HONG KONG MONETARY AUTHORITY

Working Paper 18/2008

30 December 2008

MEASURING FINANCIAL MARKET INTERDEPENDENCE AND ASSESSING POSSIBLE CONTAGION RISK IN THE EMEAP REGION[1]

Prepared by Lillian Cheung, Laurence Fung and Chi-Sang Tam
Research Department

Abstract

In this paper, we assess the interdependence between equity markets in the EMEAP region and the US, and across the EMEAP markets using two indicators, namely the dynamic conditional correlation and the spillover index. These indicators show that equity market interdependence has increased steadily since early 2006, and rose sharply following the collapse of the Lehman Brothers in September 2008. We also test for the existence of contagion, and find no significant evidence of contagion between equity markets in the US and the EMEAP region. On the other hand, intra-regional contagion is found to be more significant, suggesting that investors may have treated the regional markets indiscriminately when facing common external shocks.

JEL Classification Numbers: G01, G15, G12
Keywords: Contagion, Dynamic conditional correlation, Spillover index
Authors' Email Addresses: lcheung@hkma.gov.hk,
laurence_kp_fung@hkma.gov.hk, chi-sang_tam@hkma.gov.hk

[1] EMEAP is the abbreviation for the Executives' Meeting of East Asia-Pacific Central Banks. Founded in 1991, EMEAP is a cooperative organisation of central banks and monetary authorities in the East Asia and Pacific region. It comprises central banks and monetary authorities of the following eleven economies: Australia, China, Hong Kong, Indonesia, Japan, Korea, Malaysia, New Zealand, the Philippines, Singapore, and Thailand.

Executive Summary:

- *The breadth and depth of the impact of the current financial crisis raise concerns about spillover across financial markets around the world. A set of appropriate measures to assess the degree of co-movement of financial assets prices is therefore a useful aid for policy makers to define policy responses and contingency plans.*

- *This paper measures and tracks the interdependence between equity markets in the EMEAP region and the US by using two indicators: namely the Dynamic Conditional Correlation and the Spillover Index. Both indicators suggest that the interdependence between the equity markets in the EMEAP region and the US has been substantial. Both indicators exhibit an uptrend since early 2006 and rose sharply following the collapse of the Lehman Brothers in September 2008.*

- *We also test for the existence of contagion in a restrictive sense between the equity markets in the EMEAP region and the US, and across equity markets in the EMEAP region during the recent financial turmoil which started in September 2007. The results do not provide significant evidence of contagion between the markets in the EMEAP region and the US. Nevertheless, whether contagion took place after the collapse of the US investment bank, Lehman Brothers, in September 2008 is difficult to assess because of limited data available at the time of this research.*

- *On the other hand, our findings suggest that intra-regional contagion has been more significant in the recent turmoil, suggesting that investors may have treated the regional markets indiscriminately when facing common external shocks.*

I. INTRODUCTION

As the global financial crisis intensified, financial markets suffered large sell-offs worldwide. The rise in global risk aversion led to a general flight to safety by investors which exacerbated volatility in capital flows. In the EMEAP region, many markets have suffered sharper losses than the major developed markets, although the shock has originated far from the region. Despite sounder economic fundamentals than a decade ago, investors may still be as indiscriminate as they were then. This raises concerns over the risk of contagion between financial markets in the US and the EMEAP region as well as across regional markets.

Indeed, intensified linkages in a world of high capital mobility have increased the risk of cross-border financial contagion. At times of financial crises similar to the current episode, such contagion may have important consequences for financial stability. It is thus essential to provide policy makers with appropriate measures to assess the co-movement of financial assets prices (or their returns). This will help design policy responses and prepare contingency plans.

II. INTERDEPENDENCE VS. CONTAGION

Before assessing the co-movements of financial asset prices, it will be useful to distinguish between the meaning of interdependence and contagion. These two terms are often used interchangeably, referring to co-movement of asset returns or cross-country transmission of shocks. In this paper, we distinguish between the two concepts, and use the term interdependence to refer to asset return correlation or return spillovers. Two measures discussed in the next section, namely Dynamic Conditional Correlation (DCC) and the spillover index (SI) are related to this type of financial asset price relationship.

The term contagion will be used in a more restrictive sense to refer to that part of the transmission of shocks to other countries or the cross-country correlation, which is due to factors other than common shocks. This definition is usually referred to as excess co-movement, commonly explained by herding behaviour. In a very restrictive definition, 'contagion occurs when cross-country correlations increase during "crisis times" relative to correlations during "tranquil times".' (Forbes and Rigobon (2002)) This needs to control for rising general volatility during financial crises. It is this very specific definition which forms the basis of our test for contagion presented as the third measure in this paper.[2]

---

[2] The "Contagion of financial crises" page of the World Bank website (www.worldbank.org) provides a discussion of various definitions of contagion.

III. Dynamic Conditional Correlation and Spillover Index

One measure to assess the degree of interdependence between equity markets is the dynamic correlation derived from the Dynamic Conditional Correlation (DCC) model by Engle (2002).[3] The DCC model is commonly used to examine the time-varying correlation dynamics among asset returns. *Similar to other conventional correlation measures, a higher value of the DCC measure between markets implies a higher return co-movement in the markets*.[4]

Another method to measure cross-market interdependence is the spillover index (SI) proposed by Diebold and Yilmaz (2008).[5] The SI focuses on variance decomposition under a simple vector autoregressive model of equity returns, in which the index can be interpreted as an aggregate of return spillovers across markets. *A higher SI implies that a larger proportion of the volatility in any one market can be accounted for by shocks originating in other markets.*

Using both of the above two measures, we examine equity market interdependence among the EMEAP economies and the US. Table 1 lists the benchmark equity indices of these economies.[6]

We use Wednesday-on-Wednesday returns for all estimation in this study because weekly returns are less noisy as compared to daily returns while preserving the adequacy of data frequency, and it is also free from the problem of time differences between the US and the EMEAP economies. (For further details on methodology, please refer to the Technical Appendix.)

---

[3] See the Technical Appendix for the details of the dynamic conditional correlation model.

[4] Yu et al. (2007) employs DCC as an indicator to monitor the development, measure progress and assess the state of equity market integration in Asia. For details, see Yu et al. (2007). Furthermore, IMF (2008) also uses DCC to examine the cross-country equity price correlations between emerging market economies and the US.

[5] See the Technical Appendix for the details of the spillover index model.

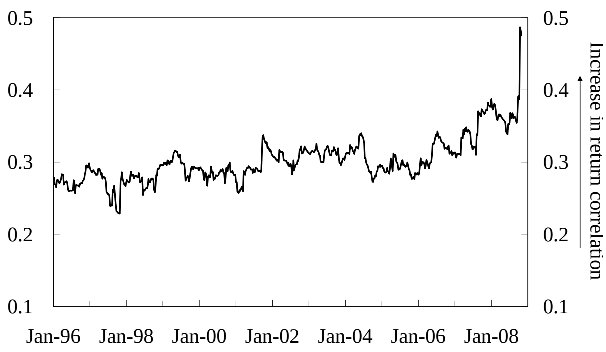
[6] The benchmark equity market indices are expressed in terms of the US dollar. The conversion is done by dividing the local currency index level by the local currency per US dollar exchange rate.

Table 1. Benchmark Equity Market Indices

Equity market	Benchmark index
EMEAP economies	
China	Shanghai A-share Index
Hong Kong SAR	Hang Seng Index
Japan	Nikkei 225 Stock Average
Korea	KSE Composite Index
Indonesia	JSX Composite Index
Malaysia	KLSE Composite Index
The Philippines	PSE Index
Singapore	Straits Times Index
Thailand	SET Index
Australia	Australian All Ordinaries Index
New Zealand	New Zealand All Ordinaries Index
External influence	
US	Dow Jones Industrial Average

Source: Bloomberg.

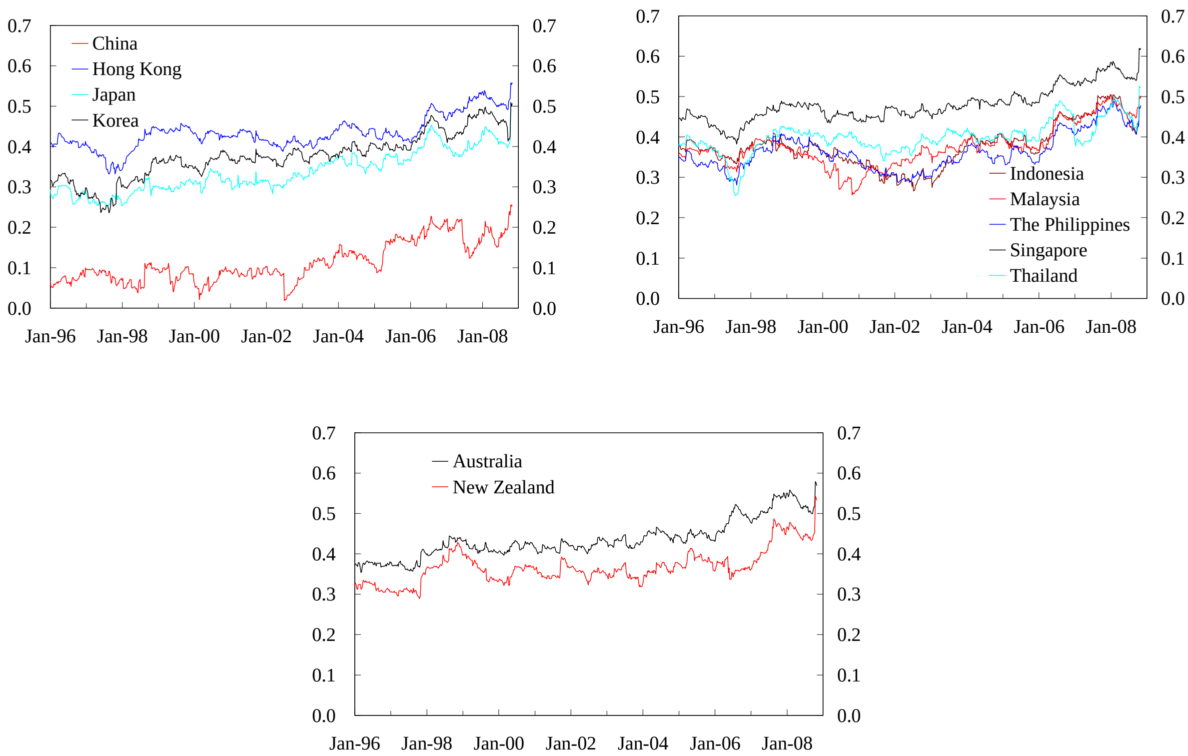
Chart 1. Average correlation between EMEAP economies and the US



Source: HKMA estimates.

Chart 1 depicts the time-varying average return correlation between the equity markets in the EMEAP economies and that in the US using the DCC method. The DCC between the equity returns in the US and those in the EMEAP economies lingered around 0.3 between 2000 and 2005, and the correlation coefficient increased from early 2006 onwards. This might be explained by the surge in portfolio capital inflows into the region in the past few of years until the crisis. Robust economic performance in the region together with improved investment climate in Asia in recent years attracted more foreign funds to increase the weight of Asian markets in their portfolios. The heightened interest of foreign investors and portfolio funds in the region led to increased integration of the region's financial markets into the global financial system. By mid-September 2008, the DCC between the equity returns in the US and those in the EMEAP economies surged dramatically on the back of the bankruptcy filing of the US investment bank Lehman Brothers, and subsequently it rose to almost 0.5 in mid-October 2008 with the sharp fall in global equity prices. Such changes are also found within the equity markets of the EMEAP economies illustrated in Chart 2.

Chart 2. Average correlation among equity markets in the EMEAP economies

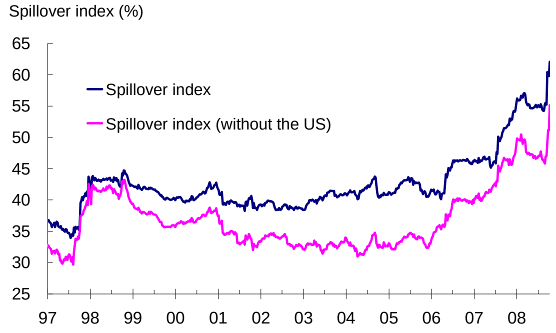


Source: HKMA estimates.
Note: The line for each economy represents the average correlation between an economy's equity market and that of other EMEAP members.

The dramatic changes in the level of DCC during the current episode of financial turmoil also contrast with the experience during the Asian financial crisis in 1997 and 1998. During the Asian financial crisis, there was an uptick followed by an upward drift in the DCC for many EMEAP markets, with the notable exception of China which was shielded by capital controls. For Japan, there was no uptick and the upward drift was also relatively flatter, given the sheer size of its economy and financial markets.

The SI, another measure of cross-market interdependence studied in this paper, presents a similar picture. Chart 3 shows two series of SI: one of them is the SI of equity markets in the EMEAP economies and that in the US, and another one is the SI without including the US market.[7]

Chart 3. Spillover index of EMEAP economies and the US



Source: HKMA estimates

The SI including the US market moved between 40% and 45% over the past decade end-2005, and the index increase steadily since early 2006. The SI hit the 50% level in Q1 this year. Similar to the DCC, the figure jumped sharply higher, to more than 55% in early October and to reach 58% at the end of October. The SI excluding the US moved in a similar trend over the past decade, and has maintained a relatively steady difference from the SI including the US since 2002. This indicates that the spillover effect from the US market to the EMEAP market has remained steady over the past few years. The figure also jumped sharply higher in October, and the increment was even larger than the SI including the US, reflecting a higher spillover effect within the region and tighter linkages across the regional markets.

Looking back into history, the SI also surged during the Asian financial crisis. During that episode, the SI without including the US increased by a larger degree compared to the SI including the US, partly reflecting the dominance of spillovers within the EMEAP region during that crisis, which is largely expected as the crisis originated within the region.

In sum, both of the above indicators have shown an uptrend since early 2006, possibly reflecting the increase in capital inflows into the equity markets in the region. They have increased substantially during the latest episode of financial turmoil, suggesting a rise in interdependence of equity returns between the EMEAP region and the US, as well as that among the equity markets in the EMEAP economies. In particular, the intra-EMEAP market correlations and spillovers show a larger jump when compared to those between the EMEAP markets and the US. Such large co-movement within the EMEAP economies in part reflects the intensified linkages within the region, and these linkages could be

---

[7] Both SI series are estimated based on a vector autoregressive system with all EMEAP economies and the US. However, the calculation of the SI (without including the US) dismissed the contributions of variance from and to the US. The system is estimated with a 150-week rolling sample.

tightened significantly by a common external shock.[8]

IV. Existence of Contagion

While both the DCC and SI suggest significant increase in interdependence between the EMEAP economies and the US during the current financial turmoil, they do not provide an answer to the question of whether such a jump in correlation could be interpreted as "financial contagion". To this end, we further test for the existence of financial contagion between the EMEAP economies and the US, as well as that across the equity markets in the EMEAP economies. As mentioned previously, we employ a very specific definition used in the literature: *contagion implies a significant increase in cross-market linkages after a shock to one or more country*. According to this definition, two markets are said to be contagious if their correlation coefficient increases significantly from normal times after the shock. Thus, two markets could have high interdependence but not contagion, even if their correlation coefficient increases during the turmoil period, but not to the extent of being significantly higher than the stable period.

To test for the existence of contagion between the equity markets in the EMEAP economies and the US, we compare the cross-market return correlation coefficients during the pre-defined "stable period" and the "turmoil period", by using the method proposed by Forbes and Rigobon (2002).[9] In this test, the correlation between a pair of equity returns during the turmoil period is adjusted against the upward bias due to heteroskedasticity of return volatility.[10]

The cross-market correlation coefficients for the test are estimated under a vector autoregressive framework, and the dates of stable and turmoil periods are determined by screening the conditional variance of return of the US.[11] Accordingly, the current turmoil is found to begin in early September 2007.

---

[8] The increase in correlation may also be due to the increase in return volatility inherent from the external shock. Forbes and Rigobon (2002) showed that, under some mild assumptions between a pair of returns, their correlation coefficient is an increasing function of volatility. For details, see Forbes and Rigobon (2002), "No Contagion, Only Interdependence: Measuring Stock Market Comovements", *Journal of Finance*, vol. LVII, no. 5.

[9] The standard correlation t-test is used to compare the size of correlation coefficients in different states.

[10] Return volatility always increases during the crisis period, while under some mild assumptions, the correlation coefficient is an increasing function of it. A test comparing the size of correlation coefficients between stable and turmoil periods thus tends to result in evidence of spurious contagion. See Forbes and Rigobon (2002) for details.

[11] The conditional variance of return is estimated by a simple univariate GARCH model. The variance is compared with its HP-filtered trend series. A period is identified as a beginning of market turmoil if the conditional variance is larger than the trend by more than 50% and the return is smaller than its long term average.

Since the US is the source of this turmoil, we examine the existence of contagion between the equity markets in each EMEAP economy and the US. Table 2 shows the results.

Table 2. Contagion test between the equity markets in the EMEAP economies and the US

	Correlation coefficients (US, individual economy)			
	Stable period (Jan-94 to Aug-07)	Turmoil period (adjusted) (Sep-07 to Oct-08)	Test statistics	Contagion?
China	-0.02	0.18	1.1	*No*
Japan	0.30	0.41	0.9	*No*
Hong Kong	0.45	0.35	-0.8	*No*
Korea	0.30	0.20	-0.7	*No*
Singapore	0.40	0.42	0.2	*No*
Indonesia	0.19	0.09	-0.7	*No*
Malaysia	0.19	0.30	0.8	*No*
Philippines	0.25	0.33	0.6	*No*
Thailand	0.28	0.30	0.1	*No*
Australia	0.49	0.52	0.3	*No*
New Zealand	0.34	0.50	1.4	*No*

Source: HKMA estimates.

The results indicate that, although the correlation coefficients rose during the current turmoil, the increments were not significant to prove the existence of contagion between the equity markets in the EMEAP economies and that in the US. This is similar to the experience in the 1997/98 Asian financial crisis where findings from Forbes and Rigobon (2002) showed that the regional markets were not contagious during that episode, while the long-term interdependence between the equity markets in Hong Kong and those of many of these 27 economies were high even during the stable period.[12] Note that the results *do not* suggest that markets are not closely linked during the current episode. In fact, all EMEAP economies suffered equity price slumps in recent months due to the US financial turbulence. Instead, the correlation coefficients indicate a high level of market co-movement between the EMEAP markets and the US market throughout the whole period under consideration, which implies high interdependence.

In order to test for the existence of contagion across the EMEAP equity markets during the recent financial turmoil, we perform the same test to examine between every possible pairs of equity markets in the region. Table 3 shows the estimation results.

[12] Forbes and Rigobon (2002) tested the existence of contagion between the equity markets of Hong Kong and those of other 27 economies (including eight East Asian economies) during the Asian financial crisis.

Table 3. Contagion test across equity markets in the EMEAP economies

		CN	JP	HK	KR	SG	ID	MY	PH	TH	AU	NZ
Adjust for return volatility increase in:	**CN**		N	C	C	N	C	C	C	C	C	C
	JP	N		C	C	C	C	C	C	C	C	C
	HK	C	N		N	C	N	N	N	N	N	N
	KR	C	C	C		C	C	C	C	C	N	N
	SG	N	C	C	C		C	C	C	N	C	C
	ID	C	C	C	C	C		C	C	N	C	C
	MY	C	C	C	C	C	C		C	C	C	C
	PH	N	C	C	C	C	C	C		N	C	C
	TH	C	C	C	C	N	C	C	N		C	C
	AU	C	N	N	N	N	N	N	N	N		N
	NZ	C	C	N	N	N	C	C	C	C	N	

Notes:
(i) N = No contagion; C = contagion
(ii) Dates of the stable and turmoil periods of each pair of markets are selected by the same method as stated in footnote 11.
(iii) Correlations are adjusted for the return volatility change in the market shown in the corresponding row.
Source: HKMA estimates.

In this set of tests, the correlation measure between each pair of markets in the row and column during the turmoil period is adjusted for the return volatility change in the market shown in the corresponding row. As such, the matrix is not necessarily symmetric. As an illustration, while there is little contagion from Hong Kong and Australia to other markets, there is significant contagion from other markets to Hong Kong and Australia. The results show that there were generally significant contagion incidences among the EMEAP equity markets. The major exception lies in Hong Kong and Australia where shocks originated from these markets are not as contagious as their neighbours in the region. Indeed, the correlation coefficients between the equity returns in Hong Kong and other markets, as well as those between Australia and other markets have been relatively stable throughout the period studied, and the changes in the correlation measures between normal times and the turmoil period for shocks originated from these two markets are not as significant as those originated from other markets in the region.

In general, these results are consistent with the larger increase in the spillover index within the region, suggesting that the turmoil has spread across equity markets within the region. When compared to the non-contagious results in Table 2, the more significant evidence of regional contagion can be explained in part, by the common negative shock of capital outflows faced by the markets in the region, as mass capital outflows would trigger investors' herding behaviour.[13]

---

[13] See Kiminsky and Reinhart (2000) for further elaboration.

V. CONCLUDING REMARKS

Statistical tests of this paper suggest that the degree of market co-movements has increased between the equity markets in the EMEAP economies and the US and across the EMEAP markets since 2006, and risen sharply following the collapse of Lehman Brothers in September 2008. Nevertheless, there is no significant evidence of contagion between the US and the EMEAP equity markets during the recent turmoil which started in September 2007. On the other hand, the contagion test across the EMEAP markets indicate evidence of contagion across most markets in the region during the recent turmoil, suggesting that investors might have treated the regional markets indiscriminately in the flight to safety.

REFERENCES

Diebold, F.X. and Yilmaz, K. (2008), 'Measuring Financial Asset Return and Volatility Spillovers, With Application to Global Equity Markets', *NBER Working Paper,* No. 13811.

Engle, R (2002), 'Dynamic Conditional Correlation: A Simple Class of Multivariate Generalized Autoregressive Conditional Heteroskedasticity Models', *Journal of Business & Economic Statistics*, Vol. 20, pp. 339-350.

Forbes, K.J. and Rigobon, R. (2002), 'No Contagion, Only Interdependence: Measuring Stock Market Comovements', *Journal of Finance*, vol. LVII, no.5, pp. 2223-2261

International Monetary Fund (2008), 'Spillovers to Emerging Equity Markets', *Global Financial Stability Report*, October, 131 – 151.

Kiminsky, G.L. and Reinhart, C.M., (2000), 'On Crises, Contagion and Confusion', *Journal of International Economics*, Vol. 51, no. 1, pp. 145-168

Yu I.W., Fung L. and Tam C.S. (2007), 'Assessing Financial Market Integration in Asia - Equity Markets', HKMA Working Paper, No. 2007-04.

Technical Appendix

METHODOLOGY AND INTERPRETATION: INDICATORS OF EQUITY MARKETS INTERDEPENDENCE AND TEST FOR THE EXISTENCE OF CONTAGION

This Appendix provides details of the methodologies for constructing the two indicators of equity market interdependence and the test for the existence of contagion.

i. Correlation using dynamic conditional correlation (DCC) method

Simple (or rolling) correlation analysis is among the simplest method for examining the co-movement of financial markets. Basically, higher correlation between markets implies higher co-movement and greater integration between the markets. The DCC model, proposed by Engle and Sheppard (2001) and Engle (2002), is a new class of multivariate model which is particularly well suited to examine correlation dynamics among assets. The DCC approach has the flexibility of univariate GARCH but without the complexity of a general multivariate GARCH. As the parameters to be estimated in the correlation process are independent of the number of series to be correlated, a large number of series can be considered in a single estimation. Furthermore, Wong and Vlaar (2003) show that the DCC model outperforms other alternatives in modelling time-varying correlations.

To measure conditional correlations, a two-step estimation procedure of the DCC model is used. Univariate GARCH models are first estimated for each asset return series. The standardised residuals from the first step are then used to estimate the dynamic conditional correlations between asset returns. Specifically, let $z_{i,t}$ and $z_{j,t}$ be the standardised residuals of asset returns of economy *i* and *j* at time *t* respectively, $I \neq j$. The GARCH process, as suggested in Engle (2002), is as follows:

$$q_{ij,t} = \bar{\rho}_{ij} + \alpha(z_{i,t-1} z_{j,t-1} - \bar{\rho}_{ij}) + \beta(q_{ij,t-1} - \bar{\rho}_{ij}) \quad \text{(A1)}$$

and

$$\rho_{ij,t} = \frac{q_{ij,t}}{\sqrt{q_{ii,t} q_{jj,t}}} \quad \text{(A2)}$$

where q_{ij} is the off-diagonal elements of the variance-covariance matrix, $\bar{\rho}_{ij}$ is the unconditional expectation of the cross product $z_{i,t}z_{j,t}$ and $\rho_{ij,t}$ is the conditional correlation between the asset returns of economy *i* and *j* at time *t*.[14]

ii. Spillover index (SI)

The spillover index, proposed by Diebold and Yilmaz (2008), measures the return spillovers across markets by aggregating the variance decomposition of equity returns in a vector autoregressive (VAR) model. A higher SI implies that a larger proportion of the volatility in any one market can be accounted for by shocks originating in other markets. Similar to the DCC, the framework of SI could facilitate study of the trend of financial markets interdependence.

In this paper, we follow the bivariate-VAR model given in Diebold and Yilmaz (2008):

$$R_t = AR_{t-1} + \varepsilon_t \tag{A3}$$

where $R_t = (r_{1,t}, r_{2,t})'$ is the vector of equity returns, A is a coefficient matrix and ε_t is the residual matrix. By covariance stationarity, the model can be written in a moving average form:

$$R_t = \Theta(L)\varepsilon_t \tag{A4}$$

where $\Theta(L) = (1 - AL)^{-1}$, which in turn can be rewritten as:

$$R_t = B(L)U_t \tag{A5}$$

where $B(L) = \Theta(L)Q_t^{-1}$, $U_t = Q_t\varepsilon_t$, $E(U_tU'_t) = I$ and Q_t^{-1} is the unique lower-triangle Cholesky factor of the covariance matrix of ε_t. The one-step ahead forecast of R_t has an error vector given by:

$$\hat{V}_{t+1|t} = R_{t+1} - R_{t+1|t} = B_0U_{t+1} = \begin{bmatrix} b_{0,11} & b_{0,12} \\ b_{0,21} & b_{0,22} \end{bmatrix} \begin{bmatrix} u_{1,t+1} \\ u_{2,t+1} \end{bmatrix} \tag{A6}$$

[14] See Engle (2002) for a detailed description of the simple DCC model and the estimation procedure.

which has the covariance matrix:

$$E(\hat{V}_{t+1|t}, \hat{V}'_{t+1|t}) = B_0 B_0' \quad \text{(A7)}$$

Therefore, the variance of the one-step ahead error in forecasting the two returns are $b_{0,11}^2 + b_{0,12}^2$ and $b_{0,21}^2 + b_{0,22}^2$ respectively. Diebold and Yilmaz (2008) thus define the SI as the cross-market error variance as a percentage of total error variance:

$$SI = \frac{b_{0,12}^2 + b_{0,21}^2}{b_{0,11}^2 + b_{0,12}^2 + b_{0,21}^2 + b_{0,22}^2} \times 100\% \quad \text{(A8)}$$

This formulation can be easily generalised to any pth-order N-variable VAR model, and making H-step ahead forecast. In our estimation, it is a 2nd-order, 12-variable VAR model, with a 10-step ahead forecast.

iii. Test for the existence of equity market contagion

To facilitate the test for the existence of contagion between equity markets, Forbes and Rigobon (2002) define contagion as a significant increase in correlation in equity returns between two markets during a pre-defined turmoil period. In their study, they proved that correlation coefficient is increasing with respect to volatility, so they proposed an adjustment for the correlation coefficient during the turmoil period. Because return volatility always increases during crisis time, a test based on the upwardly biased correlation would result in evidence of spurious contagion.

Consider a test for the existence of contagion between country A and country B, in which country A is the origin of the crisis. The standard deviations of country A during the normal period and that during the turmoil period are $\sigma_{A,normal}$ and $\sigma_{A,turmoil}$ respectively. It is usual to see $\sigma_{A,turmoil} > \sigma_{A,normal}$. If, in addition, there is no change to the fundamental relationship between the equity returns in the two markets, then the correlation of equity returns during the turmoil period will be larger than that during normal times, i.e. $\rho_{turmoil} > \rho_{normal}$. Forbes and Rigobon (2002) show that the adjusted correlation is given by:

$$\tilde{\rho}_{turmoil} = \frac{\rho_{turmoil}}{\sqrt{1+\left(\frac{\sigma^2_{A,turmoil}}{\sigma^2_{A,normal}}-1\right)\left(1-\rho^2_{turmail}\right)}} \tag{A9}$$

This is a non-linear scaling function, which is decreasing with respect to the change in variance of equity return in country A.

To examine the existence of contagion between equity markets in A and B, the null hypothesis is:

$$H_0 : \tilde{\rho}_{turmoil} = \rho_{normal} \tag{A10}$$

The simple t-test for comparing the size of two correlation coefficients is used in this study. The test statistic is given by:

$$T = \frac{F(\tilde{\rho}_{turmoil}) - F(\rho_{normal})}{\sqrt{\frac{1}{N_{turmoil}-3}+\frac{1}{N_{normal}-3}}} \tag{A11}$$

where $N_{turmoil}$ and N_{normal} are the numbers of observation of the specified periods respectively; and $F(.)$ is the operator of Fisher's transformation:

$$F(x) = \frac{1}{2}\ln\left(\frac{1+x}{1-x}\right) \tag{A12}$$