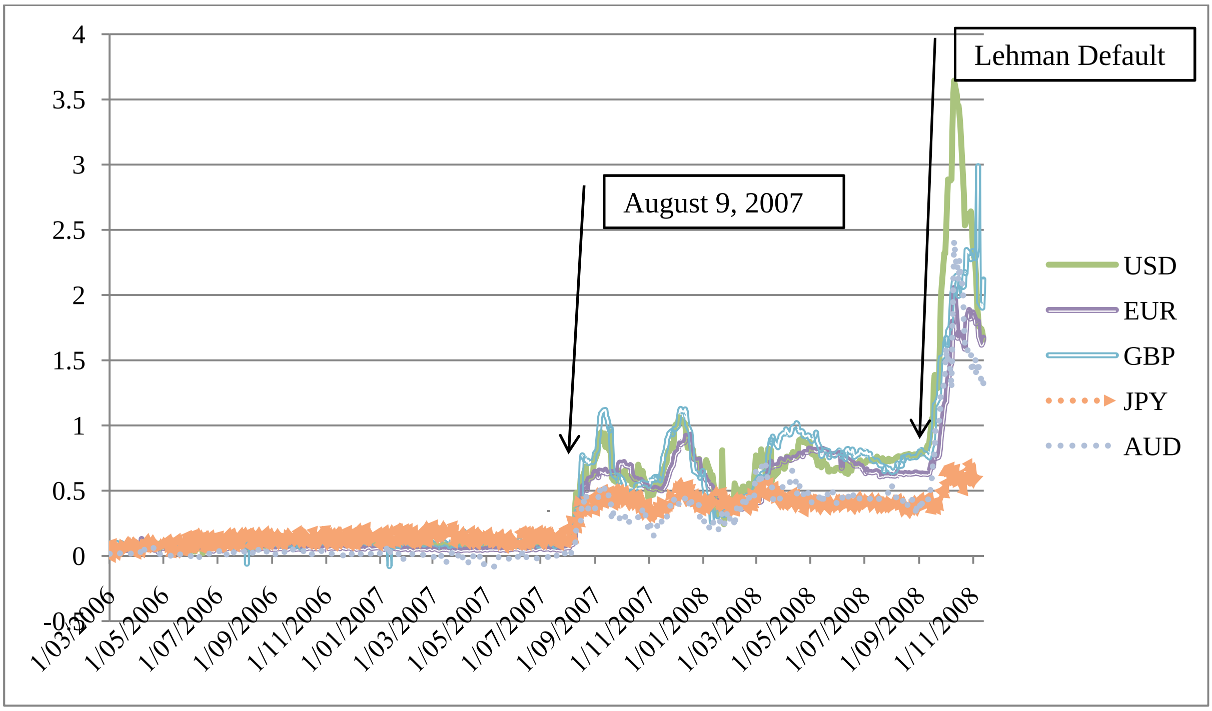

Figure 3 The time-varying correlation