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# Does Contagion Exist After Subprime Mortgage Crisis?

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# Does Contagion Exist After Subprime Mortgage Crisis?

## Abstract

This study investigate whether contagion after subprime mortgage crisis. We apply a multivariate dynamic condition correlation EGARCH framework to global stock markets, which include East Asia, OECD, Latin America and other emerging market, during the subprime mortgage crisis period. The major results of this paper are summarized as following. First, we employ a extremely short-run period and the relative long-run periods, surprisingly find that few evidence to support the existence of contagion after subprime mortgage crisis. Second, there are significant volatility spillovers and asymmetric effects from the US to international markets.

*keywords:* contagion, multivariate EGARCH, spillover effects

## 1. Introduction

Beginning in the March 2007, the subprime mortgage crisis was considered as a regional turmoil for the US financial institutions. Because of financial liberalization, the turmoil was simmering within the United States at the first time, but subsequently it boiled over global financial markets, more specific, global stock markets has been fall about 40% from 2007 to 2008. International, financial market liberalization facilitated a greater flow of funds to markets from globe. Nevertheless, the greater financial interdependence makes economics more vulnerable to financial crisis via transmission mechanism. After the US crash, Mexican peso crisis and Asian financial crisis, these comovements have led many economists to raise a question of whether there are discontinue in the international transmission mechanism.

The discussion of cross-markets transmission mechanism is well-established, and most of them suggest that there is some relationship between international financial markets, such as spillover effects, comovements and contagions. As shown in Figure 1 to 3, the comovement affected markets in East Asia, OECD, Latin America and other emerging markets after subprime mortgage crisis. This case shows that dramatic movement in one stock market can have a powerful impact on markets of vary different size and structure across the globe. However, does this period of highly correlated stock market movements provide any evidence of contagion exist after subprime mortgage crisis?

There are various definitions and disagreement of contagion in earlier empirical studies. In order to overcome this difficult, we employ a narrow definition –a significant increase in cross market linkage after a shock to one country, group or economy– that has historically been used in literatures. Therefore, a continued and highly comovement may not constitute contagion, but interdependence as opposed to contagion. According to Forbes and Rigobon (2002), this restrict definition provides two important advantages. First, it provides a straightforward framework to test contagion. Simply compare the linkages between two markets during the relatively stable period with the linkages after a shock or crisis. Second, a straightforward method to distinguish different reason of how crisis are transmitted across markets. This testing strategy can provide evidence on which group of theories were most important.

According to Chiang, Jeon and Li (2007), the existing empirical focus on contagion has two major limits. First, problematic due to the bias introduced by changing volatility in market return. Second, the various of contagion definitions and arguing. To overcome the first limitation introduced by Forbes and Rigobon (2002), this paper adapts an empirical approach based on multivariate EGARCH-DCC model in order to correct the heterskedasticity problem and investigate the dynamic linkage between the US and international stock markets after subprime mortgage crisis, and spillover effects simultaneously. For the second limitation, we employ a narrow definition that contagion must involve evidence of a dynamic increment in correlations. Though, the definition we adapt is not universally accepted, but, provided a useful method of distinguishing between explanations of how shocks are transmitted across markets.

The purpose of this study is to confirm whether contagion occurred after subprime mortgage crisis in a narrow definition, a significant increase in correlations after shock, and considering the correction of heterskedasticity as well. The major results of this paper are summarized as following. First, we employ an extremely short-run period (one month after subprime mortgage crisis period) and the relative long-run periods (three, six and twelve months after subprime mortgage crisis), find that few evidence to support the existence of contagion after subprime mortgage crisis. Second, there are significant volatility spillovers and asymmetric effects from the US to international markets.

The remainder of this paper is organized as follow. Section 2 briefly reviews the relevant empirical literature. Section 3 explains methodological issues and describes the data employed. Section 4 presents a multivariate EGARCH-DCC model and discusses its application to our context. Section 5 summarizes the study and concludes.

## 2. Literature Review

Well documented by extensive empirical work on the impact of high international turmoil, the financial contagion literature demonstrated several empirical contradictions with respect to the existence of contagion, the transmission channels of international shocks and causes of financial turmoil. Figure 1 shown an apparent trend in different capitalization size, market structure, geographic locations. The high degree of comovement suggests the existence of mechanism through which shock transmitted international. Yet, the existence of contagion in relation to the crisis remains a debatable issue. Baig and Goldfajn (1999) show a significant increase in correlation coefficients during the Asian crisis. Other researchers find that after accounting for heteroskedasticity, there is no significant increase in correlation between asset returns in pairs of crisis-hit countries, reaching the conclusion that there was ‘‘no contagion, only interdependence’’ (Forbes and Rigobon, 2002; Bordo and Murshid, 2001; Basu, 2002).

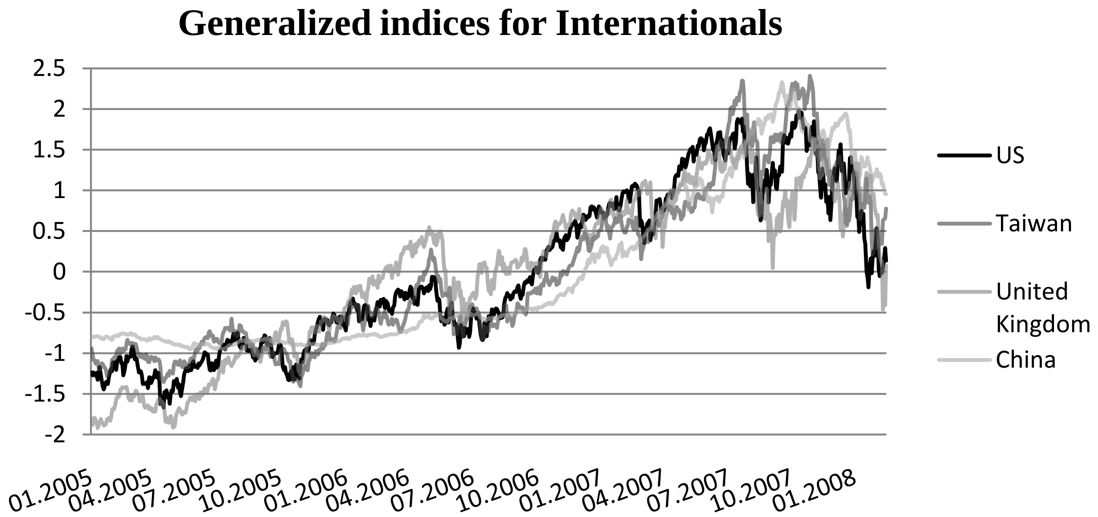


**Fig 1. Generalized stock market indices for Internationals** This figure graphs generalized stocks market indices for internationals around the time of the Subprime Mortgage. All indices are standardized as daily index minus average and divided by standard deviation.

To measure how shocks transmitted internationally, four mainly methodologies have been introduced in earlier studies: cross-market correlation coefficients, ARCH and GARCH models, cointegration techniques, and direct estimations of specific transmission mechanism. However, many literatures do not test for contagion, but conclude that contagion occurred during the financial crisis, in spite of different definition could lead a different conclusion.

Correlations analysis is the most straightforward approach to test for contagion. This strategy compares the difference between markets during the stable and turmoil period. The correlation increases significantly implies that the transmission mechanism between two markets strengthened after the shock and contagion occurred. Testing for stock market correlations, King and Wadhwani (1990) present there is significant increase between the United States, the United Kingdom and Japan after the US crash in 1987. Lee and Kim (1993) find contagion between 12 major markets; average weekly cross-market correlations increased from 0.23 to 0.39 around the 1987 US crash. Using correlations analysis, Calvo and Reinhart (1996) support to the same result between Brady bonds and stock prices after 1994 Mexican peso crisis. Overall, these empirical studies lead to a same conclusion: Contagion occurred.

The next strategy is ARCH, GARCH type model. Numerous of studies have focused on price and volatility spillovers to estimate the variance-covariance transmission mechanism between markets. To examine stock market around the 1987 US stock market crash, Hamao, Masulis and Ng (1990) employ a GARCH model and find a significant price-spillover from New York to London and Tokyo, and from London to Tokyo. Examining linkages between bond markets after the Mexican peso crisis, Edwards (1998) shows that there were spillovers from Mexico to Argentina. Aloui (2007) support the asymmetric and long-range persistence volatility spillover effect and show strong evidence of causality in the mean and variance between foreign exchange rate and stock price for both pre- and post-euro periods. However, these papers provide important evidence that volatility is transmitted across market, but most do not explicitly test for contagion as our definition.

The following procedure tests for changes in the cointegrating vector between markets over long periods of time. To analysis seven OECD countries from 1960 to 1990, Longin and Solnik (1995) show that average correlations in stock market return between the US and other countries rose by about 0.36 over this 30-year period. There are numerous long-term reasons resulting in this approach does not specifically test for contagion such as greater trade integration or higher capital mobility. Moreover, this testing strategy could miss periods of contagion when cross-market relationships only increase briefly after a crisis.

The final series of examining international transmission mechanisms attempts to directly measure how different factors affect a country's vulnerability to financial crisis. This literature is extensive and incorporates a range of testing strategies. In one of the earliest papers based on this approach, A binary-probit model is employed in Eichengreen, Rose, and Wyplosz (1996) to predict the probability of a crisis occurring in a set of industrial countries between 1959 and 1993, the empirical result suggest that the probability is correlated with the occurrence of a speculative attack in other countries at the mean time. For a different strategy, Forbes (2000) estimates the impact of Asian and Russian crises on stock return for a sample of over 10,000 companies around the world. She finds that trade linkages (which she divides into competitiveness and income effects) are important predictors of firms' stock returns and, therefore, of country vulnerability to these crises. In spite of different definition could lead a different conclusion, many literatures above do not explicitly test for contagion, but conclude that contagion occurred during the financial crisis.

To overcome the limitations found in the existing literature, we employs multivariate EGARCH-DCC model, which is appropriate for measuring time varying conditional correlations. The main advantage of our test procedure is the multivariate

EGARCH-DCC model enables us to combine the test strategy of the correlations analysis and the ARCH, GARCH model. More specific, we can compare correlations increase significant straightforward and estimate the variance-covariance transmission mechanism in the same time. Skintzi and Refenes (2006) examines the dynamic linkages among the European bond markets. The result suggests the Euro has strengthened the volatility spillover effects and the cross-correlations for most European bond markets. Chiang, Jeon, and Li (2007) suggest that there is a significant increase in correlation and that international sovereign credit-rating agencies play a significant role in shaping the structure of dynamic correlations in the Asian markets.

## 3. Methodology

A well documented empirical finding in the finance literature is the asymmetric impact of news on the volatility transmission. Using correlation coefficient to test contagion, Forbes and Rigobon (2002) have found evidence of interference of heteroskedasticity, we employ a multivariate EGARCH-DCC model with dummy variable to test whether significant increase in cross-market correlation coefficient, in other words, is there contagion or not. The multivariate EGARCH model, as developed by Nelson (1991), captures the potential asymmetric behavior of equity market returns and avoids imposing non-negativity constraints in GARCH modeling — by specifying the logarithm of the variance $\ln(\sigma_t^2)$, it is no longer necessary to restrict parameters in order to avoid negative variances. To control the fact that different markets are open during different times, we utilize the rolling-average, two-day returns construct by Forbes and Rigobon (2002) calculated as follow:

$$\mathrm{RAP}_{i,t} = \left(\mathrm{P}_{i,t} + \mathrm{P}_{i,t-2}\right)/2 \tag{1}$$

$$\mathrm{r}_{i,t} = \ln\left( \mathrm{RAP}_{i,t} \,/\, \mathrm{RAP}_{i,t-2} \right) \tag{2}$$

Where $\mathrm{P}_{i,t}$ stands for the stock index price of the $i^{th}$ country at time *t*. More specifically, the conditional mean equations for U.S. ($\mathrm{r}_{US,t}$) and the $i^{th}$ country ($\mathrm{r}_{i,t}$) at time *t* as follow:

$$\mathrm{r}_{US,t} = \alpha_{\mathrm{US},0} + \sum_{\mathrm{j}=1}^{p} \alpha_{US,j}\mathrm{r}_{US,t-j} + \sum_{\mathrm{j}=1}^{q} \alpha_{i,j}\mathrm{r}_{i,t-j} + \varepsilon_{US,t} \tag{3}$$

$$\varepsilon_{US,t}\big|\Omega_{t-1} \rightarrow \mathrm{N}\left(0, \sigma_{US,t}^2\right)$$

$$\mathrm{r}_{i,t} = \beta_{i,0} + \sum_{\mathrm{j}=1}^{p} \beta_{i,j}\mathrm{r}_{i,t-j} + \sum_{\mathrm{j}=1}^{q} \beta_{US,j}\mathrm{r}_{US,t-j} + \varepsilon_{i,t} \tag{4}$$

$$\varepsilon_{i,t}\big|\Omega_{t-1} \rightarrow \mathrm{N}\left(0, \sigma_{i,t}^2\right)$$

$$\sigma_{US,t}^2 = \exp\,[\, C_{US,0} + b_{US,1} \cdot \ln\left(\sigma_{US,t-1}^2\right) + \theta_{US,US} Z_{US,t-1}$$

$$+\delta_{US,US}\left(\left|Z_{US,t-1}\right|-E\left|Z_{US,t-1}\right|\right)+\theta_{US,i}Z_{i,t-1}+\delta_{US,i}\left(\left|Z_{i,t-1}\right|-E\left|Z_{i,t-1}\right|\right)] \quad (5)$$

$$\sigma^2_{i,t}=\exp[C_{i,0}+b_{i,1}\cdot\ln\left(\sigma^2_{i,t-1}\right)+\theta_{i,i}Z_{i,t-1}$$

$$+\delta_{i,i}\left(\left|Z_{i,t-1}\right|-E\left|Z_{i,t-1}\right|\right)+\theta_{i,US}Z_{US,t-1}+\delta_{i,US}\left(\left|Z_{US,t-1}\right|-E\left|Z_{US,t-1}\right|\right)] \quad (6)$$

$$\rho_{US,i,t}=\left[(1-k_1-k_2)\left(\bar{\rho}_{US,i}+\rho_{US,i,after}\cdot D\right)+k_1\rho_{t-1}+k_2\psi_{t-1}\right] \quad (7)$$

In the above equation, $\alpha_{US,0}$, $\beta_{i,0}$, $\alpha_{US,j}$, $\beta_{i,j}$, $\alpha_{i,j}$, $\beta_{US,j}$ for $j$ = 1, 2, ..., $n$ are parameters to be estimated and $\varepsilon_{US,t}$ and $\varepsilon_{i,t}$ are the stochastic error term. $\Omega_{t-1}$ is the information set at time *t-1*. According to Forbes and Rigobon (2002), they found that frequency of returns, lag structure, and the currency denomination have no effect on main result. Therefore, an AR(1) term and the one-day lagged U.S. stock return are included in the mean equation, the AR(1) is used to account for the autocorrelation of stock returns. $\sigma^2_{US,t}$ and $\sigma^2_{i,t}$ are the time varying conditional variances of US and the $i^{th}$ country stock returns.

Equations (5) and (6) are the conditional variance equations for US and the $i^{th}$ country stock market returns, respectively, and reflect the EGARCH(1,1) representation of the variance of $\varepsilon_{US,t}$ and $\varepsilon_{i,t}$. The standard residuals for US and the $i^{th}$ country stock market returns were expressed as $Z_{US,t}$ and $Z_{i,t}$. Conditional on $\Omega_{t-1}$, $\varepsilon_{US,t}$ and $\varepsilon_{i,t}$ are assumed to be normally distributed with zero mean and variance of $\sigma^2_{US,t}$ and $\sigma^2_{i,t}$. According to the EGARCH representation, the variance is condition on its own past values as well as on past value of standardized residuals.

The coefficient $b_{US,1}$ and $b_{i,1}$ present the persistence of volatility for the US and the $i^{th}$ country stock market returns, respectively. The $b_{US,1}$ and $b_{i,1}$ values are less than one, a result that is necessary for the conditional variances to be finite. The term $\theta_{US,i}Z_{i,t-1}$ + $\delta_{US,i}$( $|Z_{i,t-1}|$ - E$|Z_{i,t-1}|$ ) and $\theta_{i,US}Z_{US,t-1}$ + $\delta_{i,US}$( $|Z_{US,t-1}|$ - E$|Z_{US,t-1}|$ ) measure the ARCH effect, and the parameters $\theta_{US,US}$ and $\theta_{i,i}$ allow this effect to be asymmetric. The volatility spillover effect from the US to the $i^{th}$ country is measured by the term $\theta_{i,US}Z_{US,t-1}$ + $\delta_{i,US}$( $|Z_{US,t-1}|$ - E$|Z_{US,t-1}|$ ) in equation (6). Also, the spillover effect running from the $i^{th}$ country to the US is captured by the term $\theta_{US\,i}$ $Z_{i,t-1}$ + $\delta_{US,i}$( $|Z_{i,t-1}|$ - E$|Z_{i,t-1}|$ ) in equation (5). The coefficient $\delta_{US,i}$ is specifies spillovers from the US to the $i^{th}$ country and indicates whether these spillover is asymmetric. If $\theta_{US,i}$ is negative implies that negative US stock market return shocks increase the volatility of the $i^{th}$ country more than positive ones. Similarly, $\delta_{i,US}$ measures spillover from the $i^{th}$ country to US, and $\theta_{i,US}$ indicates whether these spillover is asymmetric.

To adjust the bias of heteroskedasticity, Engle (2002) and Tse and Tsui (2002) proposed a dynamic conditional correlation (DCC) specification such that $\sigma_{US,i,t}$ = $\sigma_{US,t}\sigma_{i,t}\rho_{US,i,t}$. This study adapts the modification constructed by Lien and Yang (2006) as equation (7), which describes the correlation coefficient between US and the $i^{th}$ country stock market return, where $\psi_{t-1} = \frac{\sum_{h=1}^{m} z_{US,t-h} z_{i,t-h}}{\sqrt{(\sum_{h=1}^{m} z_{US,t-h}^2)(\sum_{h=1}^{m} z_{i,t-h}^2)}}$ , for $m \geq 2$, $Z_{US,t} = \varepsilon_{US,t}/\sigma_{US,t}$ and $Z_{i,t} = \varepsilon_{i,t}/\sigma_{i,t}$. $\bar{\rho}_{US,i}$ is the unconditional correlation coefficient between U.S. and the $i^{th}$ country. $\rho_{US,i,after}$ is the correlation coefficient between the US and the $i^{th}$ country after the subprime mortgage crisis. D is the dummy variable for the turmoil period. In this case, contagion does happen if the coefficient of $\rho_{US,i,after}$ is significant differs from zero.

The main advantage of this multivariate EGARCH-DCC model compared to other series of papers examining contagion is that we test the cross-market correlation straightforward, and test mean, volatility spillover effect simultaneously.

# 4. Empirical Study

## 4.1. Data

The data set used in this paper consists of daily closing stock indexes for East Asia, Latin America, OECD, and other emerging markets, which includes 29 countries (32 markets): the 24 largest markets, plus Argentina, Chile, Philippines, and Russia. All indexes were collected from TEJ and sample period runs from 01/01/2005 to 03/16/2008. Stock market returns are calculates as rolling-average, two-day returns based on each country's aggregate stock market index in order to control for the fact that different markets are not open during in the same time. The rolling-average, two-day returns calculated as equation (1) and (2), where $R_{i,t}$ stands for the stock market return in market *i* at time *t*; $P_{i,t}$ is the stock price in country *i* at time *t*.

The summary of these description statistics of the indexes are presented from Table 1 to 4. The returns of Hong Kong, Indonesia, Korea, Singapore, Brazil, Chile, Mexico, Canada, Germany, Spain, India, Russia, Shanghai A, Shanghai B, Shenzhen A, Shenzhen B and South Africa are statistically different from zero at the 10 percent level of significance. Moreover, the sample mean range from 0.02% (for Japan) to 0.23% (for Indonesia) in East Asia, from 0.12% (for Argentina, Chile) to 0.24% (for Brazil) in Latin America, from 0.01% (for Italy) to 0.11% ( for Germany) in OECD and from 0.22% (for India, South Africa) to 0.38% (for Shenzhen A) in other emerging market. In the other hand, the sample standard error range from 1.15% (for Malaysia) to 1.83% (for Philippine) in East Asia, from 1.37% (for Chile) to 2.00% (for Brazil) in Latin America, from 0.95% (for U.S.) to 1.46% (for Germany) in OECD and from 1.48% (for South Africa) to 3.12% (for Shanghai B) in other emerging market. In shortly, the other emerging market region has the highest average sample return and standard error, while

OECD is the lowest. The skewness and excess kurtosis suggest that most of the return distributions are negatively skewed and leptokurtic relative to the normal distribution, except Shenzhen B (not for skewness) and Brazil (not for Kurtosis). The Ljung-Box Q statistics for 12 lags indicate that all of the return series exhibit strong linear dependence and ARCH effects. In sum, these preliminary results are consistent with most empirical findings in the literature.

**Table 1**
**East Asia Region Summary Statistics**

| | HK | IDA | JAP | KOR |
|---|---|---|---|---|
| Sample Mean | 0.12%* | 0.23%*** | 0.02% | 0.15%** |
| Standard Error | 1.61% | 1.81% | 1.50% | 1.60% |
| Skewness | -0.7149*** | -1.1332*** | -0.82383*** | -0.7282*** |
| Kurtosis | 3.8162*** | 4.1176*** | 2.5949*** | 2.1324*** |
| JB | 531.4388*** | 4.1176*** | 297.6203*** | 213.0982*** |
| Q(12) | 314.7550*** | 359.5677*** | 321.0406*** | 339.7756*** |
| $Q^2$(12) | 685.3779*** | 239.5949*** | 281.9157*** | 169.8422*** |
| | MAL | PHI | SIN | TAI |
| Sample Mean | 0.07% | 0.12% | 0.10%* | 0.08% |
| Standard Error | 1.15% | 1.83% | 1.27% | 1.45% |
| Skewness | -1.4890*** | -0.4545*** | -0.8576*** | -1.0036*** |
| Kurtosis | 8.3283*** | 2.5588*** | 3.5277*** | 3.2984*** |
| JB | 2490.3184*** | 234.1158*** | 484.6783*** | 469.6070*** |
| Q(12) | 445.4715*** | 416.1747*** | 322.7584*** | 390.1728*** |
| $Q^2$(12) | 317.9968*** | 280.1411*** | 390.4462*** | 248.4482*** |
| | THAI | | | |
| Sample Mean | 0.05% | | | |
| Standard Error | 1.54% | | | |
| Skewness | -0.7320*** | | | |
| Kurtosis | 5.02638*** | | | |
| JB | 862.1959*** | | | |
| Q(12) | 406.2089*** | | | |
| $Q^2$(12) | 186.3556*** | | | |

Note: JB for the Jarque-Bera test for normality. Q(12) and $Q^2$(12) for the Ljung-Box statistics applied to returns and squared returns respectively for each index. ***, ** and * denote significance at 1%, 5% and 10%, respectively.

## Table 2
## Latin America Region Summary Statistics

| | ARG | BRA | CHI | MEX |
|---|---|---|---|---|
| Sample Mean | 0. 12% | 0. 24%*** | 0.12%** | 0.21%*** |
| Standard Error | 1.83% | 2.00% | 1.37% | 1.71% |
| Skewness | -0.6691*** | -0.3220*** | -0.6703*** | -0.3362*** |
| Kurtosis | 1.4693*** | 0.1428 | 1.9249*** | 1.0707*** |
| JB | 127.5288*** | 13.8897*** | 178.1501*** | 52.1534*** |
| Q(12) | 398.8283*** | 363.4327*** | 470.4026*** | 407.0084*** |
| $Q^2(12)$ | 309.5256*** | 179.3286*** | 598.2939*** | 346.7526*** |

Note: JB for the Jarque-Bera test for normality. Q(12) and $Q^2(12)$ for the Ljung-Box statistics applied to returns and squared returns respectively for each index. ***, ** and * denote significance at 1%, 5% and 10%, respectively.

## Table 3
## OECD Region Summary Statistics

| | AUS | BEL | CAN | FRA |
|---|---|---|---|---|
| Sample Mean | 0. 07% | 0.06% | 0.10%** | 0.05% |
| Standard Error | 1.22% | 1.14% | 1.02% | 1.15% |
| Skewness | -0.8730*** | -0.8301*** | -0.7378*** | -0.8728*** |
| Kurtosis | 7.7820*** | 2.7629*** | 1.0029*** | 2.7387*** |
| JB | 1892.3239*** | 344.1532*** | 104.3707*** | 349.3976*** |
| Q(12) | 302.5500*** | 404.0669*** | 414.4720*** | 357.6804*** |
| $Q^2(12)$ | 389.3170*** | 498.5633*** | 245.3014*** | 344.7495*** |
| | GER | ITA | NEL | SPA |
| Sample Mean | 0. 11%** | 0.01% | 0.05% | 0.10%** |
| Standard Error | 1.46% | 1.02% | 1.14% | 1.13% |
| Skewness | -1.4058*** | -1.0450*** | -0.7226*** | -0.9962*** |
| Kurtosis | 8.7577*** | 3.1229*** | 2.3941*** | 5.0633*** |
| JB | 2795.3842*** | 494.2540*** | 259.0516*** | 974.5394*** |
| Q(12) | 390.3485*** | 384.8668*** | 410.3842*** | 358.7698*** |
| $Q^2(12)$ | 226.6720*** | 308.0402*** | 391.3818*** | 310.3965*** |
| | SWD | SWIZ | UK | US |
| Sample Mean | 0.08% | 0.06% | 0.04% | 0.02% |
| Standard Error | 1.31% | 1.08% | 1.04% | 0.95% |
| Skewness | -0.8515*** | -0.6344*** | -0.5710*** | -0.4876*** |
| Kurtosis | 1.3430*** | 1.4554*** | 1.5225*** | 1.4308*** |
| JB | 152.2959*** | 121.9345*** | 118.9351*** | 100.5598*** |
| Q(12) | 363.2328*** | 402.3877*** | 332.1902*** | 386.1850*** |
| $Q^2(12)$ | 365.5601*** | 527.5871*** | 493.7432*** | 359.3595*** |

Note: JB for the Jarque-Bera test for normality. Q(12) and $Q^2(12)$ for the Ljung-Box statistics applied to returns and squared returns respectively for each index. ***, ** and * denote significance at 1%, 5% and 10%, respectively.

**Table 4**
**Emerging Market Region Summary Statistics**

| | SHANG A | SHANG B | SHEN A | SHEN B |
|---|---|---|---|---|
| Sample Mean | 0. 31%*** | 0. 36%*** | 0. 38%*** | 0. 25%** |
| Standard Error | 2.22% | 3.12% | 2.42% | 2.59% |
| Skewness | -0.4474*** | 0.1932** | -0.5322*** | -0.0200 |
| Kurtosis | 1.5120*** | 3.5927*** | 1.2956*** | 2.5774*** |
| JB | 96.2118*** | 407.4710*** | 87.5108*** | 207.0832*** |
| Q(12) | 429.2529*** | 526.5348*** | 431.3147*** | 405.3274*** |
| $Q^2$(12) | 212.8256*** | 711.2229*** | 318.0231*** | 253.3596*** |
| | IND | RUS | SAFR | |
| Sample Mean | 0. 22%*** | 0. 33%*** | 0. 22%*** | |
| Standard Error | 2.04% | 2.19% | 1.48% | |
| Skewness | -0.9149*** | -0.8992*** | -0.5485*** | |
| Kurtosis | 3.97986*** | 3.8008*** | 2.35577*** | |
| JB | 613.1856*** | 554.7334*** | 218.9073*** | |
| Q(12) | 362.1792*** | 391.4672*** | 377.2669*** | |
| $Q^2$(12) | 293.9356*** | 393.4504*** | 418.4397*** | |

Note: JB for the Jarque-Bera test for normality. Q(12) and $Q^2$(12) for the Ljung-Box statistics applied to returns and squared returns respectively for each index. ***, ** and * denote significance at 1%, 5% and 10%, respectively.

## 4.2 Empirical Result

Table 5 presents the estimation result for equation (3) and (4). For the $\beta_{US,1}$, there is significant price spillover from the US stock market to the other countries in our sample, the effect of the US stock return on international stock markets is obvious, especially East Asia. The effect of the US stock returns on East Asian stock return is, $\beta_{US,1}$ equals to 0.439 on average, highly significant huge relative to Latin America (0.159), OECD (0.296) and other emerging markets (0.413). However, there is a strong price spillover from East Asia and OECD to U.S., either. The average $\alpha_{i,1}$ for East Asia and OECD is 0.081 and 0.082, higher than Latin America and other emerging market, relative. The result of our empirical analysis indicates that there is a significant relationship between global markets, East Asia and OECD especially.

Table 6 present the estimation result for equation (5) and (6). The coefficients for the lagged variance in the variance equation are highly significant, which is consistent with time-varying volatility and justifies the appropriateness of the GARCH(1,1) specification. The persistence of volatility is measured by $\beta_{US,1}$ for the US and $\beta_{i,1}$ for the $i^{th}$ country stock market, high and very close to, but less than, unity. This implies that that the unconditional variance is finite. The relevant coefficient $\theta_{i,US}$ is negatively and statistically significant for all markets. Thus, the volatility of U.S. stock market return has an asymmetric impact on the other markets.

Table 7 presents the estimation result for equation (7). Using a dummy variable for different sub-sample allows us to investigate the dynamic correlation changes associated with pre- and post-crisis. Before analysis linkage between the US and international stock markets, it's interesting to note that some of the coefficients of $\rho_{US,i,after}$ are negative, meaning the correlation coefficient decrease significantly after the subprime mortgage crisis. This phenomenon may not consist with our anticipation. According to Figure 1, the stock markets trend shows a highly correspond. Some empirical literature present the similar result that there are both positive and negative linkage after financial crisis. Baur and Fry (2009) presented that there are both positive and negative movement between Asian countries after Asian financial crisis. Moreover, Morris and Shin (1998) and Ahluwalia (2000) both suggested investors do tend discriminate during the periods of crisis. However, the situation of correlation coefficients decrease significantly doesn't confirm to our definition.

As the model implies, the significance of the estimated coefficient of dummy variable indicates structure changes in correlation coefficient due to external shocks during the different periods of the crisis. The most important evidence shows that contagion from a few countries. For the extremely short-run period (one month after subprime mortgage crisis period), we found that only Brazil, Shanghai B and Shenzhen B have a significant increase in correlation coefficient. It's interesting to note that, most of market participants in Shanghai B and Shenzhen B stock markets are foreign investor. Compare the B markets with the A markets, we fund a significant different reaction between different type of participant during the same period and the same event. For the relative long-run periods, Brazil had contagion in three months-period and six months-period, Canada Brazil and Mexico in twelve months-period. We fund that the subprime mortgage crisis shock has a significant effect at America region. However, our main result still consistent to Forbes and Rigobon (2002), most of countries are interdependent, not contagion. The similar result also provided by Corsetti, Pericoli and Sbracia (2005) indicates some contagion, some interdependence.

## 5. Conclusion

In this paper we have explored the linkage between international stock markets for the time around the subprime mortgage crisis. The sample period enables us to explore the dynamic relationships between the US and international stock markets at the time of the subprime mortgage crisis in March 2007 in an era of increasing integration of financial markets. To capture the dynamic, heteroskedasticity-adjusted correlations, volatility persistence and asymmetries simultaneously, we employee a multivariate EGARCH-DCC model to test whether significant increase in cross-market correlation coefficient. In particular, we test for contagion and spillover effect from the US to another for the period of 01/01/2005 to 03/16/2008. Surprisingly, our empirical evidence presents that only Brazil, Shanghai B and Shenzhen B had contagion in a extremely short-run period. For the relative long-run period, the subprime mortgage crisis had a significant impact to America region. However, most of countries are interdependence, not contagion.

Despite there are only a few contagion, the US stock market still has a strong influence to international stock markets. Our results point to significant volatility spillovers and/or asymmetric effects from the US to international markets. In terms of the asymmetric impact of innovations, we show that negative innovations in the US stock market have more impact for most sample countries. Therefore, we find no evidence to show that, it's contagion when we observed comovement or spillover effect between markets. The main finding of this paper support Forbes and Rigobon (2002) and Corsetti, Pericoli and Sbracia (2005), show that contagion is not a common situation after financial crisis.

**Table 5**
**Estimation of Mean Equation for Stock markets Returns**

| | $\alpha_{US,0}$ | $\alpha_{US,1}$ | $\alpha_{i,1}$ | $\beta_{i,0}$ | $\beta_{i,1}$ | $\beta_{US,1}$ |
|---|---|---|---|---|---|---|
| E. ASIA | | | | | | |
| HK | 0.00026 | 0.72510*** | -0.12679*** | 0.00065** | 0.48481*** | 0.55131*** |
| IDA | 0.00004 | 0.63847*** | -0.0500*** | 0.00069 | 0.59830*** | 0.45416*** |
| JAP | -0.00006 | 0.67186*** | -0.06528*** | 0.00007 | 0.53416*** | 0.47203*** |
| KOR | -0.00003 | 0.64313*** | -0.04468** | 0.00044 | 0.54183*** | 0.46785*** |
| MAL | 0.00006 | 0.64249*** | -0.11923*** | -0.00002 | 0.64500*** | 0.22338*** |
| PHI | -0.00009 | 0.66597*** | -0.05281 | 0.00010 | 0.54100*** | 0.57535*** |
| SIN | -0.00002 | 0.69671*** | -0.13608*** | 0.00026* | 0.51263*** | 0.41378*** |
| TAI | 0.00010 | 0.65755*** | -0.08390*** | 0.00010 | 0.60410*** | 0.43030*** |
| THA | 0.00003 | 0.65926*** | -0.05155*** | 0.00021 | 0.59372*** | 0.36330*** |
| L. AMERICA | | | | | | |
| ARG | -0.00013 | 0.65996*** | -0.02201* | 0.00015 | 0.60758*** | 0.22827*** |
| BRA | -0.00017 | 0.66334*** | -0.01982* | 0.00041 | 0.57047*** | 0.17887** |
| CHI | 0.00020* | 0.60601*** | -0.01286 | 0.00074*** | 0.64962*** | 0.07799** |
| MEX | -0.00017 | 0.67431*** | -0.04351** | 0.00025 | 0.58486*** | 0.15083** |
| OECD | | | | | | |
| AUS | 0.00002 | 0.76199*** | -0.22224*** | 0.00025 | 0.45947*** | 0.45069*** |
| BEL | -0.00005 | 0.66418*** | -0.09782*** | -0.00001 | 0.49213*** | 0.27412*** |
| CAN | 0.00015 | 0.63971*** | -0.05948** | 0.00040* | 0.60915*** | 0.09026*** |

Note:
***, ** and * denote significance at 1%, 5% and 10%, respectively.

**Table 5 (Continued)**
**Estimation of Mean Equation for Stock markets Returns**

| | $\alpha_{US,0}$ | $\alpha_{US,1}$ | $\alpha_{i,1}$ | $\beta_{i,0}$ | $\beta_{i,1}$ | $\beta_{US,1}$ |
|---|---|---|---|---|---|---|
| OECD | | | | | | |
| FRA | -0.00009 | 0.70201*** | -0.10136*** | 0.00017 | 0.36703*** | 0.40005*** |
| GER | 0.00018 | 0.71184*** | -0.09850*** | 0.00044* | 0.42659*** | 0.40563*** |
| ITA | -0.00005 | 0.66228*** | -0.09376*** | 0.00003 | 0.47370*** | 0.24008*** |
| NEL | -0.00012 | 0.67791*** | -0.07166*** | -0.00005 | 0.50005*** | 0.29752*** |
| SPA | -0.00006 | 0.67516*** | -0.08588*** | 0.00043* | 0.52812*** | 0.22321*** |
| SWD | 0.00004 | 0.66107*** | -0.06951*** | 0.0004 | 0.50907*** | 0.30642*** |
| SWIZ | -0.00015 | 0.67785*** | -0.06787** | 0.00012 | 0.50555*** | 0.28264*** |
| UK | -0.00022 | 0.70392*** | -0.08724*** | -0.00013 | 0.47378 | 0.28053 |
| Other Emerging Markets | | | | | | |
| IND | 0.00002 | 0.60905*** | -0.03082** | 0.00088** | 0.59776*** | 0.37672*** |
| RUS | 0.00018 | 0.65875*** | -0.06347*** | 0.00164*** | 0.58001*** | 0.39256*** |
| SAFR | 0.00006 | 0.67160*** | -0.08048*** | 0.00042 | 0.56113*** | 0.37042*** |
| SHANG_A | -0.00008 | 0.62891*** | 0.0005 | 0.00049 | 0.66501*** | 0.26795*** |
| SHANG_B | -0.00025 | 0.43812*** | -0.01083 | 0.00046 | 0.49632*** | 0.39112*** |
| SHENG_A | 0.00000 | 0.62048*** | -0.00471 | 0.00093 | 0.69872*** | 0.19326*** |
| SHENG_B | 0.00003 | 0.63301*** | -0.0116 | 0.00059 | 0.65764*** | 0.30149*** |

Note:
***, ** and * denote significance at 1%, 5% and 10%, respectively.

**Table 6**
**Estimation Result for Variance Equation**

| | $\theta_{US,i}$ | $\delta_{US,i}$ | $b_{i,1}$ | $\theta_{i,i}$ | $\delta_{i,i}$ | $\theta_{i,US}$ | $\delta_{i,US}$ |
|---|---|---|---|---|---|---|---|
| E.ASIA | | | | | | | |
| HK | 0.02759 | 0.01048 | 0.99682*** | 0.00638 | 0.06305** | -0.01101 | 0.03587 |
| IDA | 0.03944* | -0.01259 | 0.84455*** | -0.13899*** | 0.51692*** | -0.06667* | 0.03546 |
| JAP | 0.00521 | 0.01536 | 0.95490*** | -0.10320*** | 0.31383*** | -0.0543 | 0.09231* |
| KOR | 0.05273*** | 0.03371 | 0.92765*** | -0.06841** | 0.23572*** | -0.12493*** | 0.02989 |
| MAL | 0.02444 | 0.04964 | 0.94837*** | -0.02846 | 0.35079*** | -0.07740*** | 0.06445 |
| PHI | 0.02988 | 0.00995 | 0.80002*** | -0.05814 | 0.43335*** | -0.06654* | 0.12064* |
| SIN | 0.00238 | 0.09108*** | 0.91346*** | -0.06619* | 0.38970*** | -0.09115** | 0.13620** |
| TAI | 0.05396*** | 0.04218 | 0.96197*** | -0.02949 | 0.12818*** | -0.10969*** | 0.09314** |
| THA | 0.06622*** | 0.02461 | 0.84482*** | -0.09883** | 0.24834*** | 0.02 | 0.16524*** |
| L.AMERICA | | | | | | | |
| ARG | 0.02791 | -0.09752*** | 0.86286*** | -0.06877* | 0.27461*** | -0.10583*** | -0.11490** |
| BRA | 0.07059*** | -0.06399** | 0.96687*** | -0.02401 | 0.07954*** | -0.16873*** | -0.06865** |
| CHI | 0.01714 | 0.07834** | 0.90394*** | -0.13822*** | 0.41823*** | 0.02061 | 0.04876 |
| MEX | 0.02785 | -0.02262 | 0.92205*** | -0.12623*** | 0.15657*** | -0.09871** | -0.13540*** |
| OECD | | | | | | | |
| AUS | 0.05446** | 0.06428** | 0.88100*** | -0.08941** | 0.24327*** | -0.11978*** | 0.12916** |
| BEL | -0.02653 | 0.02135 | 0.94129*** | -0.03285 | 0.07337** | -0.13862*** | 0.13048*** |

Note:
***, ** and * denote significance at 1%, 5% and 10%, respectively.

**Table 6 (Continued)**
**Estimation Result for Variance Equation**

| | $\theta_{US,i}$ | $\delta_{US,i}$ | $b_{i,1}$ | $\theta_{i,i}$ | $\delta_{i,i}$ | $\theta_{i,US}$ | $\delta_{i,US}$ |
|---|---|---|---|---|---|---|---|
| OECD | | | | | | | |
| CAN | 0.01839 | -0.024 | 0.93399*** | -0.18406*** | 0.08456** | 0.00401 | 0.04366 |
| FRA | -0.02069 | -0.00917 | 0.94653*** | -0.05312** | 0.06229* | -0.13802*** | 0.03018 |
| GER | 0.00504 | 0.00899 | 0.99921*** | -0.08260*** | 0.09325*** | 0.00832 | 0.01238 |
| ITA | -0.05169** | -0.00811 | 0.88966*** | -0.15963*** | 0.11551*** | -0.11099*** | 0.07828* |
| NEL | -0.01843 | -0.00761 | 0.95490*** | -0.07757*** | 0.04586 | -0.11657*** | 0.04775* |
| SPA | 0.01322 | 0.02502 | 0.88616*** | -0.10393*** | 0.30203*** | -0.05679* | 0.04572 |
| SWD | -0.04283 | -0.00925 | 0.89612*** | -0.18494*** | 0.17312*** | -0.05768 | 0.09295** |
| SWIZ | -0.01687 | 0.04772* | 0.92451*** | -0.08639*** | 0.19357*** | -0.07217* | 0.04948 |
| UK | 0.00566 | 0.07592*** | 0.96023*** | -0.06855** | 0.09043** | -0.12764*** | 0.03561 |
| Other Emerging Markets | | | | | | | |
| IND | 0.00017 | 0.01254 | 0.90438*** | -0.19096*** | 0.39272*** | -0.10482*** | 0.12559** |
| RUS | 0.03085* | -0.00848 | 0.89865*** | -0.06560** | 0.34460*** | -0.03112 | 0.10214** |
| SAFR | -0.00798 | -0.0028 | 0.93575*** | -0.14481*** | 0.22700*** | -0.07704** | 0.06894* |
| SHANG_A | 0.03211** | 0.06154*** | 0.91998*** | -0.07400** | 0.33343*** | -0.03701 | 0.0023 |
| SHANG_B | 0.05065*** | 0.04758*** | 0.86193*** | -0.03037 | 0.37107*** | -0.12563*** | 0.00731 |
| SHENG_A | 0.03148* | 0.06474*** | 0.87925*** | -0.07596** | 0.39959*** | -0.04973 | 0.06124 |
| SHENG_B | 0.03031 | 0.07774*** | 0.82251*** | -0.05943 | 0.60120*** | -0.04702 | 0.10261* |

Note:
***, ** and * denote significance at 1%, 5% and 10%, respectively.

**Table 7**
**Estimation Result of Correlation Coefficient**

| | One Month | Three Months | Six Months | Twelve Months |
|---|---|---|---|---|
| | $\rho_{US,i,after}$ | $\rho_{US,i,after}$ | $\rho_{US,i,after}$ | $\rho_{US,i,after}$ |
| E.ASIA | | | | |
| HK | 0.07485 | 0.00925 | -0.13615* | -0.10945 |
| IDA | 0.0716 | 0.00752 | 0.02433 | -0.09071 |
| JAP | 0.1874 | -0.01203 | -0.18043* | -0.11936** |
| KOR | -0.26029 | -0.14959 | -0.14614* | -0.17498*** |
| MAL | 0.22844 | 0.01186 | -0.05411 | -0.09808* |
| PHI | -0.00606 | 0.10525 | 0.01796 | -0.08322 |
| SIN | 0.08476 | -0.07221 | -0.16026* | -0.13978** |
| TAI | -0.33778 | -0.15462 | -0.24736*** | -0.1959*** |
| THA | 0.16183 | 0.17103* | -0.0172 | -0.08321 |
| L.AMERICA | | | | |
| ARG | 0.0355 | 0.05038 | 0.05038 | 0.05102 |
| BRA | 0.22751*** | 0.13709*** | 0.09125*** | 0.05372** |
| CHI | 0.06646 | -0.14518 | -0.14021** | -0.10140*** |
| MEX | 0.07849 | -0.05737 | -0.0024 | 0.05228** |
| OECD | | | | |
| AUS | -0.07876 | -0.00625 | -0.15018 | -0.23483*** |
| BEL | -0.33517 | -0.03223 | -0.03949 | -0.07257* |

Note:
***, ** and * denote significance at 1%, 5% and 10%, respectively.

**Table 7 (Continued)**
**Estimation Result of Correlation Coefficient**

| | One Month | Three Months | Six Months | Twelve Months |
|---|---|---|---|---|
| | $\rho_{US,i,after}$ | $\rho_{US,i,after}$ | $\rho_{US,i,after}$ | $\rho_{US,i,after}$ |
| OECD | | | | |
| CAN | 0.094 | 0.04483 | 0.05785 | 0.05653** |
| FRA | -0.1336 | -0.10378 | -0.08636 | -0.06280* |
| GER | -0.21153 | -0.18492** | -0.13532** | 0.00911 |
| ITA | -0.257 | -0.19074* | -0.08700* | -0.08669** |
| NEL | -0.14636 | -0.03889 | -0.07133 | -0.08095** |
| SPA | -0.2717 | -0.15403 | -0.14452** | -0.12969*** |
| SWD | -0.08944 | -0.05836 | -0.03472 | -0.06185 |
| SWIZ | 0.02678 | -0.06339 | -0.10139 | -0.08636** |
| UK | -0.01029 | -0.02976 | -0.03085 | -0.08323** |
| Other Emerging Market | | | | |
| IND | 0.14529 | 0.15427 | -0.02051 | -0.10556* |
| RUS | -0.30348 | -0.08037 | 0.01211 | -0.0333 |
| SAFR | 0.06483 | -0.13536 | -0.05865 | -0.10019* |
| SHANG_A | -0.00353 | -0.12439 | -0.08042 | -0.08441 |
| SHANG_B | 0.40247** | 0.0754 | -0.01175 | -0.0299 |
| SHENG_A | 0.38175 | 0.00441 | -0.01827 | -0.02823 |
| SHENG_B | 0.41840*** | -0.08851 | -0.13190* | -0.10485* |

Note:
***, ** and * denote significance at 1%, 5% and 10%, respectively.

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