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A STUDY ON THE TRANSMISSION OF MONEY MARKET TENSIONS IN EMEAP ECONOMIES DURING THE CREDIT CRISIS OF 2007 – 2008

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Abstract

The recent tension in the interbank markets following the global financial crisis has raised concerns about the turbulence in interbank markets. This paper utilises two widely used indicators for measuring interbank stress (the interbank rate less the Overnight Index Swap rate and the interbank rate less the yield of government securities) to examine the transmission of interbank tension from the US dollar to nine interbank markets in the EMEAP economies. Using a vector autoregression model, we show that during the credit crisis of 2007 – 2008, the distress in the US dollar money market had a material impact with durations of seven to 13 days on the interbank markets for the Hong Kong dollar, Japanese yen, Australian dollar and New Zealand dollar. Moreover, based on a bivariate regime switching ARCH model, we also find evidence of volatility co-movement between the interbank stress indicator of the US dollar and that of the Hong Kong dollar, Japanese yen, Australian dollar, New Zealand dollar, Korean won and Singapore dollar during the crisis. The expected duration when two money markets are both in a high-volatility state is estimated to be as long as seven days. The short-lived impact on the EMEAP economies from a shock in the US dollar money market can be attributed to the policy actions taken by central banks and monetary authorities in the region and the coordinated efforts by policy makers worldwide to contain the credit crisis.

JEL Classification Numbers: E50, E58, G15

Keywords: Interbank stress; Vector autoregression; Regime-switching ARCH

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Executive Summary:

- *Global money markets have been under extremely tight funding conditions since the second half of 2007. The unprecedented spread of interbank rates over policy rates for major currencies after the Lehman Brothers incident in September 2008 has raised concerns over the turbulence in interbank markets and how the distress in one economy's money market transmits to other money markets.*

- *To understand the transmission of distress in interbank markets, we examine the interaction of two commonly used indicators for measuring interbank stress ((1) the spread between the 3-month interbank rate and the Overnight Index Swap rate, as well as (2) that between the 3-month interbank rate and the yield of 3-month government securities) in the empirical work. Nine interbank markets in the EMEAP economies and the US dollar from January 2007 to mid-February 2009 are included in the study.*

- *Using a vector autoregression model and a regime-switching ARCH model, we investigate how the distress in the US dollar money market affects the region's interbank markets, in terms of their distress levels and volatilities based on these two indicators. The empirical results suggest that the shocks from the US-dollar money market had a material impact on the interbank markets for the Hong Kong dollar, Japanese yen, Australian dollar and New Zealand dollar. Following a one-standard-deviation shock in the changes in the stress from the US-dollar money market, the interbank stresses for these currencies increase immediately and the impact will die out in seven to 13 days.*

- *With respect to the volatility linkage, the analyses find evidence of volatility co-movement between the interbank stress of the US dollar and that of the Hong Kong dollar, Japanese yen, Australian dollar, New Zealand dollar, Korean won and Singapore dollar during the crisis. The expected duration when two money markets are both in a high-volatility state can be as long as seven days. The short-lived impact on the EMEAP economies from a shock in the US dollar money market can be attributed to the policy actions taken by central banks and monetary authorities in the region and the co-ordinated efforts by policy makers worldwide to contain the credit crisis. The analysis provides useful information for the assessment of distress transmission between interbank markets.*

I. INTRODUCTION

The money markets of major currencies have been under extremely tight funding conditions since the second half of 2007. The London Interbank Offered Rates (LIBOR), the most widely used benchmark rates for term lending in major currencies, have seen their spreads over their policy rates surging to unprecedented levels. The distress has spread beyond the London interbank market and some money markets in the Asia-Pacific region have also been hit hard by the liquidity squeeze.[2]

Central bankers in general consider the interbank market as the main monetary transmission channel through which central banks' monetary policy actions make impact on the financial system and the economy. Any turbulence in the interbank market will therefore impair the effectiveness of central bank's monetary policy. Furthermore, the interbank rates also serve as benchmark rates for a wide variety of loans and securities. Unusually high term spreads over policy rates have adverse impact on the credit market and eventually disruptive effect on the economy. While major central banks and international organisations have mostly focused on the tensions in term funding in the London interbank market for major currencies such as the US dollar, the euro, the British sterling and the Japanese yen, little attention has been paid to interbank markets for other currencies.[3]

In this paper, we focus on some of the EMEAP economies' interbank markets where relevant data are available for analysis purposes, i.e. Mainland China, Hong Kong, Japan, Australia, New Zealand, Korea, Singapore, Malaysia and Thailand.[4] As the US financial market is the origin of the current financial crisis, we also include the London interbank market for the US dollar (USD) so as to investigate the extent of the transmission from the distress in the USD money market to these EMEAP economies' interbank markets. As in other central banks' monitoring work, this study uses the indicator of interbank stress by subtracting the Overnight Index Swap (OIS) rate of corresponding maturity from the interbank rate for those interbank markets where relevant

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[2] In this paper, the words "money market" and "interbank market" are interchangeable.

[3] See Bank of England (2007), Michaud and Upper (2008), Imakubo et al. (2008), McAndrews et al. (2008), Frank et al. (2008), Taylor and William (2008) and IMF (2008a, 2008b). In IMF (2008a), two measures of US funding stress are also linked to the bond spreads and stock market returns in Brazil, Mexico and Russia.

[4] EMEAP refers to the Executives' Meeting of East Asia-Pacific Central Banks. It comprises central banks and monetary authorities of eleven economies in the East Asia and Pacific region: Australia, Mainland China, Hong Kong, Indonesia, Japan, Korea, Malaysia, New Zealand, the Philippines, Singapore and Thailand. Due to data limitations, Indonesia and the Philippines are not included in this study.

OIS rates are available.[5] These include interbank markets for the USD, renminbi (RMB), Hong Kong dollar (HKD), Japanese yen (JPY), Australian dollar (AUD) and New Zealand dollar (NZD). For those markets where OIS rates are either not readily available or not suitable for this study, which include the Korean won (KRW), Singapore dollar (SGD), Malaysian ringgit (MYR) and Thai baht (THB), this study adopts another interbank stress indicator known as the TED spread, which is calculated as the interbank rate less the yield of government securities of corresponding maturity.[6] These interbank stress indicators are relevant from central banks' point of view for their assessment of the distress in the interbank market and relevant policy actions.[7]

The graphs in Chart 1 show the 3-month interbank rate – OIS spread and the 3-month TED spread of corresponding EMEAP economies' interbank markets against that of the USD. As shown in the graphs, money markets in some EMEAP economies (i.e. money markets for HKD, JPY, AUD, NZD and SGD) responded to the development in international financial markets with the sharp increase in the interbank rate – OIS spreads or the TED spreads in July – August 2007. As the financial crisis unfolded with more international banks reporting substantial asset write-down due to sub-prime-related investments and the collapse of Lehman Brothers in September 2008, both interbank stress series rose sharply from late September to mid-October 2008. Global efforts to support financial stability and confidence in the banking system finally eased the stress in the money markets in November – December 2008. Although the spreads have fallen substantially since October 2008, there are some interbank markets such as those for USD, AUD, NZD and KRW where the spreads remained at relatively high levels as compared with those before the crisis.

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[5] In principle, the interbank rate of a given tenor reflects current and expected future overnight interest rate, and premiums associated with liquidity and credit risks. The OIS rate, meanwhile, is closely related to the average overnight interest rate expected to prevail over the term of the swap. The spread between the interbank rate and the OIS rate can be used as an indicator to gauge the stress in the interbank market. A widened interbank rate – OIS spread reflects the increase in liquidity and/or counterparty default risks.

[6] The TED spread is used as the measure of interbank stress for these currencies because i) the OIS rates are not readily available for MYR and THB, and ii) while the OIS rates are available for KRW and SGD, the interbank rate – OIS spread are sometimes negative for these currencies. The negative spread is difficult to interpret and hence not suitable for this study. The TED spread measures the interest differential between unsecured lending to financial institutions in the interbank market and investment in government securities. A widening TED spread suggests that financial institutions expect greater risks in lending to their peers.

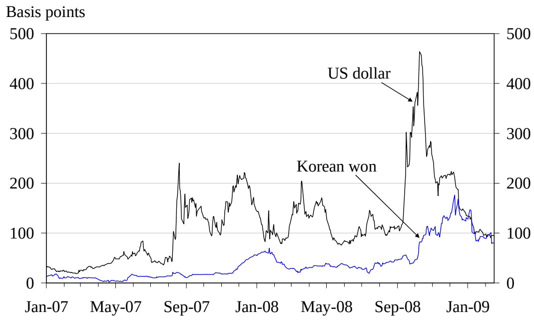
[7] Throughout the paper, the two interbank stress indicators for the money markets under study will be referred to as the interbank stress of the respective money market.

Chart 1. Interbank Stress

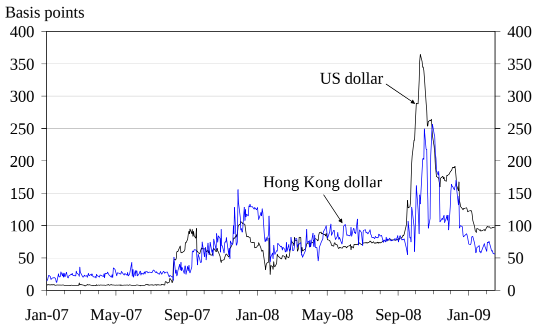
Interbank rate – OIS spread	TED spread

USD – RMB

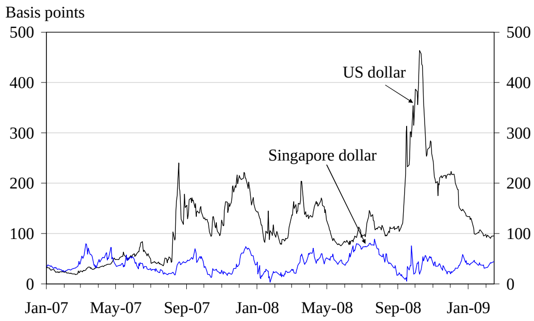
USD – KRW



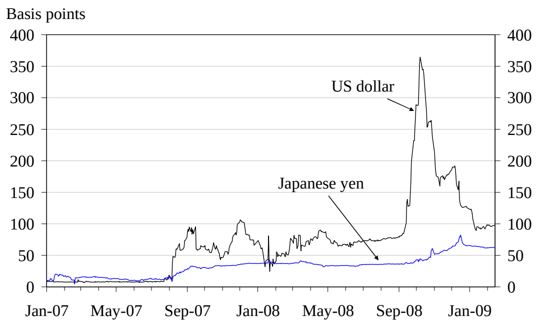
USD – HKD



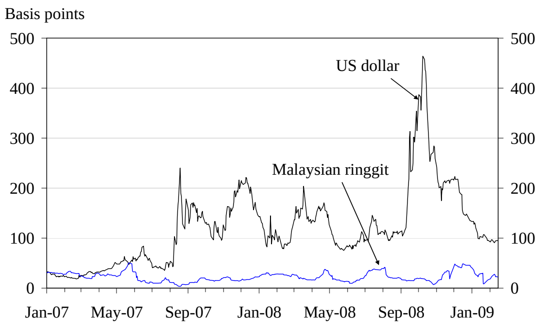
USD – SGD



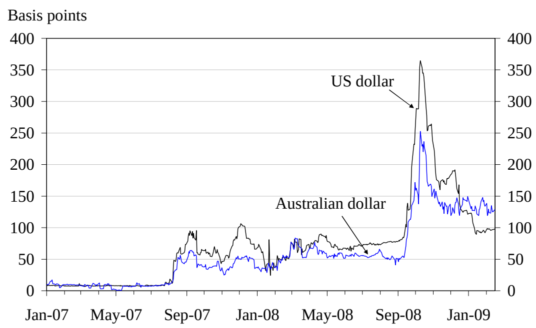
USD – JPY



USD – MYR



USD – AUD



USD – THB

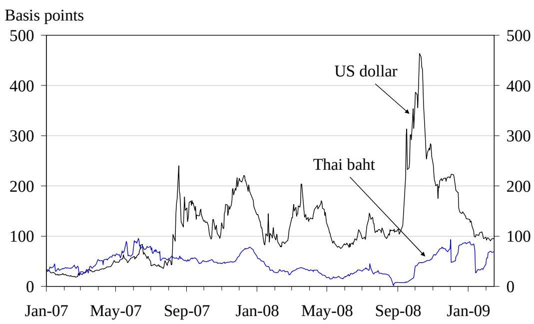
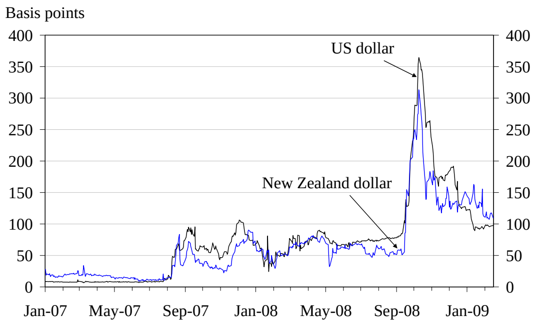


Chart 1. Interbank Stress (continued)

Interbank rate – OIS spread	TED spread
USD – NZD	



Source: Bloomberg and CEIC.

One possible transmission mechanism of the USD shock to EMEAP economies' money markets during the crisis may be the increased use of their money markets to secure US-dollar funding. As noted in Imakubo et al. (2008), financial institutions were facing a shortage of US-dollar funding when USD LIBOR surged to an unprecedented level. US banks, which encountered increased financing difficulties and had to preserve funds on hand, were reluctant to lend out their US dollar to peers. To secure US-dollar funds, non-US financial institutions had increased their borrowings in currencies other than the US dollar and actively converted them into US dollar through foreign exchange (FX) swaps. Such strategy might be a possible channel that leads to the tightening conditions in some of the EMEAP economies' money markets.[8]

As the liquidity squeeze in money markets was widespread during the global financial crisis in the fourth quarter of 2008, it is important to understand how these phenomena are interrelated among money markets. In particular, this paper analyses the cross-currency transmission of term funding shock across the USD and EMEAP economies' money markets by using two different modelling tools – the vector autoregressive (VAR) model and the regime switching ARCH (SWARCH) model. The VAR analysis provides the framework for examining the dynamic impact between the interbank stress and the impulse response function obtained from the VAR estimation traces the responses of the interbank stress of each EMEAP economy to a shock from the

[8] Genberg et al. (2009) analyse the link between the turbulence in money markets and the FX swap markets.

USD interbank market and how long such impact may last.[9] On the other hand, a regime switching ARCH (SWARCH) model is used to identify periods of unusually high volatility in the interbank stress. In particular, to investigate the volatility co-movement of these term-funding shocks, we utilise the bivariate SWARCH model to study the volatility linkage between the changes in interbank stress in the USD money market and the EMEAP economies' money markets.[10]

This paper contributes to the understanding on the transmission of liquidity shocks during the credit crisis of 2007 – 2008 on two fronts. First, this is the first attempt to model empirically the transmission of term-funding stress between the USD money market and that of the EMEAP economies during the recent financial crisis. Second, in addition to looking at the transmission in terms of the distress levels or their changes, we also investigate the volatility linkages. Results from the bivariate SWARCH model estimation provide an assessment of when the volatility interaction between money markets increases during the crisis period and the duration of market stress when two money markets are simultaneously at a high-volatility state. Together with the analysis from the impulse response function based on a VAR model, this empirical study enhances our understanding about the transmission of money market tension from the US to Asia during the credit crisis of 2007 – 2008. Such information would be helpful to the development of effective and co-ordinated policies to deal with the tension in the interbank markets in the future.

The remaining parts of this paper are organised as follows. Section 2 presents the models in the empirical analyses, Section 3 introduces the data and provides preliminary analyses on the interbank stress, Section 4 presents the analytical results on the interdependence and the volatility linkage between the interbank stress in the US dollar money market and other interbank markets and Section 5 provides a summary and conclusion.

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[9] In the literature, there are different methods used in evaluating the spillover between US and other international money markets. For example, IMF (2008a) examines the liquidity shock transmission using the Dynamic Conditional Correlation method, while the VAR model is used to capture the evolution and the interdependencies between the term funding stress of major currencies (Imakubo et al. (2008)). In this paper, we employ a VAR model as its impulse response function can help us quantitatively tracing the dynamic response of an EMEAP economy's interbank stress indicator to a shock in the USD money market. Such an assessment provides policy makers with a sense of the size of the impact on the local money market arising from a shock in the USD money market and how long the impact may last before dying out.

[10] Throughout this study, the VAR analysis and the SWARCH estimation are applied on the daily changes in interbank stress indicators.

II. MODELS AND METHODOLOGIES

2.1 The vector autoregression (VAR) model

Since the current financial crisis mainly originated from the US sub-prime crisis, the focus of this paper is on how the term-funding stress in the USD interbank market affects those in the EMEAP economies. To do this, we use the VAR model and examine the corresponding variance decomposition and the impulse response function.

In general, an unrestricted *p*-lag VAR (VAR(*p*)) model can be written as:

$$Y_t = \Phi_1 Y_{t-1} + \Phi_2 Y_{t-2} + \ldots + \Phi_p Y_{t-p} + \boldsymbol{e_t} \quad (1)$$

where Y_t is a system of (n x 1) time series vectors (i.e. the interbank stress calculated from either the interbank rate – OIS spreads or the TED spreads in different economies), Φ_i, i = 1, 2, …, p, is a (n x n) matrix of coefficients to be estimated and $\boldsymbol{e_t}$ is a (n x 1) vector of white noise error terms.[11] In lag operator notation, the VAR(*p*) in Equation (1) is written as

$$Y_t = \Phi(L) Y_t + \boldsymbol{e_t} \quad (2)$$

with $\Phi(L) = \Phi_1(L) + \ldots + \Phi_p(L^p)$ where L is the lag operator and p is the selected lag length. As will be shown in Section 3, all the interbank stress series are non-stationary. Pair-wise cointegration tests between the interbank stress of the USD and the currency of individual EMEAP economies suggest the existence of a cointegrating relationship among some pairs of series (i.e. USD – HKD, USD – JPY, and USD – KRW). Hence, for those pairs of money markets with cointegrating relationship, we proceed by estimating a Vector Error Correction Model (VECM), which is a restricted VAR suitable for non-stationary series that are known to be cointegrated.[12] In a VECM form, the VAR model as shown in Equation (2) is rewritten as:

$$\Delta Y_t = \Phi(L) \Delta Y_{t-1} + \Pi Z_{t-1} + \varepsilon_t \quad (3)$$

where Δ is the first difference operator, Z_{t-1} is the vector of error correction terms which represents the deviations from long-run relationships and ε_t is a vector of white noise

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[11] A process with zero mean, constant variance and no serial correlation is called white noise.

[12] According to Engle and Granger (1987) and Granger (1988), a VAR model in levels with non-stationary series may lead to spurious results. In such a case, error correction terms, which contain the "long-run relationships" among the non-stationary series are introduced back into the VAR model and the resulting model is known as VECM.

error terms.

After estimating the VECM (and the VAR model for those pairs of money market with no cointegrating relationship), we examine the dynamic interrelationship between the interbank stress of the USD market and those of the EMEAP economies' by mean of an impulse response function. An impulse response function allows us to trace the dynamic response of a variable to an innovation in another variable.

2.2 The regime-switching ARCH (SWARCH) model

The behaviour of volatility linkages among interbank markets during crises is also of interest to policy makers in their monitoring work. When a crisis breaks out, this may lead to the presence of structural break or regime shift in the data. When a break occurs, the family of ARCH and GARCH models that has been widely applied to modelling the variance of financial variables may not be appropriate (Lamoureux and Lastrapes (1990)). Cai (1994) and Hamilton and Susmel (1994) propose a regime-switching ARCH or SWARCH model that is time-variant and allows for the conditional volatility process to switch stochastically among a finite number of regimes. This study incorporates structural shift in the investigation of the volatility linkage between interbank markets by means of the bivariate SWARCH model. Appendix I gives details of the specification of the univariate and bivariate SWARCH models.

III DATA AND PRELIMINARY ANALYSES

3.1 Data

Daily data are used in the analyses of interbank market stress for RMB, HKD, JPY, AUD, NZD, KRW, SGD, MYR and THB, as well as the London interbank market for the USD. In this study, the sample period is from January 2007 to 16 February 2009. Due to data limitations, the study period for RMB is from 1 February 2008 to 16 February 2009. The interest rates are the 3-month interbank rates, the 3-month OIS rates of domestic money markets and the 3-month yield of government securities.[13] The 3-month interbank rate – OIS spread is used in the analysis for RMB, HKD, JPY, AUD and NZD, while the TED spread is for KRW, SGD, MYR and THB. For USD, both LIBOR – OIS and TED spreads are calculated to facilitate the bivariate analysis.

[13] For USD, AUD and NZD, the interbank rates are the 3-month LIBORs of the corresponding currencies. For other currencies, the interbank rates are those of domestic money markets. The 3-month interbank rates, 3-month OIS rates and 3-month yields of government securities are from Bloomberg and CEIC.

3.2 Stationarity and long-run property of the interbank stress series

Before performing the VAR analysis of the interbank stress series, we first examine their stationarity property and the possible existence of long-run cointegrating relationship between individual EMEAP economies' money market and that of the USD. We use the Augmented Dickey-Fuller (ADF) test to determine the unit root property of the two interbank stress series. Table 1 provides the ADF test results for each stress series.

Table 1. Stationarity Test Results of Interbank Stress Series

	ADF Unit Root Test				
	Based on interbank rate – OIS spread			Based on TED spread	
Interbank market	On the level	On the difference	Interbank market	On the level	On the difference
USD	-1.36	-5.93*	USD	-2.09	-4.80*
RMB	1.07	-4.47*	KRW	-1.18	-4.25*
HKD	-2.62	-4.76*	SGD	-3.67*	-6.26*
JPY	-0.62	-4.82*	MYR	-3.77*	-5.45*
AUD	-1.15	-4.58*	THB	-2.03	-6.57*
NZD	-1.62	-5.01*			

Notes: * indicates significance at the 5% confidence level. The critical value at the 5% level of the ADF test is -2.868 (-2.875 for RMB).

The results of the ADF tests in Table 1 show that most of the interbank stress series are non-stationary on their levels (the null hypothesis of the presence of unit root on the level cannot be rejected, except the cases of SGD and MYR), while they are stationary on their first differences. As a VAR model in levels with non-stationary series may lead to spurious results, we apply the Johansen (1988) procedure to test for the existence of any cointegrating relationships between the interbank stress of the USD and that of other currencies. The numbers of cointegrating vector based on the significance of the Johansen's Trace statistics are reported in Table 2.

Table 2. Johansen's Test for Cointegrating Vectors

	Number of cointegrating vector		
Interbank market pair	Based on interbank rate – OIS spread	Interbank market pair	Based on TED spread
USD – RMB	0	USD – KRW	1
USD – HKD	1	USD – SGD	0
USD – JPY	1	USD – MYR	0
USD – AUD	0	USD – THB	0
USD – NZD	0		

Notes: The number of lag in the cointegration test for each pair of market varies and is based on the result from the Akaike information criterion. It is 1 for USD – THB, 5 for USD – RMB, 6 for USD – AUD, 7 for USD – JPY and 8 for USD – HKD, USD – NZD, USD – SGD and USD – MYR. The number of cointegrating vectors is based on the significance of the respective Trace test at the 5% confidence level with the critical value from Osterwald-Lenum (1992).

Table 2 shows that one cointegrating relationship exists for three pairs of interbank stress series (USD – HKD, USD – JPY and US – KRW). Thus, for these three pairs of interbank stress series, the VECM as shown in Equation (3) of Section 2.1 will incorporate one error correction terms (based on the one long-run cointegration relationship), while the other six pairs with no cointegrating relationship (USD – RMB, USD – AUD, USD – NZD, USD – SGD, USD – MYR and USD – THB) will be analysed under an unrestricted VAR model with the series on their first difference. The lag length to be incorporated in the VECM and the VAR is based on the result from the Akaike information criterion.

3.3 Serial correlation tests

Table 1 shows that the interbank stress series are stationary on their first differences. Thus, in our SWARCH specification, the conditional mean equation is specified in terms of the first difference of the interbank stress series. In Table 3, we present Ljung-Box test results for serial correlation on the first difference series as well as their squared first differences of the series.

Table 3. Serial Correlation Tests of Data Series

	Ljung-Box (Q) test statistics				
	Based on interbank rate – OIS spread			Based on TED spread	
Interbank market	Q(7)	$Q^2(7)$	Interbank market	Q(7)	$Q^2(7)$
USD	60.73*	137.41*	USD	5.93	189.05*
RMB	28.76*	44.10*	KRW	33.75*	42.25*
HKD	23.93*	89.42*	SGD	31.96*	102.21*
JPY	14.97*	30.63*	MYR	36.50*	6.63
AUD	25.72*	410.56*	THB	6.82	5.73
NZD	36.29*	159.82*			

Notes: * indicates significance at the 5% confidence level. Q(7) and $Q^2(7)$ are the Ljung-Box statistics based on the first difference and the squared first difference of the respective interbank stress series up to the 7th order. Both statistics are asymptotically distributed as $\chi^2(7)$. The critical value of $\chi^2(7)$ at the 5% level is 14.07.

The serial correlation test results up to the 7th order provide evidence of serial correlation in the squared first difference for most of the interbank markets. This suggests the presence of autoregressive conditional heteroskedasticity (ARCH) in the change of interbank stress series, and justifies the use of ARCH model in modelling the variance of the interbank stress series (on their first difference).

IV ESTIMATION RESULTS

4.1 VAR / VECM analysis

The VAR model is useful in capturing the interdependence between multiple time series. As the current financial crisis was mainly originated from the US sub-prime crisis and we are interested in how the tension in the USD interbank market is associated with the distress in the EMEAP economies' money markets, we estimate a bivariate VAR or VECM system with the (daily changes in) USD interbank stress as the anchor. Based on the stationarity and cointegration test results in Section 3.2, a restricted form of VAR model, i.e. the VECM is specified for three pairs of interbank markets (USD – HKD, USD – JPY and USD – KRW), each with one error correction term, and an unrestricted VAR model for the other six pairs of markets (USD – RMB, USD – AUD, USD – NZD, USD – SGD, USD – MYR and USD – THB) based on their first difference. The interbank stress for the USD is the first series in the VAR / VECM system. Once the VAR / VECM is estimated, we examine the impulse response function of the impact of USD interbank market shocks on the EMEAP economies' interbank markets.

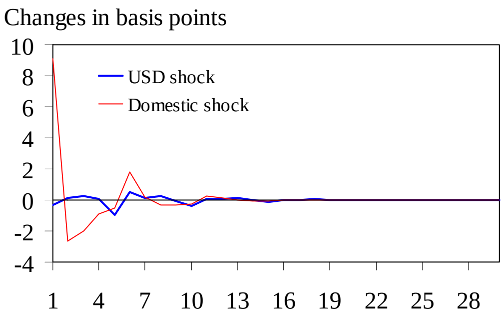
The dynamic interrelationship between a pair of interbank stress series can be examined through the impulse response function of their changes on each other. Chart 2 provides the responses of changes in interbank stress of each EMEAP economies to a one-standard-deviation innovation in the changes in USD series as well as its own series for a period up to 30 days.[14]

[14] An innovation refers to a shock to the random disturbance term on a series in the VAR or VECM system. Through the dynamic structure of the VAR / VECM system, a shock to one of the series is also transmitted to the other series in the system.

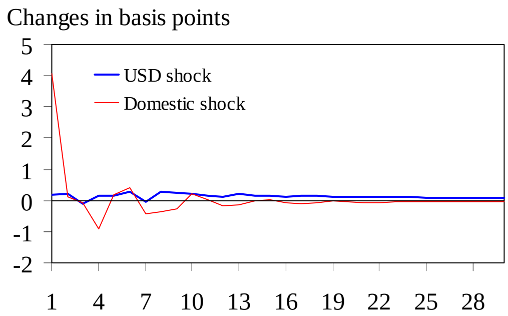
Chart 2. Responses of Individual Money Market's Changes in Interbank Stress to One-standard-deviation of USD and Domestic Shocks

Based on the interbank stress derived from interbank rate – OIS spread	Based on the interbank stress derived from TED spread

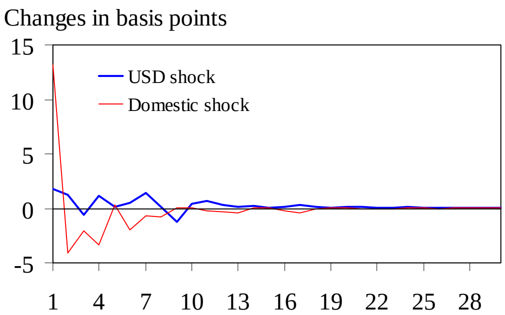
RMB



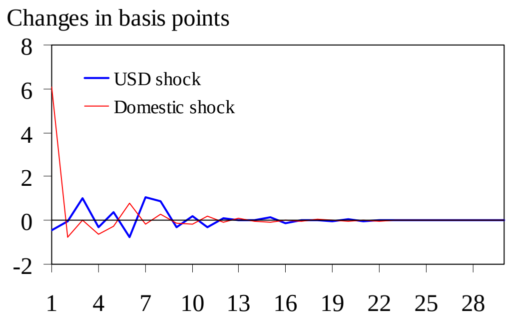
KRW



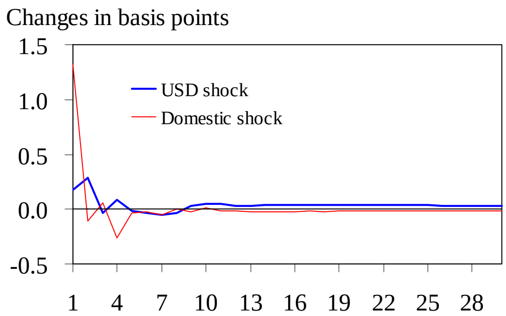
HKD



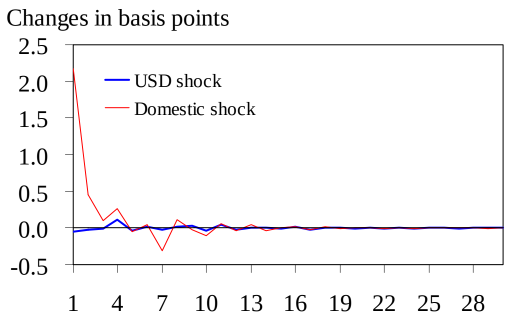
SGD



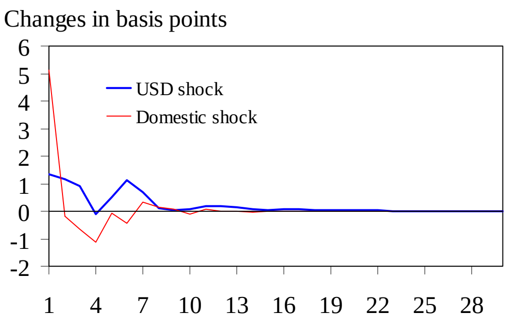
JPY



MYR



AUD



THB

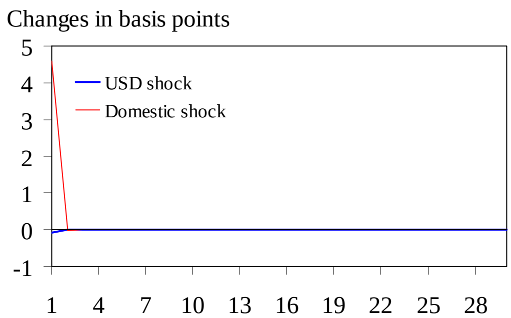
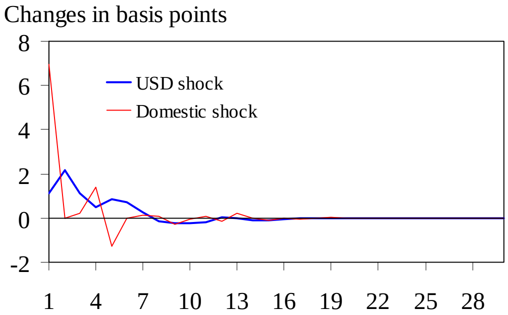


Chart 2. Responses of Individual Money Market's Changes in Interbank Stress to One-standard-deviation of USD and Domestic Shocks (continued)

Based on the interbank stress derived from interbank rate – OIS spread	Based on the interbank stress derived from interbank rate – OIS spread

NZD



Source: HKMA staff estimates.

From the graphs in Chart 2 it is possible to detect some similarities among interbank markets. In the interbank markets for RMB, MYR and THB, the responses to the USD shock are completely negligible over the 30-day horizon. For other money markets, the responses are more gradual and persistent. For example, in the cases of HKD and AUD, the impacts of a USD shock die out after 13 days. For JPY and KRW, it takes more time for the impact to vanish completely. For NZD and SGD, the impacts of a USD shock die out within seven days.[15] With respect to the size of the impact immediately after a USD shock, it is larger for HKD, AUD and NZD when compared with JPY, SGD and KRW, and negligible for RMB, MYR and THB.[16] Regarding domestic shocks to their own money markets, even though they are overwhelmed by the changes in their respective interbank stress on the first day, the impacts die out rapidly after five to seven days.

The results from the impulse response function suggest that for some interbank markets such as the HKD, AUD, JPY and KRW, the changes in their term-funding stress are subject to pronounced and persistent influences from the USD shock. Hence, it appears that changes in the interbank stress in the USD money market fed through to these interbank markets. For the HKD interbank market, this result is not surprising, given Hong Kong is a small and open economy under the Linked Exchange Rate system with the US dollar, and an international financial centre with the long-term participation of some of the major international financial institutions in the local interbank market. In fact, as the funding stress was first unfolded in the US-dollar money market with many of these major international financial institutions being put under pressure, their

[15] It is noted that the USD shock on USD money market itself is quite persistent as well, with the impact dying out after five to 16 days.

[16] Similar impact on the JPY money market is also found in Imakubo et al. (2008).

ability to obtain term funding in the local interbank market might be affected as well.[17] The feed-through effect is less marked for the NZD and SGD money markets, and seems to be irrelevant for the RMB, MYR and THB money markets. The results appear to reflect the characteristics of the financial markets in these EMEAP economies. For the money markets of RMB, MYR and THB which are relatively more restrictive to the participation of foreign institutions, they are less influenced by what happens in the US market.

The above findings provide an assessment about the transmission of money market tensions in terms of the changes in the interbank stress. If the variations in the interbank stress across different currencies are highly synchronised, the linkages may have implications on financial stability. To further examine whether these interbank stresses are synchronised, we next apply the bivariate SWARCH model to study the linkages of the volatility of the interbank stress indicators between the USD money market and other money markets.

4.2 Volatility linkages and SWARCH estimation results

(i) Univariate analysis

As a first step of the volatility linkage analysis, it is important to check whether the variations in the changes in interbank stress of different money markets are affected by structural shifts or other events that lead to switches in their variance regimes. To model the possible switch in variance regimes and take this condition into account, a univariate AR(1) SWARCH(2,1) model with two volatility regimes is estimated for the daily changes in each interbank stress series to identify periods of unusually high volatility.[18] The graphs in Chart 3 feature the smoothed probabilities of the high-volatility state in each money market's interbank stress along with the changes in interbank rate – OIS or TED spreads.[19]

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[17] This may be due to the reappraisal of counterparty risks and the needs to preserve liquidity by local banks.

[18] The AR(1) SWARCH(2,1) model has one autoregressive term (AR(1)) in the conditional mean equation. The conditional variance equation is constructed under a two-regime setting with one ARCH term (SWARCH(2,1)). Details of the SWARCH model are presented in Appendix I.

[19] The smoothed probability provides information about the likelihood that the changes in spread are in a particular volatility state at time *t* based on the full sample of observations. The AR(1) SWARCH(2,1) estimation results are available upon request.

Chart 3. Smoothed Probabilities of High-volatility State and Changes in Interbank Stress

Based on the interbank stress derived from interbank rate – OIS spread	**Based on the interbank stress derived from TED spread**

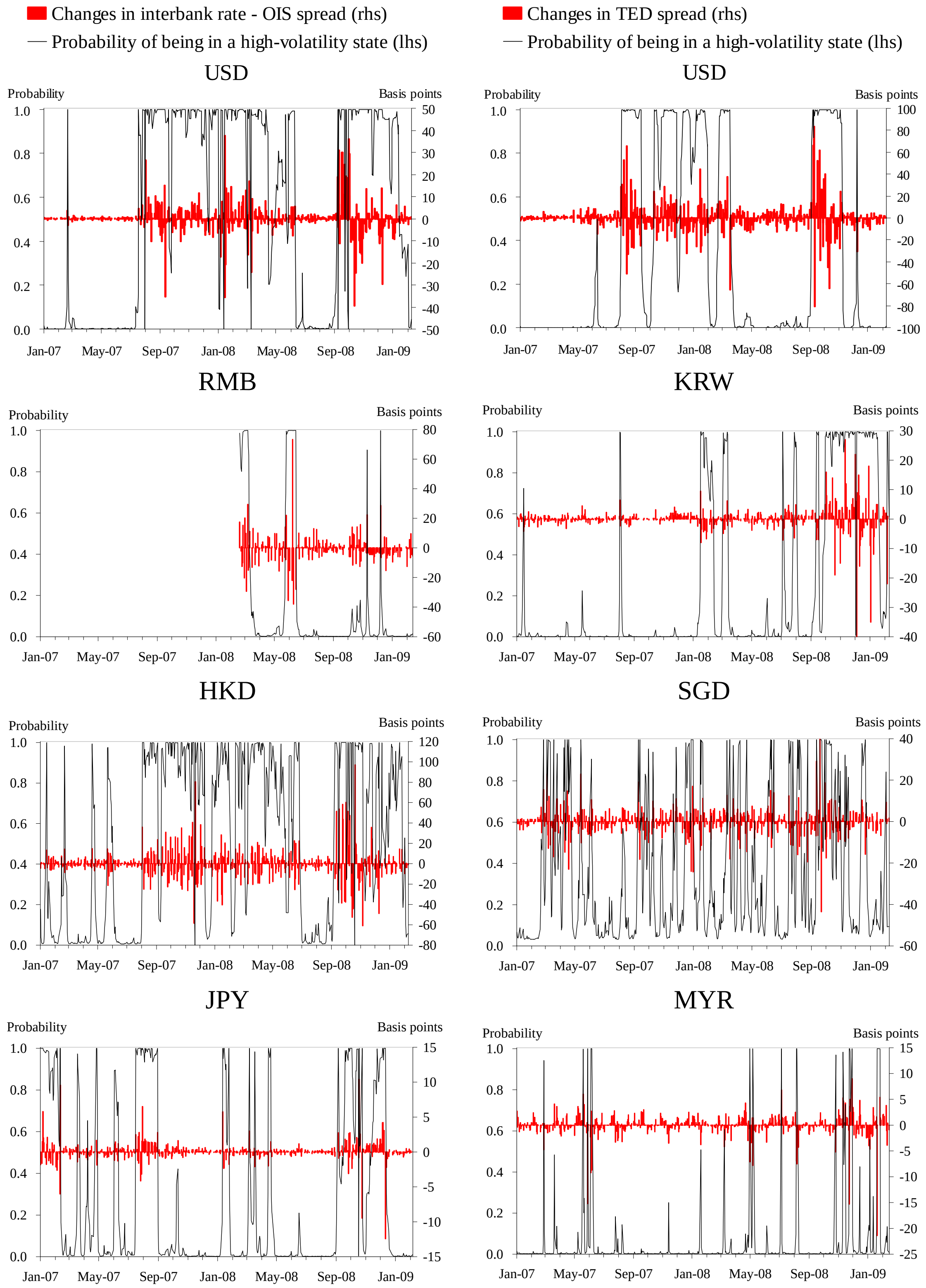
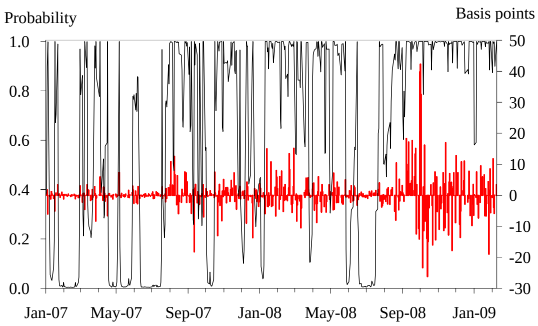


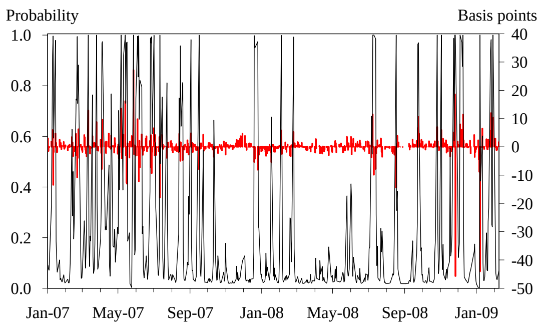
Chart 3. Smoothed Probabilities of High-volatility State and Changes in Interbank Stress (continued)

Based on the interbank stress derived from interbank rate – OIS spread	Based on the interbank stress derived from TED spread

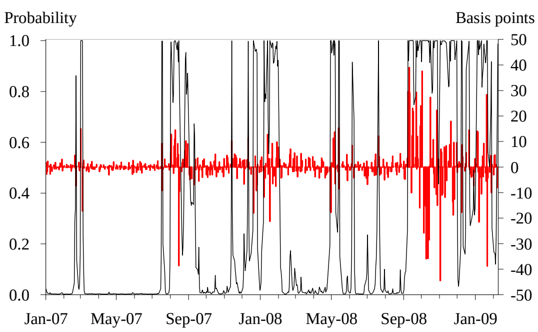
AUD



THB



NZD



Source: HKMA staff estimates.

By comparing the patterns of the smoothed probabilities across different money markets, one can examine whether the high-volatility state happened concurrently during the financial crisis started in the second half of 2007. As shown in Chart 3, the daily changes in the interbank stress in the money markets experience high volatility simultaneously on several occasions, suggesting that volatility linkage or co-movement exists between the money markets. For instance, in the case of USD and HKD, the interbank rate – OIS spreads shifted to a high-volatility state in August 2007. And for all money markets, the interbank stresses were in a high-volatility state in early or mid-September 2008. With the exception of AUD and KRW, the interbank stress condition in most of the money markets shifted to a low-volatility state by the end of January 2009.

(ii) Bivariate analysis

In order to examine the issue of volatility linkages, especially in the high-volatility state, the univariate SWARCH model is extended to a bivariate one with the daily changes in the USD interbank stress as the anchor against the other money markets. The estimated scale parameters for high-volatility state (g_2) from the bivariate AR(1) SWARCH(2,1) model are reported in Table 4.[20] All the estimated scale parameters are statistically significant and much greater than one for all pairs of money markets, suggesting that structural shifts need to be taken into account when modelling the volatility process of the interbank stress. In our sample period (from 1 January 2007 to 16 February 2009), the estimated scale parameters in a high-volatility state for USD are comparably larger than those for other currencies, with the exception of RMB, KRW and MYR. For these three markets, the variances of the changes in their interbank stress are even larger than that of the USD in a high-volatility state.

Table 4. Estimated Scale Parameters for Market Pair at High-volatility State (g_2)[1]

Based on the interbank stress derived from interbank rate – OIS spread									
USD – RMB[2]		USD – HKD		USD – JPY		USD – AUD		USD – NZD	
18.5*	20.2*	82.2*	28.0*	91.3*	35.5*	101.9*	60.9*	98.5*	38.8*
Based on the interbank stress derived from TED spread									
USD – KRW		USD – SGD		USD – MYR		USD – THB			
22.7*	50.6*	28.5*	12.0*	34.5*	125.6*	29.0*	18.2*		

Notes: The estimated scale parameter at high-volatility state for a currency in a market pair is the figure underneath that particular currency.
* denotes significance at the 5% confidence level.
1. Results based on a bivariate AR(1) SWARCH(2,1) model with the USD interbank stress as the anchor in the bivariate estimation. The estimation period starts from January 2007 to 16 February 2009.
2. The estimation period for the USD – RMB pair is from February 2008 to 16 February 2009.

Source: HKMA staff estimates.

Chart 4 contains graphs of smoothed probabilities when the selected pairs of money markets are both in a high-volatility state. There is a striking resemblance in the smoothed probabilities when the daily changes in the interbank stress in the money market pairs for the USD – HKD, USD – AUD and USD – NZD were simultaneously in a high-volatility state. Meanwhile, the smoothed probabilities for the money market pairs between USD and JPY, and KRW and SGD were very similar from mid-2008 onwards.

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[20] In the SWARCH model, the scalar parameters capture the size of volatility in different regimes. Under a two-regime setting, the scale parameter for the first state (g_1, low-volatility state) is normalised at unity while the scale parameter for the second state (g_2, high-volatility state) is greater than or equal to one. The complete estimation results are available upon request.

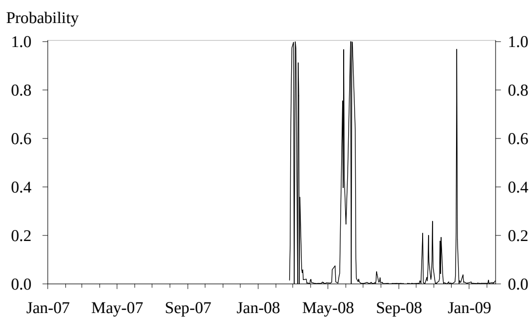
Nevertheless, if we focus on the situation in September 2008, these money market pairs responded significantly to the collapse of Lehman Brothers and shifted to a high-volatility state, and many of them remained at the high-volatility state for over a month. From the graphs, the pattern of the smoothed probabilities appears to suggest that volatility movements in the changes in interbank stress are highly synchronised across money markets following the collapse of Lehman Brothers in mid-September 2008. Therefore, a very significant adverse shock (i.e. a substantial increase in the variations of interbank stress) in the USD money market might have destabilising impacts on the money markets of many EMEAP economies, such as HKD, AUD, NZD, JPY, KRW and SGD.

On the other hand, volatility linkages between money markets for USD and RMB are less obvious. The two money markets were at the high-volatility state simultaneously on a few occasions and only for a short period. Similarly, for the USD – MYR and USD – THB pairs, the volatility linkages were not particularly strong as the smoothed probabilities of the respective market pairs being in a high-volatility state jumped a lot and the linkages were not particularly persistent.

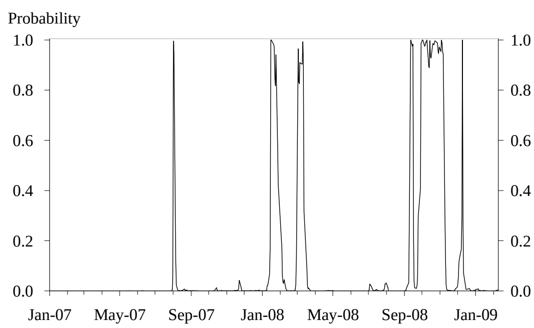
Chart 4. Smoothed Probabilities of Market Pair in High-volatility State

Based on the interbank stress derived from interbank rate – OIS spread	Based on the interbank stress derived from TED spread

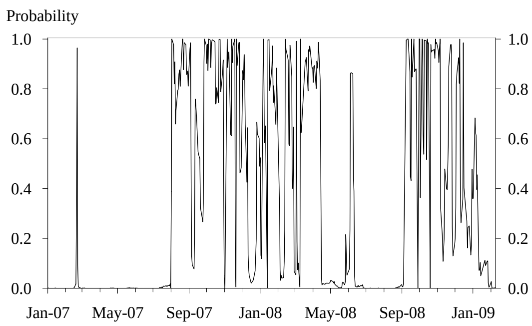
USD – RMB



USD – KRW



USD – HKD



USD – SGD

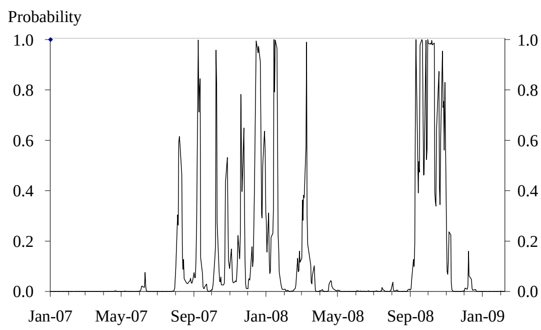
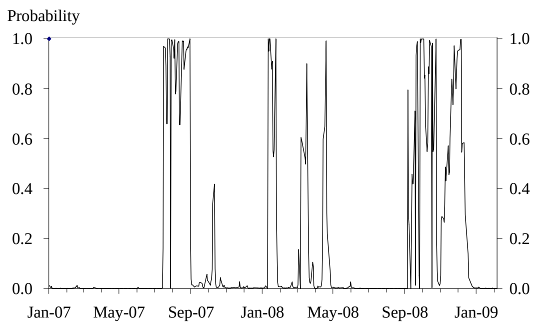


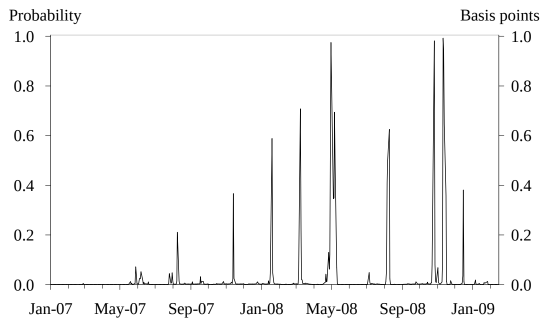
Chart 4. Smoothed Probabilities of Market Pair in High-volatility State (continued)

Based on the interbank stress derived from interbank rate – OIS spread	Based on the interbank stress derived from TED spread

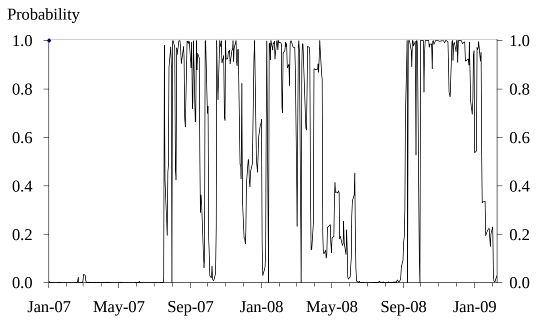
USD – JPY



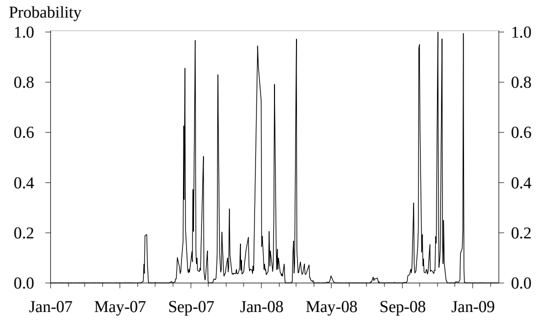
USD – MYR



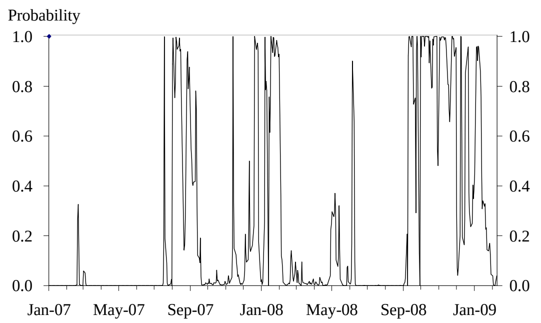
USD – AUD



USD – THB



USD – NZD



Source: HKMA staff estimates.

Using the transition probability estimated through the SWARCH model, one can derive the expected duration of both money markets being in a high-volatility state.[21] The results are given in Table 5.

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[21] The transition probability refers to the probability that the changes in interbank stress indicator switch from one volatility state to another volatility state. Given the transition probability, the expected duration can be derived as $(1 – \text{transition probability})^{-1}$.

Table 5. Expected Duration Derived from Estimated Transition Probabilities

Based on the interbank stress derived from interbank rate – OIS spread		Based on the interbank stress derived from TED spread	
USD – RMB	2.2	USD – KRW	7.7
USD – HKD	5.1	USD – SGD	3.0
USD – JPY	5.4	USD – MYR	2.5
USD – AUD	7.5	USD – THB	1.8
USD – NZD	5.0		

Note: Expected duration is in terms of a number of days and is calculated as $(1 - \text{transition probability})^{-1}$.
Source: HKMA staff estimates.

For a pair of money markets jointly in the high-volatility state, the expected duration ranges from 1.8 days to 7.7 days.[22] That means, on average, individual market pairs are expected to stay in the high-volatility state from as short as slightly less than two days to as long as over a week before they shift into other states of volatility. The USD - THB pair has the shortest duration of 1.8 days, followed by the USD – RMB pair of 2.2 days. On the other extreme, money markets in Australia and Korea are expected to be in the high-volatility state jointly with the US dollar money market for a period of longer than a week. Hence, the expected duration provides useful information on the extent of the volatility linkage between money markets during a crisis period.

V. Summary and Conclusion

The distress in the interbank markets following the eruption of the global financial crisis in the second half of 2007 is unprecedented. Given the importance of the interbank market as the main monetary transmission channel and as the benchmark for interest payments, any turbulence in this market would have disruptive impact on the financial system and the economy. This study looks specifically at the stress in the interbank market by using the interbank rate – OIS spread and the TED spread as indicators of interbank stress for the US dollar and nine interbank markets in the EMEAP economies. Using a VAR / VECM analysis and a bivariate SWARCH model, this study examines the interaction between the daily changes in these interbank stresses in the region against that for the US dollar money market.

Results from the impulse response function in the VAR / VECM analysis show strong interdependence between the variations in the interbank stress of the US dollar (USD), Hong Kong dollar (HKD), Japanese yen (JPY), Australian dollar (AUD)

[22] The study period for the USD – RMB pair is from February 2008.

and New Zealand dollar (NZD), and to a lesser extent Korean won (KRW) and Singapore dollar (SGD), while that of the renminbi, Malaysian ringgit and Thai baht appear to be isolated. Following a shock in the US-dollar money market, the interbank stresses for HKD, AUD and NZD increase immediately. The magnitude of the impact on the money markets of HKD, AUD and NZD is comparably larger than those for JPY, KRW and SGD and the impact will die out in around seven to 13 days. These may be due to the different characteristics of the individual money markets. For those markets which are open and with a high degree of participation of foreign institutions, the US influence on them may be more profound. Similarly, based on a bivariate SWARCH model, the analyses find evidence of co-movements in interbank stress volatility in the US market and in some of the EMEAP economies' interbank markets during the crisis. The expected duration when two money markets are both in a high-volatility state can be as long as seven days. The short-lived impact on the EMEAP economies from a shock in the US dollar money market can be attributed to the policy actions taken by central banks and monetary authorities in the region and the co-ordinated efforts by policy makers worldwide to contain the credit crisis.

Overall, the empirical results enhance our understanding about the transmission of money market tension from the US to Asia in terms of the dynamic impact and the volatility linkage during the credit crisis of 2007 – 2008. The analyses provide useful information regarding the size of the impact, the possible duration of distress in interbank markets during a severe shock and a thorough understanding of volatility linkage between interbank markets.

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Appendix I: The specification of SWARCH model

This Appendix illustrates the specification of univariate and bivariate SWARCH models. A univariate case is first considered. Let y_t be a financial time series at time t and the residual with respect to the information set Ω_{t-1} is denoted as ε_t. The process ε_t obtained from a first-order autoregression for y_t under a SWARCH(K, q) model which is specified as:

$$
\begin{aligned}
& y_t = w_0 + w_1 y_{t-1} + \varepsilon_t && \varepsilon_t \mid \Omega_{t-1} \sim \mathrm{N}(0, \sigma_t^2) \\
& \varepsilon_t = \sqrt{g_{s_t}}\, u_t && \\
& u_t = h_t v_t && \qquad\qquad (\text{A1}) \\
& h_t^2 = c_0 + \sum_{i=1}^{q} \alpha_i u_{t-i}^2 && i = 1, 2, \ldots, q, \ and \ s_t = 1, 2, \ldots, K
\end{aligned}
$$

where q is the number of ARCH terms, K is the number of regime states, and the g_{s_t} are scale parameters that capture the size of volatility in different regimes. It follows that the underlying ARCH variable μ_t is multiplied by the scale parameter $\sqrt{g_1}$ when the process is in the regime represented by $s_t = 1$. It is multiplied by $\sqrt{g_2}$ when $s_t = 2$ and so on. The scale parameter for the first state g_1 is normalised at unity with $g_{s_t} \geq 1$ for $s_t = 2, 3, \ldots, K$. The K-state regime switching is assumed to follow a Markov process, where

$$
\begin{aligned}
& \mathrm{Prob}(s_t = j \mid s_{t-1} = i, \ s_{t-2} = k, \ldots; \ y_t, y_{t-1}, y_{t-2}, \ldots) \\
& = \mathrm{Prob}(s_t = j \mid s_{t-1} = i) = p_{ij} \qquad\qquad (\text{A2})
\end{aligned}
$$

for $i,j,k = 1, 2, \ldots, K$. Under this specification, the transition probabilities, the p_{ij}s, are constant. In a two-state setting, for example, if the financial time series was in a high-volatility state in the last period ($s_t = 2$), the probability of it changing to the low-volatility state ($s_t = 1$) is a constant p_{21}. In addition, the estimation of the model gives the "smoothed probability", $\mathrm{Prob}(s_t \mid y_1, y_2, \ldots, y_T)$, which provides information about the likelihood that the asset is in a particular volatility state at time t based on the full sample of observations.

There are several advantages of using the SWARCH specification to model volatility. First, the SWARCH model incorporates the possibility of regime shifts or structural breaks in the conditional variance process in explaining volatility persistence, a phenomenon that is commonly observed in the literature. Second, the SWARCH model can date the period of high volatility based on the smoothed probabilities. This will help detect whether periods of "high volatility" coincide across different financial markets. Finally the identification of breakpoints can also be used to "time" the impact of policy changes on financial markets.[23]

A limitation of the SWARCH model is the technically non-trivial and very time-consuming estimation process. In this study, the application of the SWARCH model is restricted to pairs of the daily changes in interbank stress only, each with one ARCH term in the conditional variance process and two volatility states. Under this bivariate AR(1) SWARCH(2,1) specification, the total number of states is four. For instance, considering the interbank stress of the US dollar and the Hong Kong dollar pair, the four possible states, s_t^*, are as follows:

s_t^* = 1: US – low volatility, Hong Kong – low volatility.

s_t^* = 2: US – low volatility, Hong Kong – high volatility.

s_t^* = 3: US – high volatility, Hong Kong – low volatility.

s_t^* = 4: US – high volatility, Hong Kong – high volatility.

Similar to the univariate case, the system for the bivariate model can be written as:

$$y_t = A + B\, y_{t-1} + e_t, \quad e_t \,|\, \Omega_{t-1} \sim N(0, H_t) \qquad \text{(A3)}$$

where $y_t = \begin{bmatrix} y_{1,t} \\ y_{2,t} \end{bmatrix}$ is a 2x1 vector of returns, $e_t = \begin{bmatrix} e_{1,t} \\ e_{2,t} \end{bmatrix}$ is a 2x1 vector of disturbances, which are assumed to follow a bivariate normal distribution with zero mean and a time varying conditional covariance matrix H_t. The time varying conditional covariance matrix H_t is specified as a constant correlation matrix where the diagonal elements follow a SWARCH(2,1) process. $A = \begin{bmatrix} w_{10} \\ w_{20} \end{bmatrix}$ is a 2x1 vector and $B = \begin{bmatrix} w_{11} & 0 \\ 0 & w_{22} \end{bmatrix}$ is a 2x2 matrix. The parameters of the bivariate AR(1) SWARCH(2,1) model are estimated using GAUSS by numerically maximising the likelihood function in the algorithm developed by Broyden, Fletcher, Goldfarb and Shanno (BFGS), subject to the constraints that $g_1 = 1$, $g_2 \geq 1$, $\sum_{j=1}^{2} p_{ij} = 1$ for i = 1, 2 and $0 \leq p_{ij} \leq 1$ for i,j = 1, 2.[24,25]

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[23] A review of the SWARCH model and its application can be found in Ramchand and Susmel (1998), Susmel (2000), Edwards and Susmel (2001) and Edwards and Susmel (2003).

[24] GAUSS programs and most of the routines are obtained from websites of James Hamilton and Rauli Susmel.

[25] The BFGS algorithm is described in Press et al. (1988).