

The transmission of international stock market volatilities

Bruce Q. Budd¹ 

Published online: 3 May 2017

© Springer Science+Business Media New York 2017

Abstract This paper examines the spillover effects of cluster volatility between the equity markets of the U.S. and four Asia-Pacific countries in the context of two significant U.S. market crises (the financial crisis of 2007 and the threat of the U.S. government refusing to raise its “debt ceiling” and subsequently defaulting on its debt in 2011). The paper seeks to determine whether market crises in the U.S. and the increased volatility that they generate in the U.S. equity market, lead to similar increases in equity market volatilities in Asia-Pacific countries. Results from a VECH multivariate generalized autoregressive conditional heteroskedasticity GARCH specification model indicate that own-volatility clustering is evident in the analyzed sample, while cross-volatility clustering, has an economically smaller effect. The lags of both own- and cross-volatility show a significant explanatory power in the sample. The dummy coefficients of the two U.S. market crises are positive and significant, implying that volatility effects were exacerbated during the two sampled U.S. crisis periods. A series of second stage DCC-GARCH estimations are calculated between the five national stock exchange indices. Results show evidence of dynamic conditional correlation (integration) between the returns of the respective stock markets and the S&P500 Index during the crisis periods. These results are meaningful in the context of portfolio diversification and trade strategies within, and across markets. U.S. investors seeking the diversification benefits from foreign equity indices during crisis periods of high domestic market volatility may find those benefits diminished by linked patterns of stock price activity and increased market integration.

Keywords Co-movement · GARCH · Spillovers · Structural break · Volatility

JEL Classification G15 · F36

✉ Bruce Q. Budd
bbudd@dah.edu.sa

¹ Hekma School of Business & Law, Dar Al-Hekma University, Prince Majed-Al Faiha 6702, Jeddah 22246, Saudi Arabia

1 Introduction

Empirical observations of linked patterns of stock price activity between national equity exchanges are becoming more apparent as global trade and markets move closer together. Manifestly these observations of financial disturbances were particularly witnessed during the aftermath of the 2007 U.S. financial crisis when the subsequent impact on western stock markets displayed distinct linked clusters of global volatilities. This paper examines the spillover effects of cluster volatility between the equity markets of the U.S. and four Asia-Pacific countries (Australia, China, Japan, South Korea) in the context of two significant U.S. market crises: the financial crisis of 2007 and the threat of the U.S. government refusing to raise its “debt ceiling” and subsequently defaulting on its debt in 2011). The former crisis originating from the sprawling U.S. structural domestic financial banking collapse and the latter having developed from the release of U.S. debt ceiling announcements relating to a potential threat of a US debt default for the first time in the history of the economy. Both events triggered periods of high anxiety across U.S. financial markets and the broader U.S. economy. This paper seeks to determine whether market crises in the US and the increased volatility that they generate in the U.S. equity market, lead to similar increases in equity market volatilities in Asia-Pacific countries.

The motivation of this paper relates to the identification and implications of excess volatilities affecting cross-country spillovers on global markets generated by exogenous shocks from the richest economy in the world, namely the United States. The events of a financial crisis provide a unique and practical opportunity to measure the changes and characteristics in stock returns. The investigation of any relationship between stock returns and volatility is of vital relevance to modern portfolio theory. Patterns of co-movement between these exchanges as well as potential evidence towards global capital market integration are investigated. It is against this background that this study seeks to answer the following research questions and provide further insight into the internal links between the financial return and the past errors and the relations between the five sample stock exchanges: Are asset returns of each exchange linked? Does the volatility of one market lead the volatility of other markets in the Asia-Pacific region? Does a shock on a market increase the volatility on another market? Are market movements converging and becoming more integrated? Does the US S&P 500 show evidence of financial transmission signals to Asia-Pacific equity markets in a clear leader-follower relationship, or are other equity markets in the Asia-Pacific markets in the region more influential?

The index price of each stock market provides a proxy for business confidence and future expectations of economic activity of that country. It is this signal which is used to gauge each country’s market exposure. Countries are becoming more sensitive to the global impact of systemic economies such as China and their financial spillovers. While macroeconomic policies can ease the global exposure of financial shocks, inevitably some impacts are felt. Boorman et al. (2010) researched the slowdown on emerging and developing markets due to the global financial crisis. Initially, though these countries were affected by the crisis, the implementation of swift policy reforms showed evidence of prompt recovery. Raghaven, (2008), researched the impact of the Asian financial crisis on Malaysia, Singapore and Hong Kong. She concludes the world factors to be more prominent during the pre-crisis era while regional factors seem to

have gained more impetus in the post crisis era. The economic prominences of Asia-Pacific financial markets have emerged considerably, particularly since the aftermath of the Asian Financial crisis 1997 to 1998 and subsequent exponential growth of global trade. This increase in global expansion has been stimulated by the improved cooperation of heightened cross-border capital flows, transparency of transactions via information technology, the ease of capital mobility regulations, as well as added competitive market pressure on corporations to seek capital outside their home country.

This paper compares cluster volatility of asset returns transmission of four Asia-Pacific equity markets and the S&P500 Index using VECH-Multivariate Generalized Conditional Heteroskedasticity (MGARCH) methodology. It further tests for the transmission of returns and volatilities across all the stock markets incorporating asymmetric responses. In addition, a simultaneous estimation, using the Dynamic Conditional Correlations of the four Asia-Pacific countries with that of the US S&P500 is followed to detect any evidence of correlation (contagion) changes during the period 2000 to 2014.

Weekly data from the US Standard and Poors 500 and the top four major stock exchanges: Australia, China, Japan and South Korea are collected, collated, analysed and estimated for the period January 5th 2000 to September 8th 2014, ($n = 765$ observations). Caution is taken of the different methodologies of each country’s index calculation. For example, the S&P500 and Nikkei are different in nature; the former is a weighted average of stocks with each weight being proportional to its market value while the latter is a simple average of stocks. The four selected markets are highly integrated and prominent in the Asia-Pacific region in terms of capitalization of stock markets. As illustrated in Table 1, collectively these top four countries represent, according to the Dow-Jones Asia/Pacific total stock market Indices, more than 73% of market capitalization by value of the 18 countries represented in the region, (Financial, 2014). These samples should therefore provide plausible benchmarks of each countries’ global equity market sensitivity.

As a barometer of economic climate, any innovation or shock, economic or otherwise, impacting on these economies will be translated in the movements of their respective stock markets. The Asia-Pacific region is inherently oriented on export trade and therefore possibly more sensitive to any global turbulence than other regions. All financial crises impact stock values to a greater or lesser degree. Shocks impact business expectations, consumer confidence, price earnings and ultimately stock prices. Within a background of widening international trade and the ensuing integration of financial activities, these countries have been selected as a representative sample of a strategically important region in a global perspective of international finance.

Table 1 Country percentage distribution of Asia/Pacific total stock market indices, July 2014

Country	Percentage
Japan	39.67
Australia	13.18
China	10.85
South Korea	9.06
14 other countries	27.24

Source: (Financial, 2014)

This empirical analysis investigates any insight into the nature of interaction and linkage between these equity markets. The time series data are tested for any structural breaks. Parameter stability and multiple structural break tests developed by Bai and Perron, (2003) are used separately to identify such endogeneous breaks which, if not identified, could generate spurious results. The subsequent identified structural break dates are then incorporated into the equation as dummy variables to observe volatility integration and contagion. The inclusion of these dummy variables measure any statistical impact identified by the 2008 Financial Crisis or/and the 2011 US Debt ceiling debacle on the sample economies. The volatility persistence within each countries' stock exchange returns is also measured using these coefficients. The impact of the fiscal ceiling debacle and subsequent global distress of debt default may have had volatility implications for those particular indebted markets. There are no *a priori* expectations.

The following section provides a literature review. Section three describes model specification used in this study. Section four and five, respectively report the data analysis and results. The final section provides discussion and concluding observations.

2 Literature review

Much literature investigates spillover volatility employing a variety of GARCH models (Bollerslev, 1986). These models analyse volatility clustering, fat tails, and volatility spillover: common features in time-series stock data. Many provide evidence of linkages and contagion effects on different countries and their respective financial markets and foreign currencies (Hamao and Masulis, 1990; Lin et al. 1994; Longin and Solnik, 2001; Forbes and Rigobon, 2002; Bekaert et al. 2005). Further literature reports an increasing amount of evidence on the predictability in volatility across various financial assets and markets (Bollerslev et al. 1992; Adjaoute et al. 1998). In a world of market uncertainties, the study of cluster volatility is clearly of crucial prominence to the research topic of global risk. The interpretation of cluster volatility in asset returns means that “large price changes follow large price changes of either sign and small price changes follow small prices changes of either sign” (Mandelbrot, 1963). Many studies have modeled volatility by controlling for structural changes in case of stock returns such as Cunado et al. (2004), Malik et al. (2005), (Hammoudeh and Li, 2008), (Wang and Moore, 2009), exchange rate returns, such as (Malik, 2003), Rapach & Struss, (2008) and real GDP growth Cecchetti, Flores-Lagunes, & Krause. However all neglect to consider or identify the impact of any endogenous break dates in their data samples.

The Autoregressive Conditional Heteroskedasticity (ARCH) process proposed by Engle (1982) and the generalized ARCH (GARCH) by Bollerslev (1986) are well known empirical applications for measuring time-varying volatility modelling of speculative prices. Evidence from Kanas, (1998) using Exponential GARCH (EGARCH) model to capture potential asymmetric effects of volatility of daily stock market returns across the three largest European stock markets, Frankfurt, London and Paris, reveal reciprocal spillovers between London and Paris, and between Paris and Frankfurt. Further supporting evidence from Savva et al. (2009), using the asymmetric Dynamic Conditional Correlations (DCC) version of the VAR- multivariate EGARCH model

across four global markets: Frankfurt, London, New York and Paris stock markets, show further evidence of the presence among foreign markets for both returns and volatility spillovers. Using EGARCH, Nam et al. (2008), investigate volatility spillovers from US market to Hong Kong, Korea, Malaysia, Singapore and Taiwan stock markets before and after the 1997 Asian financial crisis. The investigation of daily prices show there was a decrease in price and volatility spillovers post 1997 crisis except for Korea. More specifically researchers have focused on empirical evidence of volatility transmission across several financial markets, dividing them between how individual return series are integrated across markets (Eun and Shim, 1989), and how volatility transmits in different markets (Caporale et al. 2006). Johnson and Soenen, (2002); and Sharma & Wongbangpo, (2002) research stock market integration in the Asian region using a cointegration technique among different Asian stock markets. Results suggest some countries have closer ties to the US while others are closer to the Japanese market. More recently, Neaime, (2012), using the GARCH model, examines the global and regional financial linkages between MENA stock markets and the more developed financial markets, and on the intra-regional financial linkages between MENA countries' financial markets. Results show the presence of spillover volatilities among stock markets of MENA countries. Abbas, Khan, & Ali Shah, (2013) employ a bivariate EGARCH model to examine the volatility transmission among regional equity markets of China, India, Pakistan, and Sri Lanka. Their paper provides ample statistical evidence of the presence of volatility transmission and the long running relationship among Pakistan's regional equity markets China, India and Sri Lanka. The volatility spillover is mostly from a larger market to a smaller market and identifies that the comparative size of the markets to the world financial market is clearly a significant factor to consider.

Using another adaptation of the GARCH model, Gilenko and Fedorova, (2014) use the Multivariate GARCH-in-mean approach. They examine the mean-to-mean and volatility-to-volatility spillover effects for the stock markets of the BRIC countries. Their 4-dimensional BEKK-GARCH-in-mean model compares the pre-crisis and recovery periods of the USA, Germany, Japan and the MSCI Emerging index. The research identifies spillover effects differ considerably depending on the time period under study: pre-crisis, crisis or recovery period. For each period they show that the influence of the developed stock markets (USA, Germany and Japan) on the BRIC stock markets, though present, it decays over time.

(Ding et al. 2014) analyze the volatility linkage across the U.S., European, German, Japanese, and Swiss equity markets from 1999 to 2009. Both the unconditional and conditional correlations exhibit large fluctuations during the sample period. The structure of the volatility correlation before and during the recent global financial crisis does not show significant changes. Other papers have examined the implied volatility correlations in the global equity markets analyze the implied volatilities from the stock index option prices in the U.S., the U.K., German, and Finnish markets. They find a strong relation, and the U.S. stock market is the leading source of uncertainty (Nikkinen and Sahlstrom, 1996).

Lee et al. (2014) adopt a bivariate generalized autoregressive conditional heteroskedasticity (GARCH) model on a sample of eight global markets: Japan, Korea,

Taiwan, Belgium, Germany, Netherlands, UK, and the Eurozone. They identify a long-run equilibrium relationship existed between market sentiment in the US and other major global markets during the subprime crisis period, and a global contagion of market sentiment occurred from the US market on September 15, 2008 to Japan, Korea, Belgium, Germany, Netherlands, and the Eurozone. They conclude that the major global markets are all interrelated.

The contribution of this paper is to extend previous cited research to ascertain whether market crises in the U.S. and the increased volatility that they generate lead to similar volatilities in other global equity markets. Unlike other research, this paper uses the VECH-MGARCH and the asymmetric Dynamic Conditional Correlation-EGARCH models to investigate the extent of financial integration of the five stock markets. The former allows the investigation of the persistence of own domestic volatiles as well as the magnitude and direction between the international cross-volatilities linkages of these equity markets. The strength of this framework allows past conditional variances to appear in the current conditional variance equation and is used in the presence of heteroskedasticity, leptokurtic residuals and time-changing conditional variances. The latter model uses simultaneous estimations to detect any evidence of correlation (contagion) changes of the sample countries during the period 2000 to 2014.

3 Model specifications

Financial time series data are unique due to the fact they typically exhibit volatility clustering, and stock market returns often exhibit heteroskedasticity. Hence the advantage of the Multivariate GARCH model is, that it takes into account the interaction of more than one volatility spillover in more than one time series, which improves the analysis of time-varying and volatility clustering analysis within and between markets. The concern of this paper is to analyse the relationships between volatilities of several markets and variance-covariance matrices of the major stock markets. In this case the VECH model proposed by Bollerslev et al. (1988). The acronym VECH refers that the model is expressed in terms of vectorised conditional matrices. According to Scherrer and Ribarits (2007), the VECH model allows for more flexibility. Unlike a univariate model which considers the volatility of single asset or market over time, the VECH multivariate model allows for the estimation of time-varying volatilities and covariances of several different assets (markets) into a vector to estimate returns and volatility simultaneously and systematically. Hence a multi-variable asymmetric GARCH in the line of the diagonal VECH-MGARCH conditional variance-covariance equation incorporating asymmetric responses model, proposed by Engle and Kroner (1995), is followed. This model accounts for any irregularities observed within the price indices and further, tests for the transmission of returns and volatilities across all the stock markets simultaneously.

The traditional parsimonious multivariate GARCH model is extended to incorporate the conditional variance matrix (H_t) which has five dimensions representing five exchanges. Each diagonal and non-diagonal element of the

matrix represents the variance and the covariance terms, respectively. In matrix notation, (H_i) can be written as:

$$H_i = \begin{bmatrix} h_{11t} & h_{12t} & h_{13t} & h_{14t} & h_{15t} \\ h_{21t} & h_{22t} & h_{23t} & h_{24t} & h_{25t} \\ h_{31t} & h_{32t} & h_{33t} & h_{34t} & h_{35t} \\ h_{41t} & h_{42t} & h_{43t} & h_{44t} & h_{45t} \\ h_{51t} & h_{52t} & h_{53t} & h_{54t} & h_{55t} \end{bmatrix} \tag{1}$$

where $i = 1$ for US, $i = 2$ for Japan, $i = 3$ for Australia, $i = 4$ for China; $i = 5$ for Korea; and h_{iii} is a conditional variance at time t of the stock return of country i and h_{ijt} denotes the conditional covariance between the stock returns of country i and country j (where $i \neq j$) at time t . The element i incorporates the own-volatility spillover and j cross-over spillover for each country from country j to i when $i \neq j$. The diagonal VECH model can be written incorporating the VECH matrix as follows:

$$\text{Vech}(H_t) = C + \gamma_0 GFC_t + \gamma_1 DC_t + \text{Avech}(\varepsilon_{t-1} \varepsilon'_{t-1}) + B\text{vech}(H_{t-1}) \tag{2}$$

where A and B are $\frac{1}{2} N(N+1) \times \frac{1}{2} N(N+1)$ parameter matrices and C is a $\frac{1}{2} N(N+1) \times 1$ vector of constants. The diagonal elements of matrix A ($a_{11}, a_{22}, a_{33}, a_{44}$ and a_{55}) measure the influences from past squared shocks on the current volatility ie own-volatility shocks, while non-diagonal elements (a_{ij} where $i \neq j$) determine the cross product effects of the lagged shocks on the current co-volatility. Similarly, the diagonal elements of matrix B ($b_{11}, b_{22}, b_{33}, b_{44}$, and b_{55}) determine the influences from past squared volatilities on the current volatility and non-diagonal elements (b_{ij} where $i \neq j$) measure the cross-volatility spillovers of the lagged co-volatilities on the current co-volatility. The dummy variables $\gamma_0 GFC_t$ and $\gamma_1 DC_t$ represent the periods of global financial crisis and debt ceiling debacle, respectively. Parameter stability and multiple structural break test developed by Bai and Perron (2003) are used to identify endogeneous break dates for the period 2004–2014. The maximum likelihood function is used to generate the number of parameters to be estimated and ensure positive semi-definiteness of the variance-covariance transformation as suggested by Bollerslev et al. (1988).

This research further extends the investigation by employing a two-step bivariate GARCH and Dynamic Conditional Correlation (DCC) calculation to model the time varying volatility (conditional heteroskedasticity) of each market return. This model (Engle, 2002) provides the flexibility of univariate GARCH models coupled with parsimonious parametric models for the correlations. They are not linear but can often be estimated very simply with a two-step method based on the likelihood function. Its correlation structure is defined as:

$$P_t = [Q_t \odot I_N]^{-1/2} Q_t [Q_t \odot I_N]^{-1/2} \tag{3}$$

$$Q_t = (1-\alpha-\beta)Q + \alpha z_{t-1} z'_{t-1} + \beta Q_{t-1} \tag{4}$$

Where

$$\alpha + \beta < 1 \text{ and } \alpha > 0, \beta > 0$$

P_t time-varying positive definite conditional correlation matrix of the process ε_t .

$$\begin{aligned} \rho_{ij,t} = E\left(z'_t z_t | \mathcal{F}_{t-1}\right) &= \frac{E\left(z'_t z_t | \mathcal{F}_{t-1}\right)}{\sqrt{E\left(z'^2_{it} | \mathcal{F}_{t-1}\right) E\left(z'^2_{jt} | \mathcal{F}_{t-1}\right)}} = \frac{E\left(\epsilon'_t \epsilon_t | \mathcal{F}_{t-1}\right)}{\sqrt{E\left(\epsilon'^2_{it} | \mathcal{F}_{t-1}\right) E\left(\epsilon'^2_{jt} | \mathcal{F}_{t-1}\right)}} \\ &= \text{Corr } E\left(\epsilon'_t \epsilon_t | \mathcal{F}_{t-1}\right) \end{aligned}$$

I_N $[z'_t z_t]$

⊙ the Hadamard or element wise product of the two conformable matrices.

Q a sample covariance matrix of z_t .

ε_t $n \times 1$ vector of mean-corrected returns of n indices at time t .

z_t $n \times 1$ vector of *iid* errors with $E(z_t | z_{t-1}) = 0$ and $E(z'_t z_t | \mathcal{F}_{t-1}) = P_t = [\rho_{ij,t}]$,

Where \mathcal{F}_{t-1} is the information set up to and including $t-1$.

The proposed DCC estimators have the flexibility of univariate GARCH but not the complexity of conventional multivariate GARCH. These models, which parameterize the conditional correlations directly, are estimated in two steps— a series of univariate GARCH estimates and the correlation estimate. It is the outcome of the latter result of the series of correlations which are the focus of this paper.

4 Data

Weekly stock market price indices for the period January 5th 2000 to September 8th 2014 ($n = 763$ observations) are collected from Yahoo Finance (Yahoo.com, 2015). These data are computed from the stock market price index of US (S&P500), Japan (Nikkei225), Australia (ASX200), China, (Shanghai Composite), and South Korea (KOSPI Composite). Using weekly data rather than daily data provides the advantages of avoiding distortions of data associated with dissimilar public holidays and time zones of different markets. The data are all expressed as $r_t = \ln\left(\frac{p_t}{p_{t-1}}\right)$. Table 1 shows the descriptive statistics of weekly returns on the share price indices of the five countries. The coefficients are computed as first differences of natural logarithm. The mean returns range from a minimum negative -0.000145 for Japan to a maximum positive 0.000925 for Korea. The highest volatility (risk) of price changes, measured by the standard deviation, is 0.035904 for Korea. The variation between Korea, Japan (0.031219) and China (0.032929) are very close to each other suggesting close volatility between these series. A Mean Weekly S&P500 index return (adjusted for inflation but not for dividends) of 0.000336 reflects an average annualized return of 1.74% . This compares with: Japan -0.75% ; Australia 3.60% ; China 3.12% ; and Korea 4.81% . The comparatively low historical U.S. average annualized return reveals the devastating domestic impact of the GFC on the S&P500 Index compared to other

markets. The anomaly of Japan’s Nikkei225 average annualized return of -0.75% is attributed more to the deeper negative impacts of the latter years of the Japanese financial crisis (1997–2002), the GFC 2008 and the earth quake and tsunami of 2011. A visual representation of each countries’ market returns, depicted in Fig. 1, highlight these disparities. The measures of skewness indicate that all countries are negatively skewed, except for China. Negative skewness implies the left tail of the distribution of returns is particularly extreme, indicating large negative stock returns are more common than large positive returns. Excess kurtosis indicates that the distributions of returns for all markets are leptokurtic. The statistical distribution of the data are thereby interpreted as being more clustered around the mean, corresponding to a high peak and corresponding fat tails than a normal distribution. High kurtosis coefficients indicate a larger possibility of extreme movements. Generally, values higher than three are the given benchmark for higher peaks. The Jarque-Bera statistics are large and corresponding p -values are highly significant, rejecting the null hypothesis that the series are not normally distributed. Student- t distribution is followed for the VECH-GARCH and EGARCH (1, 1) processes. In a risk management context, assuming

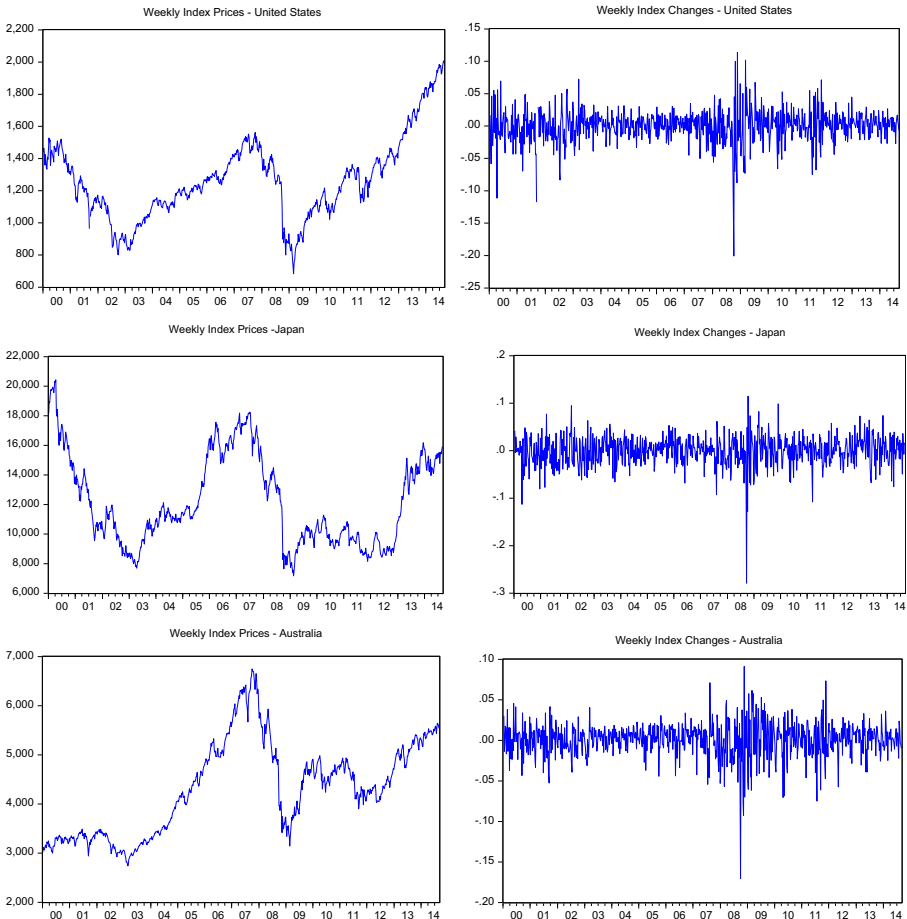


Fig. 1 Stock market weekly indices and weekly index changes, by Country, January 2000 to September 2014

normality when returns are fat-tailed will result in a systematic underestimation of the riskiness of the output (Brooks, 2014).

The estimated Pearson correlation coefficients of the five stock markets are also presented in Table 2. All statistics are positive except between China and Australia. The highest correlation results are revealed between Korea and Japan, (0.50), and US and China (0.29). The lowest (−0.04) is reported between China and Australia. Statistically these data generally reveal a relatively low positive inter-relationship between all equity markets and little evidence of integration except for Korea and Japan.

Figure 1 provides a visual perspective of each country's weekly closing prices of each index and the weekly returns of each index from January 2000 to September 2014. A cursory look at the weekly index price changes of U.S. indices show a period of instability in the financial markets identified by two sharp fluctuations in the weekly returns of the S&P500 Index during 2008 and to a much lesser extent in 2011. The larger shock occurred during the global financial crisis triggered by the bankruptcy of Lehman Brothers in September 2008. The second period is identified as the debt ceiling which was triggered by a surprise announcement from the Republican Speaker of the House of Representatives, John Boehner, in a speech to the Economic Club of New York, May 8th 2011, stating: "... there will be no debt limit increase..." (The New York Times, 2011). This announcement prompted a period of high anxiety across US financial markets and the broader US economy over the following three months. Comparison of the Asia-Pacific time series indices during the same periods show some

Table 2 Descriptive statistics of five national stock market weekly indices, 2000 to 2014

	U.S.	Japan	Australia	China	Korea
Mean	0.000336	−0.000145	0.000694	0.000601	0.000925
Median	0.001599	0.002293	0.002615	8.02E-05	0.003577
Maximum	0.113559	0.114496	0.091137	0.139447	0.170319
Minimum	−0.200837	−0.278844	−0.170163	−0.148979	−0.229288
Std. Dev.	0.025709	0.031219	0.021306	0.032929	0.035904
Skewness	−0.857883	−1.159919	−1.059781	0.045034	−0.519823
Kurtosis	9.983249	11.56977	9.889984	5.159836	7.528776
Jarque-Bera	1643.935	2505.903	1652.036	48.5626	686.4035
Probability	0.000000	0.000000	0.000000	0.000000	0.000000
Observations	763	763	763	763	763
Correlation coefficients					
US	1.00				
Japan	0.16	1.00			
Australia	0.16	0.10	1.00		
China	0.29	0.13	−0.04	1.00	
Korea	0.16	0.50	0.09	0.25	1.00

Sources: Weekly stock market price indices for the period January 5th 2000 to September 8th 2014 ($n = 763$ observations) are collected from www.finance.yahoo.com. These data are computed from the stock market price index of S&P500 (U.S.), Nikkei225 (Japan), ASX200 (Australia), Shanghai Composite (China), and KOSPI Composite (South Korea)

visual evidence that these countries were also affected by the financial crisis, to a greater or lesser degree, though evidence of the debt crisis is far from apparent. The purpose of this purpose to examine the spillover effects of cluster volatility between the equity markets of the U.S. and the four Asia-pacific markets and to determine whether these two market crises in the U.S. and the increased volatility that they generated in the U.S. equity market, lead to similar increases in equity market volatilities in Asia-Pacific countries.

It is observed that all series show varying degrees of volatility especially after the global financial crisis. These series each illustrate a feature specific to non-linear models, namely volatility clustering i.e. large (small) volatility followed by large (small) volatility. In addition, the excess returns display periods of turbulence and tranquility. This suggests there is volatility clustering. Since the clusters of each Exchange tend to occur simultaneously, volatility must be modelled systematically. Thus, the non-linear dependencies can be explained by the presence of conditional heteroskedasticity, a feature common to the financial variables.

The residuals of the data are each tested for heteroskedasticity, i.e. ARCH effect. Results of all five markets for heteroskedasticity show that both the F-statistic and LM-statistics (Obs*R-squared) are very significant, signifying the presence of ARCH in the series. The respective graphs in Fig. 1 pick out runs of positive and negative residuals around the zero. The residuals are the unexplained part of the regression in which estimates of the errors can be observed. Long runs of positive residuals and long runs of negative residual can provide strong visual evidence of serial correlation. The time series data reveal that the volatility of all market prices are nonlinear and the conditional variances are time-varying. To statistically and efficiently measure these time changing variances an ARCH-type model introduced by Engle (1982) and generalized by Bollerslev (1986) is adopted. To capture these volatility clustering effects over time the application of a GARCH model would be valid. The GARCH model allows the conditional variance to be dependent on its previous lags. But first to ensure the GARCH framework is appropriate, the presence of a unit root is tested. The Augmented Dickey Fuller test is used to test the stationarity of the time series. Results first show failure to reject the null of a unit root of the stock market returns providing evidence that the series are $I(1)$ variables with stochastic trends. The equity indices' returns are further transformed as the difference of the logarithm of these indices to ensure stationarity. This is consistent with much of the empirical evidence found for developed capital markets, in which the behavior of the stock prices is characterized by a martingale process. Tests using the Ljung-Box Q-Statistic and the Breusch-Godfrey Serial Correlation LM Test for the five-return series and their corresponding squared returns accepted the null hypothesis of no serial correlation.

Researchers using the GARCH model often assume the existence of a stable GARCH process in volatility forecasting. Failure to account for structural breaks in the unconditional variance of stock market returns can lead to sizeable upward biases in the degree of persistence in estimated GARCH models Diebold (1986), Hendry (1986), Lamoureux and Lastrapes (1990) and Mikosh and Starica (2004)). A parameter stability and multiple structural break test developed by Bai and Perron (2003) is used to identify any endogeneous break dates for the period 2000–2014.

EViews9 software supports both the Bai and Perron (2003) tests of breaks versus none test and information criterion methods for determining the number of breaks. The

sample is tested for parameter constancy with unknown breaks. The break date is determined when the null hypothesis of constancy cannot be accepted. The procedure is repeated until all the subsamples do not reject the null hypothesis, or until the maximum number of breakpoints allowed or maximum subsample intervals to test is reached. Table 3 shows the test results for the relevant two structural break points. In the first case, the maximized value clearly exceeds the critical value, so that the null of no breaks is rejected in favor of the alternative of a break in August 2008 and May 2011. Data for the VECG-GARCH specification estimation are appropriately restricted to accommodate dummy variables for the two U.S. market crises (financial crisis and the U.S. debt crisis) to capture the effects of these U.S. crises in Asia-Pacific equity markets. The value of one for the period from last week of August 2008 to April 2009 is taken to represent the structural break for the financial crisis and the structural break for the U.S. debt crisis debacle is designated to the second week of May 2011 to the end of October 2011.

5 Results

Table 4 provides the estimated variance coefficients for the Diagonal VECG-MGARCH(1,1) model, including the dummy variables. Student- t distribution is followed for the process. In a risk management context, assuming normality when returns are fat-tailed will result in a systematic underestimation of the riskiness of the output (Brooks, 2014). The diagonal elements of parameter coefficients of the matrix A as denoted in Eq. 2: a_{11} , a_{22} , a_{33} , a_{44} , and a_{55} quantify the impact from past squared shocks on the own domestic disturbances. These coefficients are statistically significant for all five markets which show the presence of ARCH effects and therefore imply the presence of volatility clustering. These own domestic volatility impacts are generally larger than cross-volatility impacts. The lowest own domestic spillover coefficient is recorded for Japan (0.049873) and the highest for Korea (0.0990849). This infers that past disturbance arising from one single exchange will have the strongest impact on its own future domestic volatility compared to disturbances originating from the other four foreign exchanges.

The remaining coefficients in each column represent each country's exchange market (a_{ij} where $i \neq j$) and identify the cross-product effects of the lagged shocks on

Table 3 Bai-Perron multiple structure test showing statistical significance of two breaks: August 2008; May 2011

sequentially determined breaks: 2			
Break Test	F-statistic	Scaled F-statistic	Critical value*
0 vs. 1**	75.46276	75.46276	10.58
1 vs. 2**	61.509590	61.509590	8.13
Break dates	Sequential	Repartition	
1	2008 August	2009 April	
2	2011 May	2011 October	

*Bai-Perron (Econometric Journal, 2003) critical values

**Significant at the 0.05 level

Table 4 Coefficient Estimations for Diagonal VECM-MGARCH(1,1) with Dummy Variables $Vech(H_t) = C + \gamma_0 GFC_t + \gamma_1 DC_t + Avech(\epsilon_{t-1} \epsilon'_{t-1}) + Bvech(H_{t-1})$

Diagonal VECM Parameters	US		Japan		Australia		China		Korea	
	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value
c_1	0.000008	0.0007*								
c_2	0.000004	0.0313**	0.000002	0.0036*						
c_3	0.000002	0.0009*	0.000001	0.0133*	0.000006	0.0010*				
c_4	0.000008	0.0280**	0.000003	0.9803	0.000009	0.0015*	0.000005	0.0272*		
c_5	0.000007	0.0315**	0.000007	0.0121*	0.000003	0.0037*	0.000001	0.4635	0.000002	0.0020*
$\gamma_0 GFC_t$										
γ_{01}	0.000457	0.0000*								
γ_{02}	4.38E-05	0.0000*	0.000237	0.0064*						
γ_{03}	1.89E-05	0.0046*	1.70E-05	0.0679**	0.000141	0.0080*				
γ_{04}	0.000160	0.0000*	-2.12E-05	0.0042*	0.000112	0.0000*	0.000119	0.0002*		
γ_{05}	3.52E-05	0.0050*	-1.14E-06	0.0000*	7.81E-05	0.0886**	7.01E-05	0.0967***	0.000127	0.0000*
$\gamma_1 DC_t$										
γ_{11}	1.16E-05	0.0068*								
γ_{12}	6.89E-05	0.3018	4.92E-05	0.1405						
γ_{13}	-2.08E-05	0.5971	-2.15E-05	0.1987	1.22E-05	0.3638				
γ_{14}	-1.68E-05	0.9888	-1.84E-05	0.1619	3.17E-05	0.3650	-7.35E-05	0.0352**		
γ_{15}	3.09E-03	0.3818	-1.34E-05	0.1920	1.10E-05	0.3160	1.30E-05	0.5645	1.61E-05	0.3063
$Avech(\epsilon_{t-1} \epsilon'_{t-1})$										
a_{11}	0.075838	0.0000*								
a_{12}	0.019451	0.0307*	0.049873	0.0004*						
a_{13}	0.005874	0.0000*	0.043988	0.0014*	0.047257	0.0000*				
a_{14}	-0.016490	0.0000*	0.039031	0.0481**	0.019080	0.3195	0.066364	0.0001*		

Table 4 (continued)

Diagonal Vech Parameters	US	Japan	Australia	China	Korea
	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.
a_{15}	0.010723	0.041474	0.040615	0.007715	0.090849
$Bvech(H_{t-1})$					
b_{11}	0.876229				
b_{12}	0.958138	0.920633			
b_{13}	0.950382	0.878159	0.928436		
b_{14}	0.873708	0.608173	0.845007	0.895392	
b_{15}	0.957085	0.904402	0.928725	0.939006	0.884257
$a_{it} + b_{it}$	0.952067	0.970506	0.975693	0.961756	0.975106
	<i>p-value</i>	<i>p-value</i>	<i>p-value</i>	<i>p-value</i>	<i>p-value</i>
	0.2059	0.0007**	0.0000*	0.5391	0.0000*
	0.0000*	0.0000*	0.0000*		
	0.0000*	0.0000*	0.0000*		
	0.0000*	0.2277	0.0000*	0.0000*	
	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*
		0.970506	0.975693	0.961756	0.975106

*1%, ** 5% and ***10% statistical significance

the current co-volatility. The size and magnitude of these estimations suggest that spillovers in each exchange influence the volatility of other exchanges, but compared to own-volatility coefficients, the impact is smaller. In other words, the lagged ARCH effects which are interpreted as the past country-specific shocks have a larger impact on their domestic future disturbances than past volatility shocks arising from other exchanges. Results show evidence of relative high and generally positive spillovers from all countries suggesting the markets are well-integrated. The weakest significant impact is from the China to U.S. (-0.016490) and the strongest spillover from Australia to Japan (0.043988).

Like the alpha coefficients, the diagonal elements of matrix B : ($b_{11}, b_{22}, b_{33}, b_{44}$ and b_{55}) measure the influences from past squared volatilities on the current volatility and the cross-product spillovers (b_{ij} where $i \neq j$) of the lagged co-volatilities on the current co-volatility. The coefficients are all positive and all statistically significant. Australia (0.928436) reveals the highest own-volatility spillovers effect and U.S. (0.876229) the lowest. This infers that the past volatility in Australia will have the strongest impact on its own disturbances compared to the other exchanges. The magnitudes of these effects of lagged symmetrical cross-volatiles on current cross-volatilities between the stock markets identify strong positive market integration except between China and Japan. The spillover impacts within the Asia-Pacific region show stronger cross-over volatility between themselves and the US exchange with the exception between China and Australia. Japan (0.958138) reveals the greatest degree of exposure (cross-volatility) to all market spillovers than any other market. Overall results indicate a presence of high positive volatility persistence across all markets. Japan shows the highest coefficient 0.970506 . All coefficients for volatility persistence are relatively close to one supporting the assumption of covariance stationarity.

The estimated coefficients for the dummy variable U.S. financial crisis are positive and statistically significant for all countries. The impetus of the crisis from 2008 increased the instability of stock returns in all markets. This implies the impact of the global financial crisis was indeed global and was felt in each market's own-volatility and cross-market (co-movement) volatility results identified within the structured sample break periods of the dummy variables. The global financial crisis clearly contributed to on-going volatilities throughout the four exchanges. The highest impact felt by the crisis was U.S. (0.000457) and the lowest was Korea (0.000127). The impact of spillovers is evident. In a period of catastrophic loss of investor confidence, escalating debt and rising default expenses, volatility was rife within all global stock markets. The results for the co-variance are also all positive and highly significant inferring increasing co-volatilities across all markets. The impact of the debt ceiling debacle revealed no statistical significance for any market except for China ($-7.35E5$) and the US ($1.16E-05$). The fact that China holds considerable US debt securities may suggest one explanation of this significant spillover impact. Cross-volatility spillovers are evident for U.S. to China.

To provide further evidence of market integration between these exchanges a two-step multivariate DCC-EGARCH model is adopted to estimate the conditional correlations of the indices. The objective of this analysis is to discuss the DCC outputs. The time-varying correlations can respond asymmetrically to positive or negative shocks in each stock market. The empirical DCC results indicate significant variation in the conditional correlations co-movements of the top four Asia-Pacific stock markets when

compared to the U.S. market throughout the sample period. Figure 2 illustrates these weekly dynamic correlation coefficients.

Overall the DCC coefficients provide some interesting results. All sample Asia-Pacific countries illustrate a generally positive dynamic conditional correlation with the Standard and Poors 500 Index. All the correlation series show certain common peaks and troughs, particularly during the global financial crisis though Japan seems slightly lagged compared to the rest of the markets. The markets show evidence of closer integration as the period progresses, moving generally closer together during the identified crises periods. Different magnitudes of the troughs show the relative degree of integration with the U.S. market relating to the relative impact of their economic

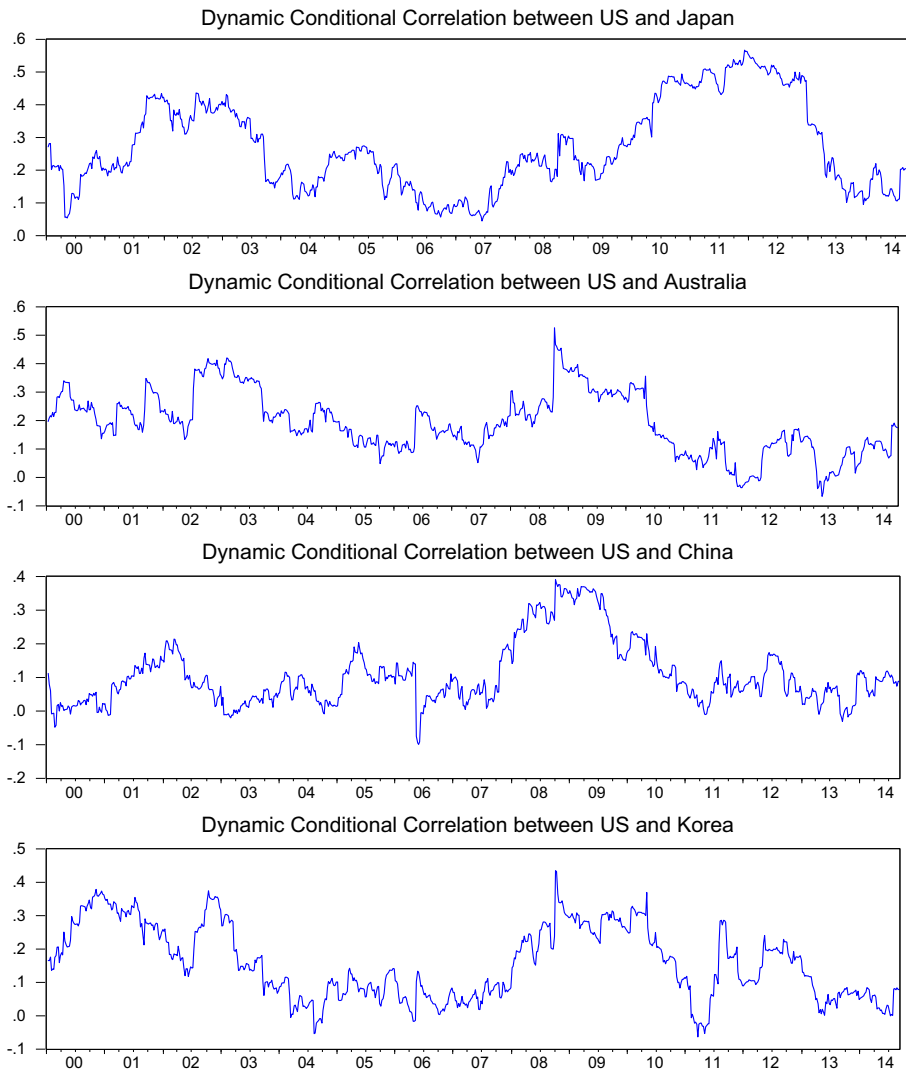


Fig. 2 Dynamic conditional correlation graph 2000–14 - S&P500 correlated with each Asia-Pacific stock market index

phase of economic growth. The significance of these data illustrate the correlations in such periods move closer together and to a higher degree of correlation during the crises periods compared to more ‘normal’ periods of stock market growth. This evidence of contagion seems stronger between the US and Japan reaching greater than +0.5 coefficient.

Consistent with prior literature, (Graham et al. 2012; Uddin et al. 2014), evidence from this analysis suggests the pattern of the relationship for all stock market integration has changed over time. Whether this phenomenon of increased co-movement between international stock markets is permanent or temporary is debatable. Findings suggest that the increase in stock co-movement of many countries is attributed to many factors. The degree of integration and subsequent spillovers between economies is influenced by many dynamic barriers such as the international immobility of capital, opacity and asymmetry information as well as the extent of political and economic obstacles. Effective short-term macroeconomic stabilising policies can provide a cushion against the global financial and European crises, dampening the regional impact of sovereign debt collapse for example. Since the earlier Asian financial crisis, an attempt by Asian countries to compete with larger western financial markets have initiated financial integration processes to remove such financial barriers (Tan et al. 2012). Markets have deepened with increasing capitalization, and become more globally integrated, broadening and potentially increasing the exposure of these regions’ financial assets (Hassan and Malik, 2007; Harju and Hussain, 2008; Karunanayake et al. 2010). Dajeman et al. (2012) suggests the global financial crisis of 2008 have increased their already high level of co-movement between stock markets. Further research suggests that the trend towards global capital market integration is now becoming more permanent (Arouri et al. 2001; Pukthuanthong and Roll, 2009). This research identifies world factors (in this case the US) being more prominent during the crisis era while regional factors seem to have gained more impetus in the post crisis era. Without doubt the economic prominences and integration of Asia-Pacific financial markets have emerged considerably.

6 Discussion and concluding observations.

Using a sample of weekly index return data from 2000 to 2014 collected from the S&P500 Index and the four largest equity indices in the Asia-Pacific market, the paper models the conditional variance-covariance structure of the five markets using a VECH-MGARCH specification. The model also accommodates time dummy variables for the two U.S. market crises to capture the possible cluster volatilities of the U.S. which may generate an impact on Asia-Pacific equity markets. The starting and ending dates of the crises are determined using a multiple structural break analysis (Bai and Perron, 2003). A two-step, multivariate DCC-EGARCH model is then estimated to analyze the degree to which the five markets being considered reveal evidence of integration over time.

The results of the VECH-MGARCH analysis indicate that own-volatility clustering is evident in the sample analyzed, while cross-volatility clustering, although still significant, has an economically smaller effect. The results also indicate that lags of both own- and cross-volatility have significant explanatory power in the sample. The

coefficients on the crisis dummies are also positive and significant, suggesting that volatility effects are worsened during crises periods in the U.S. Finally, the DCC-EGARCH estimation suggests higher dynamic correlation changes between indices during the crises periods.

Results provide strong evidence that all exchanges are well-integrated with high and positive spillovers. Asset returns of each exchange are linked. The volatility of one market does lead the volatility of other markets in the Asian-Pacific region. The U.S. S&P500 shows clear transmission signals to Asia-Pacific equity markets. The impact of the fiscal ceiling debacle and subsequent global distress of debt default showed statistically significant impact on the US exchange and the China exchange, the largest holder of US debt, but no impact on other markets. Countries are not free of country-specific risk, as illustrated by the different magnitudes of correlation coefficients, though these countries' indices move relatively in the same directions. This is clear evidence of tightening market integration. This paper suggests that these results are meaningful in the context of portfolio diversification. U.S. investors seeking the diversification benefits from foreign equity indices during crisis periods of high domestic market volatility may find those benefits diminished by linked patterns of stock price activity and increased market integration.

References

- Adjaoute K, Bruand M, Gibson-Asner R (1998) On the predictability of the stock market volatility: does history matter? *Eur Financ Manag* 4(3):293–319
- Arouri E, Boubaker S, Nguyen D (2013) *Emerging markets and the global economy: a handbook*. Academic Press, Oxford
- Bai J, Perron P (2003) Computation and analysis of multiple structural change models. *J Appl Econ* 6:72–78
- Bekaert G, Harvey C, Ng A (2005) Market integration and contagion. *J Bus* 78(1):39–69
- Bollerslev T (1986) Generalized autoregressive conditional heteroscedasticity. *J Econ* 31:307–327
- Bollerslev T, Chou R, Kroner K (1992) ARCH modeling in finance. *J Econ* 52(1–2):5–59
- Boorman J, Fajgenbaum J, Bhaskaran M, Kohli H, Arnold D (2010) The new Resilience of emerging market countries: weathering the recent crisis in the global economy. In: *ADB Regional Forum on the Impact of Global Economic and Financial Crisis*. ADB Headquarters, Manila. In *Economic Papers* 411, Oct. 2010. Economic and Financial Affairs, European Commission Publications.
- Brooks C (2014) *Introductory econometrics for finance*. Cambridge University Press, Cambridge
- Caporale G, Pittis N, Spagnolo N (2006) Volatility transmission and financial crisis. *J Econ Financ* 30(3):376–390
- Cunado J, Gomez Biscarri J, Perez de Garcia F (2004) Structural changes in volatility and stock market development: evidence for Spain. *Journal of Bank Finance* 28:1745–1773
- Dajeman S, Festie M, Kavkler A (2012) Comovement in the Eurozone. *J Int Money Financ* 37:353–370
- Diebold F (1986) Modelling the persistence of conditional variance: a comment. *Econ Rev* 5:51–56
- Ding L, Huang Y, Pu X (2014) Volatility linkage across global equity markets. *Global Financ Journal* 25:71–89
- Engle R (1982) Autoregressive conditional heteroscedasticity with estimates of the variance of United Kingdom inflation. *Econometrica* 50:987–1008
- Engle R (2002) Dynamic conditional correlation - a simple class of multivariate GARCH models. *Journal of Business and Economic Studies* 20:251–276
- Engle R, Kroner K (1995) Multivariate simultaneous generalized ARCH. Discussion Paper, University of California, San Diego, pp 89–57R
- Eun C, Shim S (1989) International transmission of stock market movements. *J Financ Quant Anal* 24:241–256

- Financial M-H (2014) Dow Jones/Pacific Total stock market indices. http://www.Djindexes.Com/mdsidx/downloads/fact_info/Dow_Jones_Asia_Pacific_Indices_Fact_Sheet.Pdf. Accessed Sept 2014
- Forbes KJ, Rigobon R (2002) No contagion, only interdependence: measuring stock market comovements. *J Financ* 57(5):2223–2261
- Gilenko E, Fedorova E (2014) Internal and external spillover effects for the BRIC countries: multivariate GARCH-in-mean approach. *Res Int Bus Financ* 31:32–45
- Graham M, Kiviahio J, Nikkinen J (2012) Integration of 22 emerging stock markets: a three-dimensional analysis. *Glob Financ J* 23(1):34–47
- Hammoudeh S, Li H (2008) Sudden changes in volatility in emerging markets: the case of gulf Arab stock markets. *International Review of Finance Anal* 17:47–63
- Hamao Y, Masulis M (1990) Structural attribution of observed volatility clustering. *J Econ* 3:281–307
- Harju K, Hussain S (2008) Intraday return and volatility spillovers across international equity markets. *International research Journal of Finance and economics* 22:205–220
- Hassan S, Malik F (2007) Multivariate GARCH Modeling of sector volatility transmission. *Quarterly Review of Economics and Finance* 47:470–480
- Hendry D (1986) An excursion into conditional variance land. *Econometric Review* 5:63–69
- Johnson R, Soenen L (2002) Asian economic integration and stock market comovement. *J Financ Res* 25(1): 141–157
- Karunanayake I, Valadkhani A, O'Brien M (2010) Financial crises and international stock market volatility transmission. *Aust Econ* 49:209–221
- Lamoureux C, Lastrapes W (1990) Persistence in variance, structural change and the GARCH model. *J Bus Econ Stat* 8:225–234
- Lee Y, Tucker A, Wang D, Pao H (2014) Global contagion of market sentiment during the US subprime crisis. *Global Financ J* 25:17–25
- Lin W, Engle R, Ito T (1994) Do bulls and bears move across borders? International transmission of stock returns and volatility. *Rev Financ Stud* 7(3):507–538
- Longin F, Solnik B, Longin F (2001) Extreme correlation of international equity markets. *J Financ* 56(2):649–676
- Malik F (2003) Sudden changes in variance and volatility persistence in foreign exchange markets. *Journal of Financial Management* 13:217–230
- Malik F, Ewing B, Payne J (2005) Measuring volatility persistence in the presence of Sudden changes in the variance of Canadian stock Returns. *Can J Econ* 38:1037–1056
- Mandelbrot B (1963) The variations of certain speculative prices. *J Bus* 4:394–419
- Mikosh T, Starica C (2004) Nonstationarities in financial time series, the long-range dependence and the IGARCH effects. *Review of Economics and Statistics* 86:378–390
- Nam J, Ky-Hyang Y, Kim S (2008) What happened to pacific-basin emerging markets after the 1997 financial crisis? *Applied Financial Economics* 18(8):639–658
- Neaime S (2012) The global financial crisis, financial linkages and correlations in returns and volatilities in emerging MENA stock markets. *Emerg Mark Rev* 13(3):268–282
- Nikkinen J, Sahlstrom P (1996) International transmission of uncertainty implicit in stock index option prices. *Global Finance Journal* 52:17–34
- Pukthuanthong K, Roll R (2009) Global market integration: an alternative measure and its application. *J Financ Econ* 94:214–232
- Raghaven M (2008) The impact of Asian financial crisis and the spillover effects on three Pacific-basin stock markets-Malaysia, Singapore and Hong Kong. *The ICAFI Journal of Applied Finance* 14:5–16
- Rapach D, Struss J (2008) Structural breaks and GARCH models of exchange rate volatility. *J Appl Econ* 23: 65–90
- Savva C, Osborn D, Gill L (2009) Spillovers and correlations between US and major European stock markets: the role of the euro. *Appl Financ Econ* 19(19):1595–1604
- Scherrer W, Ribarits E (2007) On the parameterization of multivariate GARCH models. *Econometric Theory* 23:464–484
- Sharma S, Wongbangpo P (2002) Long-term trends and cycles in ASEAN stock markets. *Rev Financ Econ* 11(4):299–315
- Tan H, Cheah E, Johnson J, Sung M, Chuah C (2012) Stock market capitalization and financial integration in the Asia Pacific region. *Appl Econ* 44:1951–1961
- Uddin G, Arouri M, Tiwari A (2014) Co-movements between Germany and international stock markets:some new Evidence from DCC-GARCH and wavelet approaches. IPAG business school, Paris, Working paper 143
- Wang P, Moore T (2009) Sudden changes in volatility: the case of five central European stock markets. *Journal of International Financial Markets, Institutes and Money* 19:33–46