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TESTING FOR CONTAGION TO VIETNAM STOCK MARKET DURING GLOBAL FINANCIAL CRISIS USING COPULA

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Abstract

In this paper, we test the hypothesis of contagion during the Global financial crisis by applying the theory of copulas to measure the contagion among a sample of seventeen emerging stock markets, including Vietnam stock market and seven developed stock markets. The empirical results show that this new approach proves more appropriate to describe the non-linear and complex dynamics of the financial market returns than traditional modeling which imply a normality hypothesis. In addition, this study confirms the contagion of the crisis from both emerging and developed stock markets to Vietnam stock market during the Global Financial Crisis

1. Introduction

There is a quantity of severe financial and currency crises which affected both emerging and developed countries these decades. One significant characteristic of these crises was how an initially country specific shock was speedily transmitted to other markets of different degrees and structures all around the global. This raised research into the nature of the spill-over of these crises across markets, and attracted the interest in a concept which are often concerned: contagion.

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Forbes and Rigobon (2002) defined contagion as a significant increase in crossmarket linkages after a shock to an individual country (or group of countries); otherwise, a continued market correlation at high levels is considered to be “no contagion, only interdependence”. Contagion remains a subject of great debate in the academic field. Several studies have tried to model the various channels that may contain the spread. These studies have been enriched by trying to highlight, quantitatively, the existence of the contagion using various econometric techniques. Among these techniques, the studies of correlations and covariance in asset prices (interest rates, exchange rates, stock indexes, bond spreads) were of particular interest (Baig và Goldfajn, 1996; Forbes và Rigobon, 2000). Under this approach, a significant increase in correlations can be considered as evidence of contagion. There are also the co-integration tests which try to establish a long-run relationship between markets, leaving behind components such as the markets’ short-run volatilities (Kasa, 1992; Login và Solnik, 1995). In addition, the ARCH and GARCH models are used measure the transmission of crises as spread volatility (Hamao et al., 1990; Edwards, 1998) and the probit-logit regressions test the significance of the channels contagion affects through a study of different financial markets (Eichengreen et al., 1996; Kaminsky and Reinhart, 2000). Although a wide range of methodologies have been used, there is no theoretical or empirical procedure used for the identification of contagion on which economists can agree. Quantitative faces many difficulties. First, there is a heteroskedasticity problem when measuring correlations caused by volatility increases during a crisis. Second, there are often omitted variables in the estimation of cross-country correlation coefficients (Forbes and Rigobon, 2002; Corsetti et al., 2002). In addition, one more problem of measuring contagion between two markets is modeling of the joint distribution of individual returns during a certain period. Normal distribution has been usually used since the contagion between financial markets therefore can be described fully given the normal marginal distributions and the correlation coefficients. However, this framework is rare in finance because the existence of skewness and kurtosis have been shown in the literature review. Distributions often have heavy tails. Therefore, to avoid the limitations found in the existing literature and to look for an answer concerning the existence of contagion, a new approach, copula, has been organized widely. Besides, some research has been carried out in cases of developed countries, but few in cases of emerging countries like Vietnam. This paper seeks to find an answer to the following problem: are there evidences of contagion to a potential of the emerging stock market of Vietnam during periods of crisis and how do they show? The aim of this paper consists of modeling the contagion of the stock returns by considering tails dependence. Then, dependence is modeled and tested using copulas to examine the possible effects of contagion. There is considered to be contagion when there is an increase in the copula parameters between different markets as the market moves from a period of stability to a crisis period. The idea of detecting financial market contagion using copula is derived from Boubaker and Salma (2011). Boubaker and Salma (2011) found empirical results of contagion from the USA market to other 15 markets including both emerging and developed markets thanks to copula parameters only and in the future research, the authors claimed that 'a new definition of contagion where the contagion is defined as an increase in the asymptotic tail dependence could be envisaged. This would allow a describe dependence based on the level of the tail and to then examine the simultaneous occurrence of extreme values using dependence tail coefficient's. Therefore, breaks in the tail dependence structure show a dimension contagion'. We indeed use the asymptotic tail dependence coefficients calculated by copulas to investigate the financial contagion to Vietnam stock market during the Global Financial Crisis. So the paper contributes in new situation of Vietnam and new methodology in the available topic.

The paper proceeds as follows: Section 2 presents the concept of copula and the contribution of the theory of copulas to the detection of the contagion. Section 3 clarifies the empirical methodology and presents the sample. Section 4 synthesizes the results data and Section 5 concludes.

2. Concept of Copula and One Application of Copula in Modeling the Dependence Structure and Contagion

The limitations of conventional measures of contagion were presented in detail in Boubaker and Salma (2011). Copula is a prosperous tool for modeling the dependence structure of the random multivariate. Indeed, correlation is not sufficient to measure the dependence found in financial markets because it is only reliable when the random variables are jointly

Gaussian and the dependency is linear. Also, correlation is a scalar measure which is not designed to measure the dependence structure. Besides these weaknesses a correlation of zero does not indicate independence between the random variables or an increase in the correlation between two variables can be due merely to an increase in the variance of one variable (Rodriguez, 2006). For these reasons, the copulas function is appropriate to present a complete picture of the dependence structure. For simplicity, this study is limited to the theory of bivariate pairs.

2.1. The 2-dimensional copula concept. Copula is a joint distribution function or univariate distribution function with margins of 1-dimensional variable. We have the concept of 2-dimensional copula (Nelsen, 2006) as follows:

Definition 1. *An* 2*-dimensional copula* (*or* 2*-copula*) *is a function* C *whose domain is* $[0; 1] \times [0; 1]$, *and* $C(x) \in [0; 1]$ *satisfies the following properties*:

(*i*) $C(x) = 0, \forall\lambda\, [0; 1]^2$ *if at least one coordinate of* x is 0.

(*ii*) $C[1; x] = C(x; 1) = x, \forall x \in [0; 1]$.

(*iii*) $\forall(a_1; a_2), (b_1; b_2) \in [0; 1]^2$ voi $a_1 \leq b_1,\ a_2 \leq b_2$, *we have*:

$$C(a_2; b_2) - C(a_1; b_2) - C(a_2; b_1) + C(a_1; b_1) \geq 0.$$

One of copulas' characteristics which help it become an effective probabilistic application in the financial sector is that from the distribution of the component variables (they are maybe different and not necessarily independent), we can determine a copula as a joint distribution of those variables. This is significant when we consider a portfolio of assets whose distributions are not the same and dependent. Copula is defined as a joint distribution function where variables are the marginal distribution functions of the original variables. The importance of the copula is that it can capture the dependence structure of a multivariate distribution. This is justified by the Sklar's theorem (Nelsen, 2006).

Theorem 1. *Let* F_{XY} *be a joint distribution function with margins* F_X *and* F_Y. *Then there is a copula* C *such that for all* x, y in

$$C(\mu_x, \mu_y) = C(F_x(x), F_y(y)) = F(F_x^{-1}(\mu_x), F_y^{-1}(\mu_y)), \tag{1}$$

$$C(\mu_x, \mu_y) = F(x, y). \tag{2}$$

If F_X *and* F_Y *are continuous, then C is unique; otherwise, C is uniquely determined on* $\mathrm{Ran}F_X \times \mathrm{Ran}F_y$ *and C is invariant under strictly increasing transformations of the random variables.*

From Sklar's theorem (Nelsen, 2006), the joint distribution F_{XY} can be decomposed into its univariate marginal distributions F_X and F_Y, and a copula C, which captures the dependence structure between the variables *X* and *Y*. From these the marginal distribution's behaviors of the dependence structure can be determined. The density of a bivariate law can be written also in terms of the density of the copula associated *c* and marginal densities f_x and f_y :

$$f(x, y) = c(F_X(x), F_Y(y)) \times f_x(x) f_y(y). \tag{3}$$

That is, the density of *F* is expressed as the product of the copula density and the univariate marginal densities.

Copula models, which are different from linear correlation, focus on the asymmetric association between random variables. So they provide rich information on both dependence degree and dependence structure.

2.2. Modeling the dependence structure and contagion. The definition of contagion which we employ in this paper can be realized by the so called asymptotic tail dependence coefficients introduced by Sibuya (1960) (hereinafter TDC), which is considered our measure of contagion. The coefficients describe the tendency of financial markets to crash or boom together, i.e., they measure the dependence between extreme outcomes of the variables. The upper (lower) TDC is a limiting probability of one variable exceeding (falling behind) a high-order (low-order) quantile, given that the other variable exceeds (falls behind) the same quantile. Formally, if (X, Y) is a vector of continuous random variables with marginal distributions F_X and F_Y, respectively, then the upper and lower TDCs are defined as:

$$\lambda_U = \lim_{t \to 1^-} P(Y > F_y^{-1}(t) \mid X > F_x^{-1}(t)), \tag{4}$$

and

$$\lambda_L = \lim_{u \to 0^-} P(Y \leq F_y^{-1}(t) \mid X \leq F_x^{-1}(t)). \tag{5}$$

If the upper or lower TDC equals zero, the respective extreme values are independent, otherwise we say that there is dependence between extreme values of the variables considered. Significantly, for the copulas considered in this paper the TDCs are simple functions of copula parameters. Table 1 gives an overview of the copulas we employ along with their TDCs. Parameters of the copulas are obtained by maximizing the respective likelihood functions.

Copula	$C(u, v)$	λ_L	λ_u
Gaussian	$\Phi_p(\Phi^{-1}(u), \Phi^{-1}(v))$, where Φ_ρ is the bivariate standardized Gaussian cdf with Pearson's correlation ρ and Φ^{-1} is the inverse of the univariate standardized Gaussian cdf	0	
Clayton	$(u^{-\alpha} + v^{-\alpha} - 1)^{-1/\alpha}$ $\alpha > 0$	$2^{-1/\alpha}$	0
Rotated Clayton	$u + v - 1 + C(1 - u, 1 - v)$ where C is Clayton copula	0	$2^{-1/\alpha}$
Plackett	$\left((1 + (\theta - 1)(u + v)) - \frac{\sqrt{(1 + (\theta - 1)(u + v))^2 - 4uv\theta(\theta - 1)}}{2(\theta - 1)}\right)$, for $0 < \theta \neq 1$, uv for $\theta = 1$	0	
Frank	$\frac{1}{\alpha} \text{In}\left(1 + \frac{(e^{\alpha u} - 1)(e^{\alpha v} - 1)}{(e^{\alpha} - 1)}\right)$ $\alpha \neq 1$	0	
Gumbel	$\exp(-(-\text{In}u)^{\alpha} + (-\text{In}\nu)^{\alpha})^{-1/\alpha}$ $\alpha > 1$	0	$2 - 2^{1/\alpha}$
Rotated Gumbel	$u + \nu - 1 + C(1 - u, 1 - \nu)$ where C is Gumbel copula	$2 - 2^{1/\alpha}$	0
t-Student	$t_{\nu, r}(t_\nu^{-1}(u), t_\nu^{-1}(\nu))$, where $t_{\nu, r}$ is the bivariate t-Student's cdf with parameter r and degrees of freedom v, and t_ν^{-1} is the inverse of the univariate t-Student's cdf with v degrees of freedom	$2t_{\nu+1}\left(-\sqrt{\frac{(\nu + 1)(1 + r)}{(1 + r)}}\right)$	
Symmetrised Joe-Clayton	$0.5(C_{\tau^u, \tau^L}(u, \nu) + u + \nu - 1 + C_{\tau^L, \tau^u}(1 - u, 1 - \nu))$, where $C_{\tau^u, \tau^L}(u, \nu) = -\left\{\left[(1 - (1 - u)^{\kappa})^{-\gamma} + \left[(1 - (1 - \nu)^{\kappa})^{-\gamma}\right]^{-1/\gamma}\right\}^{1/\kappa}$ for $\kappa = 1/\log_2(2 - \tau^U)$, $\gamma = -1/\log_2(t^L)$, and $\tau^U, \tau^L \in (0, 1)$	τ^L	τ^U

Source: P. 13, Adam et al., 2013

Table 1. Copula functions and their characteristics

3. Data Description and Methodology

3.1. Data description. Our interest is to test the contagion to Vietnam stock market (VSM) during the Global Financial Crisis. Therefore, the data include in this paper incorporate the close stock price of seventeen emerging markets and seven developed markets. The emerging markets include Indonesia (JKSE), Taiwan (TAIEX), the Philippines (PHP), Malaysia (KLSE), Hong Kong (HANGSENG), Brazil (BVSP), Bulgaria (SOFIX), Croatia (CROBEX), Mexico (IPC), Russia (RTS), Turkey (ISE100), Korea (KOSPI), Singapore (STI), Australia (ASX), Shanghai (SSE), India (SENSEX) and Vietnam (VNINDEX). The developed markets include France (CAC40), Germany (DAX), the UK (FTSE100), the US (NASDAQ, DOWJONES, S&P500), Japan (N225), the Netherlands (AEX), Italia (FTSEMIB). VNINDEX was collected from hsx.vn, and the others were obtained from indexbook.net and quotenet.com. The data covers the period Dec, 4th 2006 to Mar, 31st 2015. Since holiday periods and exchange time vary in the selected markets, the data were adjusted for compatibility and the total number of observations for each of the indices is 2065. Returns are defined as the log difference of index values. If P_t is the value of the index at time *t*, then the stock return will be calculated as follows:

$$R_t = \log\left(\frac{P_t}{P_{t-1}}\right).$$

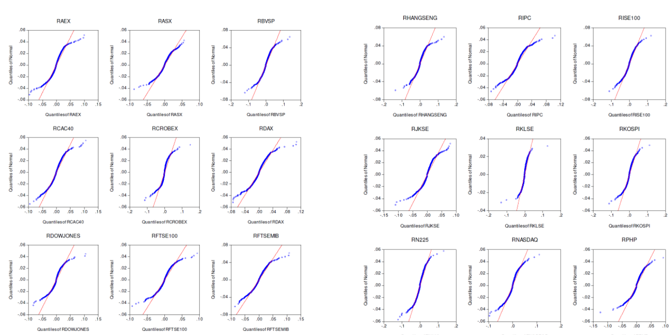
Crisis period is chosen from Feb, 12th 2008 to Oct, 13th 2009. The crisis is selected based on the historical evolution of Vietnam's economy and the world economy. So the precrisis period contains 291 observations, the crisis period contains 416 observations and the post-crisis period contains 1358 observations. Table 2 provides summary statistics for returns from the sample stock market indices.

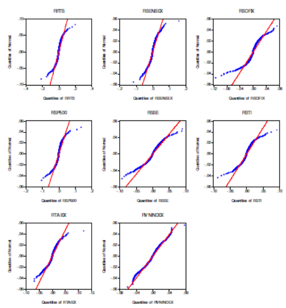
	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	Jarque-Bera	Prob.
RAEX	1.62E-05	0.000314	0.100283	-0.095903	0.014694	-0.169172	11.05016	5583.085	0
RASX	4.00E-05	7.02E-05	0.056282	-0.087043	0.012077	-0.385123	7.606591	1876	0
RBVSP	0.000103	0	0.136766	-0.120961	0.018427	-0.003459	9.294822	3407.735	0
RCAC40	-1.60E-05	0.000255	0.105946	-0.094715	0.015667	0.066858	8.826465	2921.039	0
RCROBEX	-0.000313	0	0.14779	-0.112699	0.013686	-0.217137	20.00273	24878.19	0
RDAX	0.000315	0.000724	0.107975	-0.074335	0.014919	0.039782	9.191824	3297.671	0
RDOWJONES	0.000189	0.000374	0.105083	-0.082005	0.012714	-0.07917	12.68264	8064.965	0
RFTSE100	5.70E-05	0.000118	0.093842	-0.092646	0.013038	-0.115941	10.58969	4958.522	0
RFTSEMIB	-0.000264	0	0.108742	-0.085991	0.017547	-0.029378	6.761645	1217.195	0
RHANGSENG	0.000139	0	0.134068	-0.13582	0.017019	0.114192	11.86123	6757.333	0
RIPC	0.000272	0.000334	0.104407	-0.072661	0.013349	0.143117	9.749934	3925.344	0
RISE100	0.000363	0.000211	0.121272	-0.110638	0.017674	-0.222556	7.314453	1617.886	0
RJKSE	0.000554	0.000615	0.080428	-0.109539	0.014648	-0.56849	10.73375	5254.908	0
RKLSE	0.000257	0.000316	0.127919	-0.129664	0.008989	-0.942992	52.42215	210365.1	0
RKOSPI	0.000174	6.54E-05	0.112844	-0.11172	0.013956	-0.586519	11.82377	6814.211	0
RN225	7.94E-05	0	0.132346	-0.12111	0.016433	-0.55827	11.25998	5974.753	0
RNASDAQ	0.000348	0.000726	0.111594	-0.095877	0.014635	-0.264991	9.967327	4198.909	0
RPHP	0.000599	0.000327	0.092954	-0.125204	0.013097	-0.873249	12.06404	7327.815	0
RRTS	-0.000341	6.88E-05	0.202039	-0.211994	0.023678	-0.358884	14.39822	11217.37	0
RSENSEX	0.000341	0	0.1599	-0.116044	0.01599	0.222785	11.85773	6764.58	0
RSOFIX	-0.000395	0	0.072924	-0.1136	0.013493	-1.044371	13.15049	9235.999	0
RSP500	0.000192	0.000491	0.135577	-0.103637	0.013822	-0.061799	15.55264	13552.23	0
RSSE	0.000267	0.000358	0.090343	-0.092562	0.017311	-0.411185	6.617016	1183.282	0
RSTI	9.20E-05	0.000159	0.092447	-0.08696	0.012451	-0.078015	10.18686	4444.081	0
RTAIEX	0.00011	0.000601	0.120089	-0.067692	0.013108	-0.140044	9.353949	3478.796	0
RVNINDEX	-7.29E-05	0.000287	0.077407	-0.060547	0.016159	-0.105338	3.948029	81.11035	0

Source: Calculation of the authors from collected data

Table 2: Descriptive Statistics of returns of daily stock market indices

As commonly observed, the percentage means of the daily stock index returns are close to zero in most cases. The average daily return is the highest for the Philippines stock market (0.0599%), followed by the Indonesia stock market (0.0554%) and the Turkey stock market (0.0363%). In particular, the France, Croatia, Italia, Russia, Bulgaria and Vietnam stock markets show relatively poor performance, as evidenced by a negative mean for daily stock returns. Table 2 shows that means of all return series are small relative to their standard deviations. The mean ranges from –0.0395% to 0.0599%, while the standard deviation range is from 0.8989% to 2.3678%, thus, indicating relatively high volatility in all series. The most volatile stock market is Russia market (2.3678%), followed by Brazil (1.8427%) and Turkey (1.7674%) markets, while the least volatile market is the Malaysia stock market (0.8989%). The skewness of all the series are different from zero with skewing to the left, accept for the France, Germany, Hong Kong, Mexico and India indices which are skewed to the right. Figure 1 of normal qq plots of all of the series show that all of the returns series exhibit a non-normal pattern. Intuitively, the strong departure from linearity at the end of the qq plots indicates non-normal fat-tailed behavior by all of the return series. The various stock market series also all show excess kurtosis, ranging from 3.95 to 52.42, with the Malaysia stock market displaying the highest kurtosis (52.42), which is a sign of non-normality. These interpretations are supported by the results of the Jaque-Bera test in Table 2. The Jaque-Bera test, with a *p*-value of 0.00, strongly rejects the null hypothesis of normality in all return series, indicating supports the inappropriateness of using the multivariate normal distribution in examining financial data.





Source: Drawing of the authors from collected data

Figure 1. Normal qq plots of returns of stock indicies

Additionally, Tables 3, 4 and 5 show linear correlations between the VSM return and each of the other stock market returns pre-crisis, crisis and post-crisis.

Indicies	Correlation	Indicies	Correlation	Indicies	Correlation	Indicies	Correlation
KOSPI	0.053883489	STI	0.02639245	PHP	0.13592612	RTS	0.16572118
DOW JONES	0.111603657	ASX	0.08982704	KLSE	0.05199897	ISE100	0.2024061
NASDAQ	0.112900332	SSE	0.03895498	BVSP	0.11636222	AEX	0.21741018
N225	0.138562919	TAIEX	0.09249887	SOFIX	0.12731812	DAX	0.22682059
CAC40	0.214940319	SENSEX	0.11231704	CROBEX	0.2176682	FTSEMIB	0.21470959
FTSE100	0.206020078	JKSE	0.14329184	IPC	0.12366995	SP500	0.11153472
HANGSENG	0.045011632						

Source: Calculation of the authors from collected data

Table 3. Linear correlation between the VSM and the other markets in pre-crisis period (Dec, 4th 2006-Feb, 1st 2008)

Indicies	Correlation	Indicies	Correlation	Indicies	Correlation	Indicies	Correlation
KOSPI	0.171175456	STI	0.17010435	PHP	0.33503387	RTS	0.27606796
DOW JONES	0.385460885	ASX	0.27386949	KLSE	0.13397501	ISE100	0.33600381
NASDAQ	0.370983014	SSE	0.10498206	BVSP	0.39228681	AEX	0.35671672
N225	0.317564582	TAIEX	0.17436352	SOFIX	0.08307138	DAX	0.36797619
CAC40	0.352865929	SENSEX	0.27935848	CROBEX	0.30756425	FTSEMIB	0.35557271
FTSE100	0.355909981	JKSE	0.24984521	IPC	0.4031162	SP500	0.39697046
HANGSENG	0.177050294						

Source: Calculation of the authors from collected data

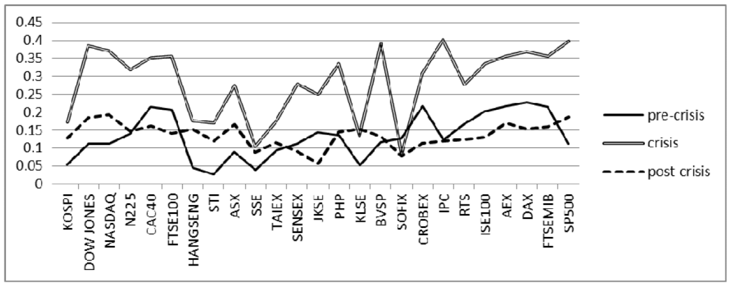
Table 4. Linear correlation between the VSM and the other markets in crisis period

Indicies	Correlation	Indicies	Correlation	Indicies	Correlation	Indicies	Correlation
KOSPI	0.127153423	STI	0.11935118	PHP	0.14396028	RTS	0.12282625
DOW JONES	0.185442151	ASX	0.16520232	KLSE	0.15345124	ISE100	0.12948476
NASDAQ	0.19281533	SSE	0.08793705	BVSP	0.13248331	AEX	0.16933454
N225	0.147154946	TAIEX	0.11444763	SOFIX	0.07779987	DAX	0.15306276
CAC40	0.160377343	SENSEX	0.09052138	CROBEX	0.11311218	FTSEMIB	0.16001351
FTSE100	0.140952887	JKSE	0.05616528	IPC	0.11897407	SP500	0.18665568
HANGSENG	0.15341092						

Source: Calculation of the authors from collected data

Table 5. Linear correlation between the VSM and the other markets in post-crisis

In all the three periods, all the correlations are positive, i.e., each pair of stock returns tends to change in the same direction. In each period, if the international stock returns increased/decreased, the Vietnam stock return would also increase/decrease. In the pre-crisis period, the linear correlation is highest in the pair comprising the VSM and the Germany stock market (22.68%), followed by the pair of Vietnam-Croatia (21.77%) and the pair of Vietnam-the Netherlands (21.74%) pairs. The lowest linear correlation is 2.64% between the VSM and the Singapore index. In the crisis period, the linear correlation is highest in the pair comprising the VSM and the Mexico stock market (40.31%), followed by the Vietnam-S&P 500 (39.70%) and Vietnam-Brazil (39.23%) pairs. The lowest linear correlation is 8.31% between the VSM and the Bulgaria index. All correlations between pairs of stock returns during the crisis have increased compared to the pre-crisis period, except for the Vietnam-Bulgaria pair. This suggests us that there has been contagion from both emerging and developed stock markets to the VSM during the Global Financial Crisis. We consider the post-crisis period to initially consider the contagion effects. In the post-crisis period, the three linear correlations in top 3 highest in the pairs comprising the VSM and the USA stock market: VNINDEX-NASDAQ (19.28%), VNINDEX-S&P 500 (18.67%), và VNINDEXDOW JONES (18.54%). The lowest linear correlation is 5.62% between the VSM and the Indonesia index. The following Figure 2 presents clearly the trend of changing of correlation coefficients in all three periods.



Source: Drawing of the authors from collected data

Figure 2. Correlation coefficients between some international stock market and the VSM returns in three periods

The post-crisis period, the correlation coefficient between pairs of stock returns reduced compared to the crisis period. The post-crisis period, there are two trends emerged: the correlation coefficients between the VSM and some international stock markets increased compared to the pre-crisis period (the US, Japan, Korea, Hong Kong, Singapore, Australia, Shanghai, Taiwan, the Philippines, Malaysia, Brazil) and the correlation coefficients between the VSM and some international stock markets decreased compared to the pre-crisis period (France, the UK, the Netherlands, Germany, Italy, India, Indonesia, Bulgaria, Croatia, Mexico, Russia, Turkey).

This analysis based on traditional dependence measure - the correlation - so that one can compare the results obtained thanks to copula below. This will reveal the advantage of correlation calculated by copula compared to linear correlation as asserted in the literature review.

3.2. Methodology. To study the 'dependence' between stock returns, we use the copula functions, introduced by Sklar (Nelsen, 2006) which is an analysis tool recently introduced in applied finance, with many advantages mentioned above. This idea has been implemented in Boubaker et al. (2011), in which the authors measured the dependence structure between S&P 500 and 15 stock market indices during the pre-crisis and crisis period in order to give evidence about the contagion using copula method. Boubaker et al. (2011) used 5 copulas: Gauss, Student, Clayton, Gumbel and Frank. In this paper, we use 9 copulas as in Cuong et al. (2012), including the copulas: Gauss, Clayton, Rotated-Clayton, Plackett, Frank, Gumbel, Rotated-Gumbel, Student, Symmetrised-Joe-Clayton to study the dependence structure of the VSM and 16 emerging stock markets and 7 developed stock markets during pre-crisis, crisis and post-crisis periods, in order to not only provide evidence of contagion but also examine the impact of financial contagion in the post-crisis period.

Table 6 presents the parameters of some copulas, the definition of these copulas can be found in Cherubini et al. (2004).

Name	Parameters	Copulas
Gaussian	ρ	$C(\mu_x, \mu_y, \rho) = \varphi_\rho(\varphi^{-1}(\mu_x), \varphi^{-1}(\mu_y))$
Student	ρ, k	$C(\mu_x, \mu_y, \rho, k) = T_{\rho,k}(T_k^{-1}(\mu_x), T_k^{-1}(\mu_y))$
Clayton	$\theta > 0$	$C(\mu, \upsilon, \theta) = (\mu^{-\theta} + \upsilon^{-\theta} - 1)^{\frac{-1}{\theta}}$
Gumbel	$\theta \geq 1$	$C(\mu, \upsilon, \theta) = exp\left[-\left[Ln(\mu)^\theta + (-Ln(\upsilon))^\theta\right]\right]^{\frac{1}{\theta}}$
Frank	$\theta \neq 0$	$C(\mu, \upsilon, \theta) = \frac{-1}{\theta} Ln\left[1 + \frac{\left(exp(-\theta_\mu)^{-1}\right)\left(exp(-\theta_\upsilon)^{-1}\right)}{exp(-\theta) - 1}\right]$
Symmetrised-Joe-Clayton (SJC)	u, v	$C(u, v \mid \tau^U, \tau^L) = 1 - \left(\left[1 - (1-u)^k\right]^{-\gamma} + \left[1 - v^k\right]^{-\gamma} - 1^{-1/\gamma}\right)^{1/k}$

Source: P. 446 Boubaker et al. (2011)

Table 6. Copula parameters

Specifically, in each period, pre-crisis, crisis and post-crisis periods, we fit the best copula to capture the dependence of each pair of stock market returns, and calculate the tail dependence coefficients by those best copulas. With the results obtained, we compare the tail dependence coefficients with linear correlation coefficients in the same period, and compare the tail dependence coefficients during the crisis period to those of the pre-crisis period test the contagion. Besides, we also compare the tail dependence coefficients in the post-crisis period to those of the prior periods to illustrate the impact of contagion.

4. Empirical Results

Recall that we can interpret the copula parameters differently. Since a Gaussian copula is considered the copula of a multivariate normal distribution, we can compare a Gaussian copula's parameters to the linear correlations of the two market pairs in Tables 7, 8, 9 and 3, 4, 5, respectively.

Indicies	Correlation	Indicies	Correlation	Indicies	Correlation	Indicies	Correlation
KOSPI	0.078977813	STI	0.00654798	PHP	0.1354357	RTS	0.21163784
DOW JONES	0.107334355	ASX	0.08353264	KLSE	0.04543445	ISE100	0.23967807
NASDAQ	0.108673931	SSE	-0.03669029	BVSP	0.14010146	AEX	0.21544712
N225	0.140792284	TAIEX	0.09300723	SOFIX	0.07145013	DAX	0.23101488
CAC40	0.217898118	SENSEX	0.0803832	CROBEX	0.2276887	FTSEMIB	0.21101486
FTSE100	0.21266475	JKSE	0.1762032	IPC	0.16734482	SP500	0.09734558
HANGSENG	0.054681207						

Source: Calculation of the authors from collected data

Table 7. Dependence coefficient of the VSM and some international stock market returns by Gaussian copula in pre-crisis period (Dec, 4th 2006-Feb, 1st 2008)

Indicies	Correlation	Indicies	Correlation	Indicies	Correlation	Indicies	Correlation
KOSPI	0.14678038	STI	0.13946507	PHP	0.31778053	RTS	0.25908749
DOW JONES	0.378062771	ASX	0.26225486	KLSE	0.17735773	ISE100	0.3367752
NASDAQ	0.366094729	SSE	0.12359763	BVSP	0.39292441	AEX	0.35534016
N225	0.295049404	TAIEX	0.16551497	SOFIX	0.07654003	DAX	0.3695869
CAC40	0.354666746	SENSEX	0.28788869	CROBEX	0.31834673	FTSEMIB	0.34934826
FTSE100	0.365813597	JKSE	0.25964085	IPC	0.39039066	SP500	0.38616078
HANGSENG	0.159239533						

Source: Calculation of the authors from collected data

Table 8. Dependence coefficient of the VSM and some international stock market returns by Gaussian copula in crisis period (Feb, 12th 2008-Oct, 13rd 2009)

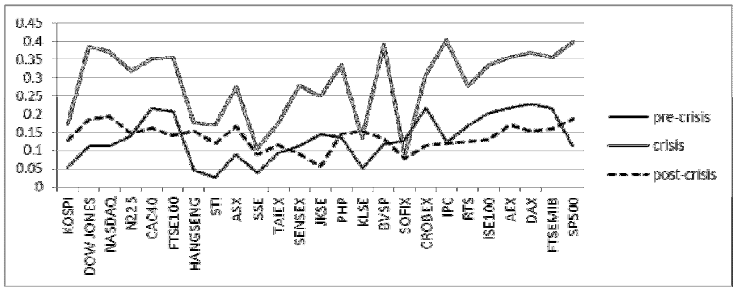
Indicies	Correlation	Indicies	Correlation	Indicies	Correlation	Indicies	Correlation
KOSPI	0.129952369	STI	0.12597401	PHP	0.12536761	RTS	0.12411813
DOW JONES	0.193641089	ASX	0.16600659	KLSE	0.15335647	ISE100	0.11828476
NASDAQ	0.192730907	SSE	0.06333267	BVSP	0.13141596	AEX	0.17315906
N225	0.154025053	TAIEX	0.12219509	SOFIX	0.06053185	DAX	0.14618012
CAC40	0.163317064	SENSEX	0.10565166	CROBEX	0.10403223	FTSEMIB	0.16447092
FTSE100	0.145902337	JKSE	0.04044663	IPC	0.11115374	SP500	0.18769271
HANGSENG	0.150354059						

Source: Calculation of the authors from collected data

Table 9. Dependence coefficient of the VSM and some international stock market returns by Gaussian copula in post-crisis period (Oct, 14th 2009-Mar, 31st 2015)

In all the three periods, almost the dependence coefficients (DC) are positive, except for the pair of Hangseng-Vnindex, i.e almost pairs of stock returns tend to change in the same direction. In each period, if the international stock returns increased/decreased, the Vietnam stock return would also increase/decrease. In the pre-crisis period, the DC is highest in the pair comprising the VSM and the Turkey stock market (23.97%), followed by the pair of Vietnam-Germany (23.10%) and the pair of Vietnam-Croatia (22.77%) pairs. The lowest DC is 0.65% between the VSM and the Singapore index. In the crisis period, the DC is highest in the pair comprising the VSM and the Brazil stock market (39.29%), followed by the Vietnam-Mexico (39.04%) and Vietnam-S&P 500 (38.62%) pairs. The lowest DC is 7.65% between the VSM and the Bulgaria index. All DCs between pairs of stock returns during the crisis have increased compared to the pre-crisis period. This suggests us that there has been contagion from both emerging and developed stock markets to the VSM during the Global Financial Crisis. The strongest increase in dependence degree, i.e. the strongest contagion, is from Singapore, USA, Malaysia, India, Australia and Hong Kong markets. The weakest increase in dependence degree, i.e. the weakest contagion, is from the Bulgarian, Russia, Croatia, Turkey, Indonesia and Germany markets. This result is consistent with the leading role of the US market to the most of the other markets and it is easy to understand that the contagion to the VSM from the countries in Asia is faster and stronger than from the other countries in Europe and in the America. We consider the post-crisis period to initially consider the contagion effects. In the post-crisis period, the three linear correlations in top 3 highest in the pairs comprising the VSM and the USA stock market: VNINDEX-DOW JONES (19.36%), VNINDEX- NASDAQ (19.27%), và VNINDEX-S&P 500 (18.77%). The lowest DC is 4.04% between the VSM and the Indonesia index. We may notice a little different of Gaussian copula's dependence parameters from the linear correlation coefficients. In which, in the pre-crisis, crisis and post-crisis, the DCs calculated by Gaussian copula increased compared to the linear correlation coefficients strongest, respectively, are Korean-Vietnam (146.57%), Malaysia-Vietnam (132.38%), India-Vietnam (116.71%). And in the pre-crisis, crisis and post-crisis, the DCs calculated by Gaussian copula decreased compared to the linear correlation coefficients strongest, respectively, are Singapore-Vietnam (24.81%), Singapore-Vietnam (81.99%), Indonesia-Vietnam (72.01%).

The following Figure 3 presents clearly the trend of changing of DCs in three periods.



Source: Drawing of the authors from collected data

Figure 3. DCs between some international stock market and the VSM returns in three periods

We can compare Figures 3 and 2 to find out the differences. DCs calculated by Gaussian copula sometimes increase and sometimes decrease compared to the linear correlation coefficients, in which, in particular, the pre-crisis period, the correlation coefficient between the pair Shanghai-Vietnam is positive, while the DC of Gaussian copula is negative. Besides, in the post-crisis period, the DCs between all pairs of stock returns reduce compared to the crisis period. In the post-crisis period, there are two trends emerged: the DCs of the VSM and some markets increase compared to the pre-crisis period (the US, Japan, Korea, Hong Kong, Singapore, Australia, Shanghai, Taiwan, Malaysia and India) and the DCs of the VSM and some markets decrease compared to the pre-crisis period (France, the UK, the Netherlands, Germany, Italy, Indonesia, Bulgaria, Croatia, Mexico, Russia, Turkey, the Philippines and Brazil). Thus, there is a slight change compared to the results measured by the linear correlation coefficients. And the contagion creates different effects to each pair of stock returns.

Tables 10, 11, 12 present in detail the choice of the best copula and the corresponding parameters of the best copula for the pair of S&P 500-Vnindex, respectively, in the pre-crissi, crisis and post-crisis periods. Among the copulas fitted, we used the log-likelihood, AIC and BIC criteria to choose the best copula. The following results obtained thanks to some matlab code from http://public.econ.duke.edu/~ap172/ with necessary modification to fit the collected data. The best copula is marked in bold in each table.

Copula	Para 1	Para 2	Para 3	Para 4	Para 5	Para 6	LL	AIC	BIC	R
Normal	0.0973						-1.1602	-2.3124	-2.2988	6
Clayton	0.1010						-0.8744	-1.7409	-1.7269	8
Rotated Clayton	0.0742						-0.3997	-0.7914	-0.7773	10
Plackett	1.3562						-1.3241	-2.6402	-2.6262	5
Frank	**0.6294**						**-1.3644**	**-2.7207**	**-2.7067**	**3**
Gumbel	1.1						0.4098	0.8276	0.8416	6
Rotated Gumbel	1.1						0.0534	0.1147	0.1288	11
Student	0.1010	100					-1.059	-2.1023	-2.074	7
Symmetrised Joe-Clayton	1.4E-05	0.0082					-0.8414	-1.6670	-1.6389	9
Time-varying normal	0.0518	-0.1217	1.6209				-1.6116	-3.1992	-3.1571	2
Time-varying rotated Gumbel	0.8845	-0.2106	-2.4350				-1.3464	-2.6689	-2.6267	4
Time-varying SJC	-11.915	-0.0484	0.0004	-11.6983	25	-6.6017	-1.6683	-3.2888	-3.2045	1

Note: Para: parameter, R: ranking Source: Calculation of the authors from collected data

Table 10. Estimation of copula parameters for S&P 500-VNINDEX in pre-crisis period and best copula

Copula	Para 1	Para 2	Para 3	Para 4	Para 5	Para 6	LL	AIC	BIC	R
Normal	0.3862						-32.3382	-64.6714	-64.6615	7
Clayton	0.5586						-30.37	-60.7352	-60.7251	8
Rotated Clayton	0.4593						-22.6005	-45.1960	-45.186	12
Plackett	3.1835						-28.7929	-57.5808	-57.5708	9
Frank	2.3479						-27.3196	-54.6343	-54.6243	11
Gumbel	1.2934						-27.9429	-55.8808	-55.8709	10
Rotated Gumbel	1.3246						-34.1727	-68.3404	-68.3305	5
Student	0.3862	8.50E+00					-34.2931	-68.5763	-68.5564	4
Symmetrised Joe-Clayton	**0.1478**	**0.2736**					**-35.7943**	**-71.5786**	**-71.5586**	**3**
Time-varying normal	0.2309	0.0687	1.4314				-33.0308	-66.0466	-66.0168	6
Time-varying rotated Gumbel	-0.22062	0.652755	-0.3203				-40.8507	-81.6864	-81.6566	2
Time-varying SJC	-0.93858	-5.7257	3.7401	-0.2511	-3.9675	1.0546	-43.4077	-86.7854	-86.7257	1

Note: Para: parameter, R: ranking Source: Calculation of the authors from collected data

Table 11. Estimation of copula parameters for S&P 500-VNINDEX in crisis period and best copula

Copula	Para 1	Para 2	Para 3	Para 4	Para 5	Para 6	LL	AIC	BIC	R
Normal	0.1877						-23.2990	-46.5964	-46.5924	8
Clayton	0.2572						-26.1437	-52.2859	-52.2820	5
Rotated Clayton	0.1770						-12.6157	-25.2299	-25.2260	12
Plackett	1.8076						-22.5530	-45.1045	-45.1006	9
Frank	1.1381						-21.3379	-42.6743	-42.6703	10
Gumbel	1.1191						-18.6473	-37.2930	-37.2890	11
Rotated Gumbel	1.1414						-27.6482	-55.2949	-55.2909	4
Student	0.1969	12.2314					-26.0926	-52.1821	-52.1742	6
Symmetrised Joe-Clayton	**0.0076**	**0.1162**					**-27.8252**	**-55.6474**	**-55.6394**	**3**
Time-varying normal	0.710	-0.1896	-1.2786				-24.0422	-48.0797	-48.0678	7
Time-varying rotated Gumbel	0.3356	0.1643	-0.4673				-28.6288	-57.2531	-57.2411	2
Time-varying SJC	3.1916	-25	-3.4983	-0.3474	-4.6714	-3.2359	-30.4289	-60.8487	-60.8248	1

Note: Para: parameter, R: ranking Source: Calculation of the authors from collected data

Table 12. Estimation of copula parameters for S&P 500-VNINDEX in post-crisis period and best copula

For the pair of S&P 500 and VNINDEX, the best copulas in the pre-crisis, crisis and post-crisis periods, respectively, are the Frank copula, the SJC copula and the SJC copula. The SJC copula can capture both left and right tail dependence at the same time, thus, making it possible to examine the existence of tail dependence in all pairs. Note that upper tail dependence indicates that the two markets are likely to go up together and lower tail dependence implies that the two markets are likely to go down at the same time. The Frank family has neither lower nor upper tail dependency.

Similarly, we can choose the best copulas for each pair of stock market indices in each period and calculate the best copulas' parameters which measure the tail dependence. Results are presented in Table 13 below:

Indicies	Pre-crisis			Crisis			Post-crisis		
	Best copula	UTDC	LTDC	Best copula	UTDC	LTDC	Best copula	UTDC	LTDC
S&P 500	Frank	0	0	SJC	0.27362	0.1478	SJC	1.16E-01	0.00759
Dow Jones	Frank	0	0	SJC	0.26553	0.14063	SJC	0.10163	0.01817
Nasdaq	Frank	0	0	SJC	0.24843	0.14105	SJC	0.11102	0.01198
N225	Student	0.00294	0.00294	Student	0.1266	0.1266	Plackett	0	0
CAC40	Student	0.01736	0.01736	SJC	0.22291	0.15812	SJC	0.09744	0.00119
FTSE100	Student	0.00717	0.00717	SJC	0.26721	0.14069	Student	0.00952	0.00952
AEX	Student	0.02906	0.02906	SJC	0.2395	0.1487	SJC	0.09632	0.00625
DAX	SJC	0.23195	0.16471	SJC	0.23195	0.16471	SJC	0.07114	0.00233
FTSEMIB	Student	0.03729	0.03729	SJC	0.20809	0.16791	Student	1.77E-06	1.77E-06
KOSPI	Clayton	0.00088	0	Student	0.09396	0.09396	Student	0.01461	0.01461
HANGSENG	Clayton	0.00259	0	Student	0.1278	0.1278	Rotated Gumbel	0.14482	0
STI	Student	0.0158	0.0158	Student	0.07211	0.07211	Rotated Gumbel	0.12214	0
ASX	Student	0.03874	0.03874	Student	0.14718	0.14718	SJC	0.07484	0.01176
SSE	Student	0.00238	0.00238	SJC	0.03234	0.01179	Clayton	0.002	0
TAIEX	Clayton	0.00475	0	Student	0.11448	0.11448	Clayton	0.01489	0
SENSEX	Student	0.05051	0.05051	SJC	0.21431	0.05746	Student	0.00175	0.00175
JKSE	SJC	0.15178	3.73E-09	SJC	0.10754	0.1087	Clayton	1.33E-05	0
PHP	Clayton	0.03879	0	SJC	0.16781	0.16588	Clayton	0.01702	0
KLSE	Frank	0	0	Student	0.05648	0.05648	SJC	0.06088	0.00507
BVSP	Clayton	0.04798	0	SJC	0.25402	0.18921	SJC	0.08736	1.61E-06
SOFIX	Student	0.05928	0.05928	Student	0.07815	5.96E-08	SJC	0.00491	1.55E-07
CROBEX	Student	0.01212	0.01212	SJC	0.22184	0.12858	Student	0.00041	0.00041
IPC	Frank	0	0	SJC	0.2576	0.16151	SJC	0.04097	0.00024
RTS	Student	0.03989	0.03989	Student	0.11465	0.11465	Student	0.0021	0.0021
ISE100	Frank	0	0	SJC	0.20215	0.14369	SJC	0.04844	3.51E-05

Source: Calculation of the authors from collected data

Note: UTDC: Upper tail dependence coefficient, LTDC: lower tail dependence coefficient

Table 13. The choice of the best copula for the VSM and some international stock market returns and tail dependence coefficients in each period

Table 13 illustrates that when the Global financial crisis occurs, investors should change the method of management of their portfolios, by changing the selection of different copula to measure the dependence structure of the pairs of stock returns. This is once again confirmed that there exists the contagion from some international stock markets to the VSM, including both developed and emerging markets. Contagion effects do not only change the dependence degree between the markets, reflected in the change of the DCs, but also change the dependence structure between markets, such as in the pre-crisis period, the dependence structure between the US and the Vietnam stock markets are the symmetrical structure measured by the Frank copula with two tail DCs are both zero, but in the crisis and post-crisis periods, the structure has been shifted to asymmetric dependence structure measured by the SJC copula with the different two tail DCs. The other pairs of stock returns also change in the dependence degree and/or the dependence structure. And the impact of contagion from different markets to the VSM varies, so the information is needed to be handled in different ways.

5. Conclusions

In this paper, we used copulas to examine the dependence structure between the VSM and the markets of 16 emerging stock markets and 7 developed stock markets in order to test the contagion to the VSM during the Global Financial Crisis.

Thanks to examining the dependence structure, we tested the financial contagion. The results obtained from the copula models also provided some interesting findings on the relationship between the VSM and other selected stock markets. The results show that there exists financial contagion from both developed and emerging stock market to the VSM at different degree. It is shown by the increasing of the DCs in the crisis period compared to the pre-crisis period. The DCs are calculated by the best copula in each period for each pair of stock returns. The strongest contagion is from the US and some emerging Asian markets. The results which identified the leading role of the US and Japanese markets on emerging stock markets in Asia can be found in Masil and Masil (1999), Climent and Meneu (2003). The findings of this paper are also consistent with Chang and Su (2009), who found that the VSM is influenced by the markets of Singapore. However, our studies provide richer information on the relationships by finding that the VSM is likely to crash with the Singapo and the US stock market during Global financial crisis period.

There are a range of policy implications resulting from our research outlines as followed. The investors who diversify their portfolio with not only on the VSM, but also on international stock markets should care about the movement of both the VSM and some international stock markets which have strong contagion to the VSM, such as Singapore, the USA, Malaysia, India, Australia and Hong Kong. Investors can specially care about the US and Singapore markets since these are strong markets in the world and in the area which show clear evidence of contagion to the VSM. The information from these stock markets can be used in making investment decision for investors. Further, innovations in these stock markets could be used as indicators to investigate or predict the performance of the VSM. At the same time, investors can diversify their portfolio with not only on the VSM, but also on international stock markets which has weak contagion to the VSM, such as Bulgaria, Russia, Croatia, Turkey, Indonesia and Germany.

As in any research, the present study has certain limits. The nominated period was divided into three periods but the data constraints meant that the pre-crisis period and the post-crisis period were not equivalent in terms of the number of observations, which could cause bias in the results.

Our findings indicate that the integration of the VSM into the world financial market. Therefore, the implication is that the policy makers and investors should care much about risk management, especially in crisis period. Having contagion evidences from some international stock markets to the VSM, investors can use some Crisis Warning Model for those international stock markets so that they can have appropriate hedging before the crisis comes into the VSM.

This research could be further extended by examining the crisis contagion by looking at different asset classes such as commodities, gold, oil and real estate. After this study, we can study the contagion from the global stock market to the VSM using some other methodologies such as Extreme Value Theory or Quantile Regression for further evidence of contagion so that we can compare with the results in this paper using Copula method.

References

[1] M. Adam, P. Bańbuła and M. Markun, Dependence and contagion between assets prices in Poland and abroad, A copula approach. NBP Working Paper No. 169, 2013.

[2] T. Baig and I. Goldfajn, Financial market contagion in the Asian Crisis, IMF Staff Papers, 2 (46) (1999), 167-195.

[3] A. Boubaker and J. Salma, Detecting financial markets contagion using copula Functions, International Journal of Management Science and Engineering Management, 6 (6) (2011), 443-449.

[4] H. L. Chang and C. W. Su, The relationship between the Vietnam stock market and its major trading partners, TECM with bivariate asymmetric GARCH model, Applied Economics Letters, 13 (17) (2009), 1279-1283.

[5] U. Cherubini, E. Luciano and W. Vecchiato, Copula Methods in Finance, John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex PO19 8SQ, England, 2004.

[6] F. Climent and V. Meneu, Has 1997 Asian crisis increased information flows between international markets, International Review of Economics and Finance, 12 (2003), 111-143.

[7] G. Corsetti, M. Pericolli and M. Sbracia, Correlation analysis of financial contagion: What one should know before running a test, Economic Growth Center, Yale University, Center Discussion Paper No. 822, Online at http://papers.ssrn.com/paper.taf?abstract_id=274894, 2002.

[8] N. Cuong, I. Bhatti and D. Henry, An Extreme Value-Copula Approach to Dependence Analysis between Vietnam Stock Market and International Market, Financial Management Association-Asian Conference 2012, Phuket, Thailand, 2012.

[9] S. Edwards, Interest Rate Volatility, Capital controls and contagion. NBER Working Paper, No. 6756, Online at http://www.nber.org/paper/w6756, 1998.

[10] B. Eichengreen, A. Rose and C. Wyploz, Contagion currency crisis, NBER Working Paper No. 5681, 1996.

[11] K. Forbes and R. Rigobon, Contagion in Latin America: Definitions, measurement and policy implications, NBER Working Paper No. 7885, 2000.

[11] K. Forbes and R. Rigobon, No contagion, only interdependence: Measuring stock market co-movements. Journal of Finance, Vol. LVII, 5, (2002), 2223-2261.

[13] Y. Hamao, R. W. Masulis and V. Ng, Correlation in price changes and volatility across international stock markets, The Review of Financial Studies, 2 (3), (1990), 281-307.

[14] G. Kaminsky and C. Reinhart, On crisis, Contagion and Confusion, Journal of International Economics, 1 (51), (2000), 145-168.

[15] K. Kasa, Common Stochastic Trends in International Stock Markets, Journal of Monetary Economics, (29), (1992), 95-124.

[16] F. Login and B. Solnik, Is the correlation in international equity returns constant: 1960-1990? Journal of International Money and Finance, 1 (14), (1995), 3-23.

[17] A. M. M. Masil and R. Masil, Are Asian stock market fluctuations due mainly to intra-regional contagion effects? Evidence based on Asian emerging stock markets, Pacific-Basin Finance Journal, 7, (1999), 251-282.

[18] R. B. Nelsen, An Introduction to Copulas, Springer Science + Business Media, Inc. USA, 2006.

[19] J. Rodriguez, Measuring financial contagion: a copula approach, Journal of Empirical Finance, 14, (2006), 401-423.

[20] M. Sibuya, Bivariate extreme statistics I, Annals of the Institute of Statistical Mathematics, 2 (11), (1960), 195-210.