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Abstract: Scholars worldwide have provided both theoretical and empirical insights into financial market contagion. The devastation from the recent financial crisis is immeasurable, and researchers commonly believe that the crisis seemingly originated from the U.S. and spread immediately to the other global financial hubs. Several studies have been conducted on financial markets, but this issue has yet to be addressed. Using U.S. dollar-denominated MSCI daily indices for the period 2006–2010, this paper employs Dynamic Conditional Correlation-Generalized Autoregressive Conditional Heteroskedasticity (DCC-GARCH) and vector error correction (VEC) models to address the multi-dimensional phenomena around financial market contagion. The empirical results demonstrate the existence of contagion in the financial markets during the global crisis. However, the crisis originated in the U.S., and its effects escalated immediately to the other global markets. The results also indicate that benefits from portfolio diversification decayed significantly among countries during the crisis.

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1. Introduction

The bankruptcy of Lehman Brothers was the world's first alarm about the imminent financial crisis that primarily began to take shape in the U.S. and was suspected to have inevitably spread throughout the world. The Lehman bankruptcy was followed by the takeover of Merrill Lynch by Bank of America and the consequent rescue of AIG. HBOS plc, Britain's largest mortgage lender, was taken over by Lloyds TSB, followed by the nationalization of the European banking and insurance giant Fortis and the rescue plan in Germany. In 2008, the tsunami-like crisis began to spread rapidly across the globe and immediately became a worldwide issue. Many countries had large budget deficits and significant national and international debt. In addition, a number of emerging market economies, such as Hungary, Ukraine, Latvia and Iceland, suffered from severe financial crises and sought emergency assistance from the International Monetary Fund (IMF). The situation in Greece was worse. Experts throughout the world agreed that the world was approaching the deepest recession since World War II. In short, large financial institutions either collapsed or were purchased, and even governments in the world's wealthiest nations had to develop rescue packages to bail out their financial systems during the crisis.[4]

The realization that a crisis would ensue, which became evident in world markets and the Dow Jones, peaked in May 2008, and the ensuing months revealed the possibility of a crisis spreading from the housing market to the entire economy. The events of September 2008 are usually synonymous with the global financial crisis. Lehman Brothers filed for bankruptcy on September 15, and Bank of America announced the purchase of Merrill Lynch on the same day. On September 7, the U.S. government used its funds to help struggling Freddie Mac and Fannie Mae and bailed out AIG on September 16. These events, which gained momentum in September, were thereafter reflected in the markets. The Dow Jones lost 6% in value during the month of September. By the end of October, compared with its value on September 1, it had lost nearly 20% of its value and lost nearly 25% of its value by the end of 2008.[5] The index continued to decline until March 2009, when it rebounded to regain a significant portion of its losses.

Similar patterns were witnessed around the world. The U.K. FTSE 100 index declined by approximately 25% by mid-October 2008 and almost 30% by the end of 2008, compared with its value on September 1, 2008. As an example from the emerging markets, the BVSPA index in Brazil declined by 35% by mid-October 2008 and by nearly half of its value by the end of October 2008, after which

[4] A detailed overview of the events of the global financial crisis is given in Acharya et al. (2009).
[5] In November, at its minimum value, the index lost 35% of its value since September 1, 2008.

point it started to recover. These examples show that the crisis hit other countries as well, thus raising the question of how the crisis spread. How many countries suffered because of the crisis that started in the U.S.? In fact, researchers across the world largely believe that the global financial crisis originated in the U.S. from its sub-prime mortgage crisis, whose severity was further intensified through a major breakdown in the financial system that spread rapidly throughout the world. Agreeing with scholars who stated that financial market contagion occurred during the crisis is therefore logical.

Without a doubt, financial market contagion is an issue of enormous interest in the finance literature. Dornbusch et al. (2000) and Pritsker (2001) adopt the definition of contagion as the dissemination of market disturbances, primarily with negative consequences, from one market to another. Researchers[6] strongly assert that an excessive increase in the correlation among the countries causing the crisis and all other countries is synonymous with the presence of contagion. We have adopted this definition of contagion in our paper. Bekaert et al. (2005) also identify contagion in equity markets as the notion that markets move more closely together during periods of crisis. Sachs et al. (1996) describe financial market contagion as a significant increase in cross-country correlations of stock market returns and volatility. Understanding whether financial market contagion occurred during the recent financial crisis is a fascinating study.

In contrast, the literature on stock market co-integration suggests that the benefits from portfolio diversification diminish across countries when financial markets move more closely together. In this regard, Arshanapalli and Doukas (1993), McInish and Lau (1993), and Meric and Meric (1997) demonstrate that global portfolio diversification benefits to investors decrease significantly when the correlation between national stock markets increases. Hon, Strauss, and Yong (2006) also suggest that the benefits of international diversification in times of crisis are substantially diminished.

This research adopted multi-approach econometric techniques to answer the research question(s). First of all, Engle and Sheppard’s (2001) model is employed to determine the nature of correlation[7] between the country indices. *Secondly*, the Dynamic Conditional Correlation-Generalized Autoregressive Conditional Heteroskedasticity (DCC-GARCH) model is applied to capture the dynamic nature of the correlation between markets in the U.S. and those of the rest of the world. *Thirdly*, principal component analysis (PCA) has been conducted to analyze the contagion at the

[6] Masson (1998 and 1999), Masson and Mussa (1995), Calvo and Reinhart (1996), Forbes and Rigobon (2002), Pesaran and Pick (2003), Pritsker (2001), Pericoli and Sbracia (2001) and Corsetti et al. (2003).

[7] Dynamic conditional correlation (DCC) is tested against the constant conditional correlation (CCC) by implementing Engle and Sheppard (2001) model.

regional level. *Fourthly*, the vector error correction model (VECM) approach is implemented within the Johansen framework to test Granger causality and the impulse response function (IRF).

The empirical results demonstrate the existence of contagion in financial markets during the global crisis. The results also suggest that the crisis originated in the U.S. and the effects escalated to the other global markets. Principal regional common factors strengthen the country-level results and are evident of the occurrence of contagion in the global financial markets during the crisis. Finally, the co-integration analysis stresses that portfolio diversification benefits decay significantly between countries during the crisis.

The rest of the paper is designed as follows. Section 2 summarizes the existing literature on the issue. Section 3 elaborates on the methodology used in the study. A description of the data is provided in section 4. Section 5 presents the empirical evidence, and the concluding remarks are provided in section 6.

2. Literature Review

The results from the relatively extensive empirical literature on contagion in equity markets are divergent. Contagion in equity markets refers to the notion that markets move more closely together during periods of crisis (Bekaert et al. 2005). Hon et al. (2006) find that major global events such as a crisis can lead to a change in the cross-country correlation of assets. Ang and Bekaert (2001) and Longin and Solnik (2001) show that cross-correlations of international equity markets are higher during periods of volatility, which is true for major events such as financial crises.

Cappiello et al. (2006) also conclude that, during periods of financial turmoil, equity market volatilities show important linkages and conditional equity correlations among regional groups increase dramatically. Baig and Goldfajn (1998) investigate the contagion effect from the Asian currency crisis on Thailand, Malaysia, Indonesia, South Korea and the Philippines. They consider the presence of contagion between equity and currency markets. Baig and Goldfajn (2000) examine whether there was contagion during the Russian crisis with regard to Brazil and conclude that contagion occurred and that the mechanism of propagation was the debt securities market. They also note the sudden halt in capital flows to Brazil and Russia. Corsetti et al. (2005) test the contagion effect between Hong Kong, the ten emerging nations and the G7 countries and their evidence suggests that at least five of the seventeen countries showed symptoms of contagion.

In line with Rigobon (2003), Caporale et al. (2003) also conclude that there was evidence of contagion during the Asian crisis. At the same time, Billio et al. (2003) observe that the Asian crisis was unable to handle contagion testing given the inadequate testing procedure. Longin and Solnik (2001) identify that correlations increased during crises but not during periods of tranquility. Bae et al. (2003) note a few points about their findings: contagion was more serious in Latin America than in Asia; contagion from Latin America to other regions was more important than that in Asia; the United States was not contaminated by the Asian crisis; and contagion is predictable and subject to prior information. Boschi (2005) analyzes contagion effects between Argentina and Brazil, Venezuela, Uruguay, Mexico and Russia but is unable to provide evidence of contagion. However, Collins and Gavron (2005) study 44 events of contagion in 42 countries and find that the Brazilian and Argentinean crisis generated most of the contagion events.

Chiang et al. (2007) investigate financial contagion during the Asian crisis. Their results reveal the contagion effect in Asian markets, and they have identified two phases (contagion and herding behavior of correlation) of correlation amongst Asian markets. Sovereign credit rating agencies have played a vital role in shaping the structure of dynamic correlation in the Asian markets. Sola et al. (2002) also test the contagion effects during the emerging market currency crises and have found evidence of contagion from the South Korean crisis to Thailand but not to Brazil. Hon et al. (2006) test whether the terrorist attacks on the U.S. on September 11, 2001 resulted in contagion in financial market. Their results indicate that international stock markets, particularly in Europe, responded closely to the U.S. stock market shocks during the three to six months after the crisis. Alper and Yilmaz (2004) present an empirical analysis of real stock return volatility contagion on the Istanbul Stock Exchange (ISE) from emerging markets. They produce evidence of a volatility contagion from financial centers, particularly on the aftermath of the Asian crisis to the ISE. Khalid and Kawai (2003) investigate the inter-linkages among different markets and countries within the Asian region but do not find any evidence to strongly support contagion.

Kawai and Khalid (2001) analyze the financial market contagion across regions during the "Tequila Crisis," the "Asian Crisis" and the "Russian Crisis." In addition to Asia, they particularly consider the effect of the collapse of the Thai baht on financial markets in Latin America and Europe. Ferna´ndez-Izquierdo and Lafuente (2004) examine the dynamic linkages between international stock market volatility during the Asian crisis in 12 relevant stock exchanges. They focus on the contagion hypothesis around the world and their empirical results tend to support the contagion hypothesis, i.e., significant leverage effects are the result of negative shocks within the market itself and foreign negative shocks.

Bekaert et al. (2005) produce no evidence that the Mexican crisis caused contagion. However, they find economically meaningful increases in residual correlations, particularly in Asia, during the Asian crisis. Dungey and Martin (2001), using a different methodology, find similar results for Asia and explore the role of currency risk in equity market contagion. Nevertheless, in a different type of study, Kaminsky and Schmukler (1999) analyze the type of news that moved markets on market jitter days during the Asian crisis. Their study reveals that movements were triggered by local and neighboring countries and that news about agreements with international organizations and credit rating agencies have the most weight.

Using correlation analysis, Lee and Kim (1993) find evidence of contagion in the global stock markets after the 1987 U.S. stock market crash. Longstaff (2010) presents strong recent evidence of contagion in the financial markets. His results support the hypothesis that financial contagion was propagated primarily through liquidity and risk-premium channels rather than through a correlated information channel.

Khalid and Rajaguru (2006) note that linkages and/or interdependence amongst financial markets increase because of a financial crisis. Forbes and Rigobon (2002) analyze the contagion effect on the equity markets of emerging and developed countries during the Asian and Mexican crises and the 1987 crash of the New York Stock Exchange. However, they conclude that most of the changes were the result of interdependence. Rigobon (2003) tests contagion during Mexican, Asian and Russian crises. For the Mexican crisis, the mechanism for the transmission of crises remained relatively constant, providing evidence of interdependence. At the same time, evidence of a structural breakdown existed for the Russian crisis and particularly for the Asian crisis.

Many studies consider the recent global financial crisis. Some tackle the specific issue of market contagion, such as Guo et al. (2011) and Longstaff (2010), who study the cross-asset contagion between several asset classes in the U.S. market. They find contagion, but because they only tackle cross-asset contagion, they cannot make any conclusions on contagion between the world's markets at the global level. Kenourgios et al. (2011) and Johansson (2011) address contagion between markets, but they have a smaller sample and focus only on either a specific region or a handful of markets. Thus, they are unable to truly gauge contagion on a global level. Another issue with Johansson (2011) is that the study uses the period from 2004 to 2008, which ends when the global financial markets enter the highest level of turmoil. All of these studies find evidence of contagion. Similarly, Bartram and Bodner (2009) study patterns within industry and groupings within several country (for example, developed and emerging). However, because their paper does not directly study correlations, it does not provide answers to the question of contagion.

Chudik and Fratzscher (2011) study twenty-six economies (defining the Euro area as a single economy and excluding China) using weekly data and find that the tightening of financial conditions was the key transmission channel in advanced economies, whereas the real side of the economy was the main channel in emerging economies. Another conclusion of their paper is that Europe suffered a greater effect than other advanced economies from the decline in risk appetite.

Furthermore, Samarakoon (2011) uses the widest sample of previously detailed studies, including sixty-three emerging and frontier markets (developed markets are excluded in his study). In line with our study, this study starts with an AR(3) model and moves to a VAR framework (whereas we move to a DCC). However, the conclusion of the paper is counterintuitive because it does not find that contagion spread from the U.S. to emerging markets (except for Latin America) but finds that contagion spread from emerging markets to the U.S. market. Nonetheless, Coudert et al. (2011) study the exchange market contagion between emerging markets and find that contagion spread from one to other neighboring emerging countries' foreign exchange markets during a global crisis.

The empirical results are inconclusive. One group of researchers define contagion as a significant increase in cross-country correlations during a crisis; however, the other group claims that, after adjusting for heteroskedasticity, there is no significant increase in cross-country correlation, which is interdependence. The issue of heteroskedasticity is very important in the empirical research on contagion. Therefore, employment of a multivariate GARCH model such as DCC can help address the issues of heteroskedasticity, or the dynamic nature of correlation.

3. Testing Procedure

In this paper, we have employed the AR model class to capture contagion in the world market during the recent global financial crisis. We consider the U.S. as the source of the contagion. As previously discussed, contagion increases in cross-country correlations of stock market returns and volatility. To capture contagion, we have employed a suitable model for capturing cross-country correlations, which can be static or dynamic. Employing the wrong approach may lead to biased results. Hence, we need to test whether the correlations are static or dynamic in nature. Testing the model for constant correlation has proven to be difficult because testing for dynamic correlation using data with time-varying volatilities may result in a misleading conclusion (Engle and Sheppard, 2001) and rejection of a true constant correlation because of mis-specified volatility models. On the one hand, Tse (1998) has conducted a null constant conditional correlation (CCC) against an autoregressive conditional heteroskedasticity (ARCH) in correlation alternative. On the other hand, Bera (1996) has tested a null CCC against a diffuse alternative. Engle and Sheppard (2001) stress that both alternatives failed to generalize the vector at a higher order, which has been identified as a limitation in the testing procedure of a null CCC against a dynamic alternative; therefore, they suggested testing a null CCC against a DCC within a vector autoregressive framework.

Following Engle and Sheppard (2001), we propose testing a null CCC against a DCC alternative in a higher order vector autoregressive (VAR) to satisfy the condition that the specific return series and U.S. returns experience a dynamic correlation. We propose a seemingly uncorrelated regression between individual series; U.S. returns have a null H_0: $\alpha=1-\beta$ against the DCC alternative. Under the null, the constant and all of the lagged parameters in the model should be zero.

If the primary conditions of a DCC are satisfied through the estimations, we proceed to apply the DCC framework to identify the presence of contagion at the country level and augment this model with asymmetric influences, as shown by Cappiello et al. (2006). Otherwise, we employ the CCC alternative. For each country *i* at time *t*, we employ the following models to test the null CCC against the dynamic alternative:

$$r_{i,t} = \alpha_0 + \beta_i r_{i,t-1} + \beta_2 r_{t-1}^{us} + \varepsilon_{i,t} \qquad (1)$$

where, $r_{i,t\text{-}1}$ is the country-specific lag return, r_{t-1}^{US} is the U.S. market return at time *t–1* and $\varepsilon_{i,t}|\Im_{t-1} \approx \mathrm{N}(0, \mathrm{H_t})$.

Following Engle (2002) and Cappiello et al. (2006), we estimate the DCC-GARCH using the following equations:

$$r_{i,t}|\Im_{t-1} \approx \mathrm{N}(0, \mathrm{D_t R_t D_t}) \qquad (2)$$

$$D_t = diag\{\sqrt{h_{i,t}}\} \qquad (3)$$

$$Q_t = (1-a-b)\bar{R} + a\varepsilon_{t-1}\varepsilon_{t-1}' + bQ_{t-1} \qquad (4)$$

$$R_t = Q_t^{*-1} Q_t Q_t^{*-1} \qquad (5)$$

where $D_t = diag\{\sqrt{h_{i,t}}\}$ is an nxn diagonal matrix with the square roots of the conditional variances in the diagonal, $h_{i,t}$ is obtained by a GARCH(1,1), $\varepsilon_{it} = r_{it}/\sqrt{h_{it}}$ is the standardized residual[8], r_{it} is the

[8] Dynamic conditional correlation (DCC) is tested against the constant conditional correlation (CCC) by implementing Engle and Sheppard (2001) model.

return of series i at time t and $\bar{R} = E[\varepsilon_t \varepsilon'_t]$; $Q_t^* = [q_{iit}^*] = \left[\sqrt{q_{iit}}\right]$. We obtain the a and b by maximizing the log-likelihood of the DCC process given by the following equation:

$$L = -\frac{1}{2}\sum_{t=1}^{T}(n\log(2\pi) + 2log|D_t| + log|R_t| + \varepsilon'_t R_t^{-1}\varepsilon_t + r_t' D_t^{-1} D_t^{-1} r_t' - \varepsilon_t'\varepsilon_t) \quad (6)$$

An imposed restriction on the model is that $a + b < 1$. We obtain the pattern of dynamic correlations by using equation 5, for which the dynamic correlation between series *i* and *j* at time *t* is simply equal to R_{ijt}.

If the primary conditions of a DCC are satisfied through the estimations previously mentioned, we proceed to apply the DCC framework to identify the presence of contagion at the country level and augment this model with asymmetric influences as shown by Cappiello et al. (2006)[9]. We employ an AR(p) model on the dynamic correlations that we obtained using eq. (1) to test the contagion of the U.S. market onto the different markets in the world. We employ

$$\hat{\rho}_{iUSt} = \gamma_0 + \gamma_1 \hat{\rho}_{iUSt-1} + \delta Crisis_t + \upsilon_t \text{.........(7)}$$

where $\hat{\rho}_{i,US,t}$ is the DCC between market *i* and the U.S. market at time t, $Crisis_t$ is a dummy variable for the crisis period and v_t is the error term. The presence of contagion is identified with the significant positive coefficient of δ.

We also apply a similar methodology to analyze contagion at the regional level. Following the methodology of Yiu et al. (2010), we first use the principal component technique of Jolliffe (2002) to identify regional factor(s). Subsequently, we perform the following VAR filter for the regional factor(s):

$$\begin{bmatrix} RF_t \\ US_t \\ RL_t \end{bmatrix} = \begin{bmatrix} \mu_{RF} \\ \mu_{US} \\ \mu_{RL} \end{bmatrix} + \sum_{j=1}^{p} A_j \begin{bmatrix} RF_{t-j} \\ US_{t-j} \\ RL_{t-j} \end{bmatrix} + \begin{bmatrix} \varepsilon_{RF,t} \\ \varepsilon_{US,t} \\ \varepsilon_{RL,t} \end{bmatrix} \quad (8)$$

We repeat the same methodology for the regional factors that we used for the country indices (eq. 7). We adopted the methodologies of Yiu et al. (2010), Engle (2002), Cappiello et al. (2006) and Jolliffe (2002) and implemented the following model:

[9] We adopted ADCC but the results did not improve; therefore, we did not pursue it any further.

$$\hat{\rho}_{iRPCt} = \gamma_0 + \gamma_1 \hat{\rho}_{iRPCt-1} + \delta Crisis_t + \upsilon_t ....(9)$$

where $\hat{\rho}_{iRPC,t}$ is the DCC between market *i* and the regional principal component at time t, $Crisis_t$ is a dummy variable for the crisis period and v_t is the error term. The presence of contagion is identified with the significant positive coefficient of δ.

To reconfirm whether the U.S. triggered the contagion, we employ a cointegration method. *First*, we employ the Johansen procedure to determine whether the series are co-integrated (Johansen, 1991). *Second*, we estimate the vector error correction (VEC) model to determine Granger causality (Engle and Granger 1987). *Third*, we employ an impulse response method to determine the country that triggered the contagion. These methods[10] are also used to determine the effect of portfolio diversification.

4. Data

In this paper, we have used daily data[11] from January 2006 to December 31, 2010 to study the presence of market contagion during the recent global financial crisis. September 2008[12] is believed to be the beginning of the global financial crisis. Thus, we have used the period from September 1, 2008[13] to December 31, 2009 as the actual crisis period for this paper.[14] This research is dedicated to determining the contagion effect among financial markets and cross-country cointegration during the global financial crisis.

All of the data have been obtained from DataStream, and we attempted to extract homogenous indices. For all countries, we have used the U.S. dollar-denominated daily MSCI indices instead of indices denominated in local currency to diminish the effects of exchange rate fluctuations. After screening for missing values and inconsistencies, sixty-four indices were obtained.

[10] The models are described in detail in the appendix. However, the appendix section is excluded from the paper because the paper is already too long.
[11] Weekly data were tested to check robustness. We found no better results using the weekly dataset.
[12] A landmark institute, Lehman Brothers, collapsed in early September 2008.
[13] We conducted the Chow test to check structural breaks for the sample countries. The F-statistics for most of the countries are rejected at the 1% level for September 2008, which helped us determine September 2008 as the beginning of the global financial crisis.
[14] There can also be different interpretations of the actual start of the crisis. Yiu et al. (2002) take the crash of the sub-prime mortgage market in the U.S. as the start of the crisis. Thus, in their study, the start of the crisis is marked in September 2007. However, we noticed that the market indices declined significantly in September 2008. Thus, we consider September 1, 2008 as the start date of the crisis. The Chow test results also support the notion that the crisis begins in September 2008.

Table 1 presents a summary of the descriptive statistics of the MSCI indices. The mean returns of the MSCI indices are negligibly different from 0, and the volatilities are approximately 2%. However, we have observed that the average daily returns are negative for 13 indices. Skewness for most indices appear as 0 or very close to 0. These findings can help characterize the crisis as a low-return regime. However, we have observed excess kurtosis in each of the 64 indices, indicating that the return series are not normally distributed. The null hypothesis of normality is also rejected through the Jarque-Bera test at a very high level of significance for all indices. Similarly, the ARCH-LM test rejects the null hypothesis of no ARCH in the series of indices. Thus, we conclude that conditional heteroskedasticity is present in the data. In addition, the results of unit root tests using ADF, PP and KPSS have rejected the null hypothesis of the unit root for all markets, indicating that the return series are trend stationary.

[Insert Table 1 about here]

5. Results

The estimates for equation (1) are presented in **Table 2** and show that the AR term in the mean equations are highly significant with a few exceptions but that the coefficients of the U.S. lagged returns are highly significant[15]. These results support a study by Dungey et al. (2003), who found that the effect of U.S. returns on global stock returns is highly significant. The results from **Table 2** clearly indicate that individual markets are driven by the global factor "the US return." The AR(1) terms in the mean equation are significantly positive for most emerging markets that indicate price friction or partial adjustment; however, these terms for developed countries are significantly negative, indicating the presence of positive feedback trading in developed countries (e.g., Antoniou et al. 2005).

[Insert Table 2 about here]

We run seemingly uncorrelated regressions (SUR) between individual series and U.S. returns within the higher order VAR framework to test a CCC against a DCC under the Engle and Sheppard (2001) proposition. The test results are rejected at the 5% level, indicating that the MSCI return series have a DCC with U.S. returns (**Table 3**). These results interpret the time-varying volatility characteristics of the return series; that is, the persistence of shocks to volatility depends on $\alpha+\beta$. Engle and Bollerslev (1986), Chou (1988), and Bollerslev et al. (1992) show that if $\alpha+\beta < 1$, the tendency is for the volatility

[15] We ran the models with the regional leading country's lag alongside the U.S., but none of the regional leaders was significant. We tested the regional leaders alongside the U.S. to see if the market contagion spread from the regional leader.

response to decay over time. If $\alpha+\beta=1$, volatility persists indefinitely given shocks over time, and if $\alpha+\beta>1$, the persistence of increasing volatility over time/covariance stationary is violated. Although time-varying volatility is evident in the results, most developed countries experience long, persisting shocks. Unfortunately, long-term persistent shocks (β coefficient) are zero for a few countries in the sample, which requires special attention.

[Insert Table 3 about here]

Figure 1 presents the DCC between the U.S. and the rest of the countries. This graph shows that the correlation increases significantly between the U.S. and other countries from September 2008 to December 2009. This finding shows that an excessive increase in correlation among the countries that caused the crisis and all other countries is synonymous with the presence of contagion (e.g., Masson and Mussa, 1995; Calvo and Reinhart, 1996; Sachs et al. 1996; Masson, 1998 and 1999; Forbes and Rigobon, 2002; Pesaran and Pick, 2003; Pritsker, 2001; Pericoli and Sbracia, 2001; and Corsetti et al. 2003).

[Insert Figure 1 about here]

Next, we turn to the DCC analysis of contagion. As previously described, we have first obtained the residuals from the return equation (eq. 1), which are then used to calculate the dynamic correlation patterns. Finally, these patterns are tested for a dominant contagion effect during a crisis using an AR(1) model (eq. 7) with a crisis dummy. The results of the AR(1) model are shown in **Table 4**. An interesting feature of the model is the significance of the coefficient δ, which implies that the crisis has significantly increased the integration between market *i* and the U.S. market. **Table 4** shows that the coefficients are significantly positive at a high level, with few exceptions. The coefficients of the crisis dummy variable are highly significant in 46 countries. The significance of the dummy variable shows that market contagion has occurred during the recent global financial crisis. The R^2 for the AR(1) models of the dynamic correlations for countries in different regions are good[16]. Furthermore, for robustness, we run eq. 7 using the three-month interbank interest rates from the global crisis period;

[16] Given space limitations, we did not produce the results for regional models.

however, the crisis is not significant in either case. These results confirm that the contagion does not spread from other channels[17].

[Insert Table 4 about here]

We have also used principal component analysis method to detect the contagion effect of the U.S. factor on the regional common factor. The results are reported in **Table 5**, which shows the principal component eigenvalues and proportion of variance explained by the methodology and each ranked eigenvector. In all regions, the first principal component explains a larger portion of the variance than the subsequent principal components. For this reason, in all further calculations, we have used only the highest ranked principal component that we term the "regional factor." After obtaining the regional factors, we have performed a test by applying a model similar to equation 1 and saved the residuals, which are then used in the DCC methodology. **Figure 1** shows the pattern of dynamic correlations obtained between each regional factor and the U.S. and indicates that, for each regional factor, the dynamic correlation is near 0.5 during the crisis. Both the South and the North American regional factor indicate a jump in the dynamic correlation with the U.S. This jump is confirmed in **Table 5**, which shows coefficients of the AR model on the dynamic correlations (eq. 9). All of the regions show highly significant changes in dynamic correlations with the U.S. These results make clear that regional common factors play a key role in spreading the contagion from the U.S. to the global markets during the crisis. Nevertheless, **Figure 2** also validates contagion during the financial crisis because the dynamic correlations between the regional common factor and the U.S. are highly significant at this time.

[Insert Table 5 about here]
[Insert Figure 2 about here]

Furthermore, we have implemented a VAR framework for contagion testing in the financial markets. First of all, the ADF, PP, and KPSS tests confirm the non-stationarity of level indices for all regional countries. The Johansen procedure is also based on two test statistics, i.e., the maximum eigenvalue

[17] The results are not reported given space limitations but are available on request.

and the trace statistic, suggesting that the data follow the VECM approach[18]. Granger causality is conducted under the VECM procedure to investigate the bi-directional linkage of the regional countries. The results for the bi-directional linkage between regional countries are presented in **Table 7**.

[Insert Table 7 about here]

The bi-directional linkages indicate a significant influence of the U.S. on the rest of the world's countries (**Table 7**). However, we graphically confirmed these results by investigating the response to Cholesky's one standard deviation innovations of the U.S. to other countries through the impulse response function within a VECM framework. Impulse responses trace the reactions of the dependent variable to a unit shock of all other variables in a dynamic system: by hitting the error term with a shock, one can trace the effects on the dependent variable over time (Brooks 2008). The impulse response between regional countries is presented in **Figure 3**. All of these figures reflect the global markets' immediate response with one standard deviation shock of the U.S., except for Sweden[19]. These results confirm the significant unidirectional causal linkages, and they confirm that contagion spreads from the U.S. to the rest of the countries throughout the world.

[Insert Figure 3 about here]

Finally, we conclude that the financial market contagion has occurred during the global financial crisis. During this crisis, the contagion originated from the U.S. and spread rapidly to the rest of the countries around the world. The regional principal component appears as a key factor for some regions. Nonetheless, the co-integration results confirm the high degree of inter-linkages among the financial markets during the crisis, indicating that portfolio diversification benefits decay between countries during a crisis.

[18] We have conducted a co-integration analysis between nine regional countries by implementing the Johansen procedure. Based on the maximum eigenvalue and the trace statistic, we concluded that all regional countries are integrated at least at level 1. Given space limitations, we are unable to provide the detailed results, which are available on request.

[19] Sweden implemented a similar resolution method when it tackled the Swedish banking crisis during the 1990s. We believe that the Swedish resolution help it escape the global crisis.

6. Conclusion

Researchers commonly believe that the crisis seemingly originated from the U.S. and spread to the rest of the global financial hubs in no time. Using U.S. dollar-denominated MSCI daily indices for the period 2006–2010, this paper attempts to investigate whether market contagion occurs during a global crisis. Multiple approach econometric techniques show that contagion occurred during the global financial crisis but that it was not present in all of the world markets. The DCC methodology shows the presence of contagion in forty-six of sixty-three countries. These countries have shown significantly increased correlation with the U.S. market during the financial crisis compared with the period before the crisis. The DCC approach, together with the PCA framework, indicated the presence of contagion at the regional level for all regions in our study, thus confirming that the financial crisis was truly global. However, the Granger causality tests and the Impulse response functions within the VECM framework also confirm these results, except for Sweden. Sweden implemented a similar resolution to address the global crisis that succeeded; therefore, the country was not hit by the global crisis. Nevertheless, diversification benefits significantly decayed between the countries during the crisis.

With respect to studies on the recent global financial crisis, our contribution is threefold. *First*, we have used a wider sample than other studies and, thus, are able to better judge the scope of contagion during the global financial crisis. We also have used daily data when other studies used weekly or monthly data. Our results confirm that the contagion effect is more prominent in the financial markets when daily data are used instead of weekly data. Samarakoon (2011) tests the contagion effect on the emerging and frontier markets, but we have tested global data. However, other studies have focused only on a single region or group of countries and are incomplete. In contrast, this study has presented a complete picture in this context because it has captured a wide range of markets, including developed, emerging, and frontier markets. Furthermore, the robustness checks using three-month interbank interest rates confirm that contagion spreads through financial markets during a global crisis and not through the banking channel. *Second*, we have tested market contagion using multi-approach econometric techniques (e.g., DCC-GARCH, PCA and VECM), whereas the existing studies on market contagion have adopted a single method. Furthermore, the results of a co-integration analysis within the VECM framework are evidence that portfolio diversification benefits decay between countries during a crisis. These results are new with respect to crisis data. *Third*, this study has provided an extensive review of the existing studies on market contagion during major financial crises witnessed in the past three decades.

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Table 1
Summary statistics of the MSCI country indices.
The table reports the descriptive statistics of the MSCI daily indices for the crisis sample (1st September 2008-31st December 2009).

Index	Mean (%)	Volatility (%)	Skewness	Kurtosis	Jarque-Bera	ARCH-LM	ADF	Phillips-Perron	KPSS
West European Countries									
AUSTRIA	-0,02	2,48	0,13	8,54	1336	39,13	-23,72	-30,96	0,16
BELGIUM	-0,03	1,94	-0,59	9,98	2176	36,56	-21,44	-30,39	0,19
FRANCE	0,02	1,93	0,34	10,96	2770	37,54	-24,57	-34,22	0,16
GERMANY	0,03	1,91	0,32	10,29	2325	48,10	-23,59	-33,10	0,18
GREECE	-0,01	2,24	0,07	7,66	943	34,72	-22,51	-30,43	0,18
IRELAND	-0,07	2,54	-0,38	9,18	1684	38,81	-23,25	-31,50	0,35
ITALY	-0,01	1,94	0,36	10,94	2760	28,30	-13,90	-32,76	0,16
NETHERLANDS	0,02	1,86	0,15	10,51	2456	37,46	-24,02	-33,16	0,17
PORTUGAL	0,02	1,60	0,17	13,42	4723	36,55	-22,70	-31,46	0,29
SPAIN	0,05	1,94	0,22	10,81	2658	36,52	-23,62	-32,80	0,15
SWITZERLAND	0,02	1,52	0,32	9,12	1646	36,87	-25,16	-33,10	0,17
UK	-0,11	2,38	-0,18	13,70	4984	38,56	-19,70	-27,86	0,13
East European Countries									
CROATIA	0,06	1,81	0,06	8,55	1339	43,16	-22,87	-27,87	0,442*
CZECH REPUBLIC	0,05	2,36	0,39	16,23	7636	38,22	-24,20	-30,84	0,12
ESTONIA	-0,05	2,06	0,26	8,06	1123	39,13	-20,94	-29,04	0,16
HUNGARY	0,04	2,93	0,39	10,81	2675	42,65	-19,10	-28,58	0,11
POLAND	0,03	2,58	0,05	6,58	558	44,79	-22,41	-29,56	0,13
ROMANIA	0,00	2,67	-0,98	14,72	6139	40,85	-22,71	-30,60	0,20
RUSSIA	0,05	3,21	0,26	15,39	6680	40,60	-22,24	-29,94	0,15
SLOVENIA	0,04	1,73	-0,22	8,73	1436	48,20	-18,35	-27,47	0,602**
Nordic Countries									
DENMARK	0,03	1,90	-0,08	9,67	1934	37,80	-23,43	-31,23	0,16
FINLAND	0,01	2,19	0,25	7,27	803	36,77	-24,10	-33,36	0,24
NORWAY	0,05	2,79	-0,12	7,40	844	39,68	-24,45	-33,21	0,14
SWEDEN	0,03	2,41	0,41	7,54	924	38,43	-25,24	-32,54	0,15
MENA Countries									
TURKEY	0,05	2,90	0,00	6,48	525	46,82	-21,70	-30,31	0,10
BAHRAIN	-0,09	1,55	-2,54	43,90	73835	40,58	-22,04	-30,96	0,394*
ISRAEL	0,03	1,25	-0,64	7,02	774	38,81	-22,90	-31,34	0,16
JORDAN	-0,06	1,49	-0,57	9,60	1949	38,54	-21,53	-29,91	0,09
KUWAIT	-0,03	1,78	-0,85	10,95	2871	38,49	-21,14	-31,44	0,22
LEBANON	0,03	1,86	0,20	14,15	5408	49,75	-23,46	-27,44	0,09
OMAN	0,00	1,64	-0,92	21,17	14495	36,66	-21,12	-28,97	0,16
QATAR-	-0,03	2,00	-0,35	10,46	2441	38,62	-21,55	-29,58	0,15
UAE	0,01	1,89	0,23	11,22	2946	37,36	-24,46	-33,79	0,20
EGYPT	0,03	1,98	-0,89	9,69	2079	41,22	-21,15	-28,22	0,12
MOROCCO	0,07	1,34	-0,30	5,69	330	40,98	-20,85	-25,43	0,68**
TUNISIA	0,06	1,11	0,27	11,28	2991	38,75	-20,40	-29,29	0,10
African Countries									
KENYA	0,01	1,61	0,65	12,11	3683	38,53	-18,16	-21,90	0,18
MAURITIUS	0,10	1,63	0,40	11,48	3152	39,90	-21,05	-28,75	0,25
NIGERIA	0,00	1,61	-0,22	5,91	376	38,69	-16,16	-17,74	0,506**
SOUTH AFRICA	0,05	2,40	-0,15	6,40	506	40,02	-23,45	-30,59	0,09
South and Centrial Asian Countries									
CHINA	0,11	2,42	0,23	8,02	1105	46,02	-22,93	-32,02	0,16
HONG KONG	0,04	1,76	0,07	9,01	1570	51,80	-22,49	-33,17	0,13
INDIA	0,08	2,38	0,43	10,81	2683	43,53	-22,41	-30,27	0,13
KAZAKHSTAN	0,08	3,13	0,56	9,65	1978	38,83	-17,77	-35,12	0,14
KOREA	0,04	2,46	0,68	25,42	21932	37,60	-21,58	-31,63	0,13
PAKISTAN	-0,04	1,99	-0,43	5,31	264	38,62	-18,88	-26,64	0,13
SRI LANKA	0,04	1,57	2,64	30,32	33637	37,57	-19,53	-26,13	0,19

TAIWAN	0,03	1,74	-0,10	5,44	260	38,42	-20,94	-31,40	0,13
THAILAND	0,04	2,03	-0,69	12,17	3739	45,60	-21,44	-32,72	0,12
Asian Pacific Countries									
AUSTRALIA	0,05	2,17	-0,64	8,93	1599	39,52	-22,79	-32,67	0,16
INDONESIA	0,11	2,35	-0,04	8,78	1452	39,05	-20,67	-28,09	0,13
JAPAN	-0,02	1,71	0,11	7,87	1032	38,59	-26,62	-36,49	0,09
MALAYSIA	0,05	1,23	-0,63	10,14	2284	39,43	-22,22	-28,73	0,23
NEW ZEALAND	-0,02	1,77	-0,31	7,13	759	37,93	-24,00	-30,95	0,17
PHILIPPINES	0,06	1,89	-0,38	7,81	1030	39,38	-21,78	-28,57	0,20
SINGAPORE	0,05	1,79	-0,06	6,71	600	47,87	-22,00	-31,98	0,17
North American Countries									
CANADA	0,04	2,02	-0,52	9,76	2032	76,73	-24,90	-31,38	0,11
MEXICO	0,05	2,23	0,29	9,01	1585	63,39	-22,61	-29,43	0,13
USA	0,00	1,63	0,02	11,97	3496	67,32	-19,89	-36,91	0,14
South American Countries									
ARGENTINA	0,04	2,54	-0,38	9,53	1880	55,18	-22,87	-31,45	0,16
BRAZIL	0,12	2,92	0,00	9,56	1869	53,41	-23,62	-31,21	0,10
CHILE	0,07	1,75	0,21	17,88	9633	43,53	-22,10	-30,19	0,12
COLOMBIA	0,07	2,24	0,00	12,06	3565	45,56	-22,54	-29,69	0,08
PERU	0,13	2,56	-0,03	7,11	734	36,44	-23,05	-30,66	0,14

Note: All results in the table are performed on the returns of the indices. The ADF and PP tests have been performed on the no time trend models of the tests. KPSS test performs a unit root test with the null of stationarity and the alternative of a unit root. Significance is not shown for Jarque-Bera, ARCH-LM, ADF and PP tests, as for all indices we find significance at 1% significance level in each of these tests. For the KPSS test: ***, **, * imply significance at 1%, 5% and 10% respectively.

*The test results for the Jarque-Bera, ARCH-LM, ADF and PP tests are not reported in the table as for each index we obtain significant results at 1%. For the KPSS test ***, **, * indicate significance at 1%, 5% and 10% significance level.

Table 2

Results for the mean model

This table presents the results for eq. 1. $r_{i,t} = \alpha_0 + \beta_1 r_{i,t-1} + \beta_2 r_{t-1}^{US} + \varepsilon_{i,t}$ for the crisis period (1st September 2008-31st December 2009). $r_{i,t-1}$ is the country specific lag return, r_{t-1}^{US} is the return on the US market at time *t-1*; and $\varepsilon_{i,t}|\Im_{t-1} \approx N(0, H_t)$.

South American Countries				North American Countries			
Country	α_0	β_1	β_2	Country	α_0	β_1	β_2
ARGENTINA	0,04	-0,096**	0,35***	CANADA	0,04	-0,21***	0,42***
BRAZIL	0,14	-0,17***	0,52***	MEXICO	0,05	-0,05	0,26***
CHILE	0,07	-0,073*	0,26***	USA	0,00	-0,13***	
COLOMBIA	0,07	-0,02	0,43***	Nordic Countries			
PERU	0,14	-0,078**	0,35***	FINLAND	0,007	-0,21***	0,54***
West European Countries				DENMARK	0,036	-0,16***	0,52***
AUSTRIA	-0,029	-0,13***	0,63***	NORWAY	0,058	-0,19***	0,65***
BELGIUM	-0,031	-0,084**	0,37***	SWEDEN	0,030	-0,009	-0,082*
FRANCE	0,022	-0,33***	0,60***	Central European Countries			
GERMANY	0,033	-0,26***	0,47***	CROATIA	0,056	0,055**	0,45***
GREECE	-0,016	-0,055*	0,49***	CZECH REP.	0,052	-0,089***	0,60***
IRELAND	-0,086	-0,13***	0,54***	ESTONIA	-0,050	0,058*	0,46***
ITALY	-0,012	-0,24***	0,53***	HUNGARY	0,034	-0,025	0,64***
NETHERLANDS	0,021	-0,27***	0,51***	POLAND	0,027	-0,030	0,51***
PORTUGAL	0,020	-0,13***	0,40***	ROMANIA	-0,004	-0,028	0,55***
SPAIN	0,056	-0,25***	0,53***	RUSSIA	0,048	-0,027	0,52***
SWITZERLAND	0,021	-0,24***	0,43***	SLOVENIA	0,035	0,087***	0,48***
UK	-0,097	0,13***	0,38***	MENA Countries			
African Countries				TURKEY	0,048	-0,069**	0,59***
KENYA	0,009	0,37***	0,13***	BAHRAIN	-0,083*	0,05	0,11***
MAURITIUS	0,089*	0,11***	0,17***	JORDAN	-0,06	0,080**	0,19***
NIGERIA	-0,003	0,54***	0,052*	ISRAEL	0,03	-0,04	0,19***
SOUTH AFRICA	0,049	-0,11***	0,67***	KUWAIT	-0,03	0,03	0,12***
Asian Pacific Countries				LEBANON	0,02	0,15***	0,12***
AUSTRALIA	0,050	-0,15***	0,84***	OMAN	0,00	0,11***	0,25***
INDONESIA	0,10	0,089***	0,55***	QATAR	-0,02	0,093***	0,34***
JAPAN	-0,02	-0,12***	0,56***	UAE	0,00	-0,31***	0,57***
MALAYSIA	0,05	0,068**	0,29***	EGYPT	0,019	0,10***	0,40***
NEW ZEALAND	-0,02	-0,056**	0,62***	MOROCCO	0,051	0,22***	0,14***
PHILIPPINES	0,05	0,090***	0,66***	TUNISIA	0,052	0,085***	0,14***
SINGAPORE	0,06	-0,11***	0,43***				
South and Central Asian Countries							
CHINA	0,11	-0,094***	0,63***	KOREA	0,04	-0,064**	0,62***
HONG KONG	0,04	-0,13***	0,48***	PAKISTAN	-0,03	0,19***	0,10***
INDIA	0,08	-0,02	0,39***	SRI LANKA	0,03	0,21***	0,11***
KAZAKHSTAN	0,11	-0,13***	0,62***	TAIWAN	0,02	-0,02	0,44***
				THAILAND	0,04	-0,089***	0,36***

Note: **α_0**, **β_1** represent the constant and the autoregressive term and **β_2** represents the lagged US return. ***, **, * represent significance at 1%, 5% and 10% levels.

Table 3
Test Results for DCC against CCC using SUR

The table presents the results for Engle & Engle and Sheppard (2001) for the crisis period (1st September 2008-31st December 2009). We propose to test a null CCC against DCC alternative in higher order VAR to satisfy the condition that the specific return series and US returns have a dynamic correlation. We propose to run Seemingly Uncorrelated Regression between individual series and US returns have a null $H_0: a = 1 - b$ against DCC alternative.

South American Countries					**North American Contries**				
Country	**Parameter** $\hat{\delta}X'X\hat{\delta}'$	**Sigma Square** $\hat{\sigma}^2$	**T-Statistics**	**Yes=reject CCC**	**Country**	**Parameter** $\hat{\delta}X'X\hat{\delta}'$	**Sigma Square** $\hat{\sigma}^2$	**T-Statistics**	**Yes=reject CCC**
argentina	18,22111	0,001211	15046,34	Yes	mexico	28,05704	0,000946	29658,6	Yes
brazil	28,25286	0,001628	17354,34	Yes	canada	22,68334	0,000941	24105,56	Yes
chile	24,06272	0,000563	42740,18	Yes	**Centrial European Countries**				
colombia	31,48028	0,000615	51187,45	Yes	**Country**	**Parameter** $\hat{\delta}X'X\hat{\delta}'$	**Sigma Square** $\hat{\sigma}^2$	**T-Statistics**	**Yes=reject CCC**
peru	18,89893	0,001213	15580,32	Yes	croatia	37,89173	0,000555	68273,38	Yes
Nordic Countries					czeck	32,49988	0,001203	27015,7	Yes
Country	**Parameter** $\hat{\delta}X'X\hat{\delta}'$	**Sigma Square** $\hat{\sigma}^2$	**T-Statistics**	**Yes=reject CCC**	estonia	17,40975	0,000869	20034,23	Yes
denmark	40,13801	0,000752	53375,02	Yes	hungary	28,98761	0,001861	15576,36	Yes
finland	36,29964	0,000905	40110,1	Yes	poland	24,42688	0,001309	18660,72	Yes
norway	32,6247	0,001671	19524,05	Yes	romania	20,59854	0,001413	14577,88	Yes
sweden	5,779751	0,000965	5989,379	Yes	russia	19,1868	0,002329	8238,215	Yes
African Countries					slovenia	34,15314	0,00054	63246,56	Yes
Country	**Parameter** $\hat{\delta}X'X\hat{\delta}'$	**Sigma Square** $\hat{\sigma}^2$	**T-Statistics**	**Yes=reject CCC**	ukraine	10,2799	0,001274	8068,991	Yes
mauritius	8,389719	0,000455	18438,94	Yes	**MENA Countries**				
nigeria	6,454406	0,000317	20360,9	Yes	**Country**	**Parameter** $\hat{\delta}X'X\hat{\delta}'$	**Sigma Square** $\hat{\sigma}^2$	**T-Statistics**	**Yes=reject CCC**
kenya	8,475562	0,000216	39238,71	Yes					Yes
south_africa	39,10662	0,000965	40524,99	Yes	bahrain	6,413345	0,000556	11534,79	Yes
South and Central Asian Countries					egypt	15,52923	0,000654	23745,01	Yes
Country	**Parameter** $\hat{\delta}X'X\hat{\delta}'$	**Sigma Square** $\hat{\sigma}^2$	**T-Statistics**	**Yes=reject CCC**	jordan	6,512875	0,000332	19617,09	Yes
india	15,96491	0,000887	17998,77	Yes	israel	14,91441	0,000237	62929,98	Yes
china	28,59444	0,000929	30779,8	Yes	kuwait	6,369213	0,000668	9534,75	Yes
pakistan	6,370053	0,000471	13524,53	Yes	lebanon	10,2069	0,000346	29499,7	Yes
sri_lanka	6,748514	0,000506	13336,98	Yes	oman	6,37382	0,000556	11463,71	Yes
kazakhstan	24,8825	0,001418	17547,6	Yes	qatar	7,314245	0,00076	9624,006	Yes
hong_kong	26,95897	0,000549	49105,6	Yes	tunisia	10,62131	0,000153	69420,35	Yes
korea	20,83271	0,001306	15951,54	Yes	turkey	25,64984	0,001108	23149,67	Yes
taiwan	17,65726	0,000466	37891,12	Yes	uae	11,69034	0,001087	10754,68	Yes
thailand	19,93301	0,000647	30808,36	Yes	morocco	11,60064	0,000243	47739,26	Yes
West European Countries					**Asian Pacific Countries**				
Country	**Parameter** $\hat{\delta}X'X\hat{\delta}'$	**Sigma Square** $\hat{\sigma}^2$	**T-Statistics**	**Yes=reject CCC**	**Country**	**Parameter** $\hat{\delta}X'X\hat{\delta}'$	**Sigma Square** $\hat{\sigma}^2$	**T-Statistics**	**Yes=reject CCC**
switzerland	44,52467	0,00047	94733,34	Yes	indonesia	16,42354	0,000856	19186,38	Yes

uk	48,10412	0,000775	62069,83	Yes	japan	10,22427	0,000485	21080,96	Yes
france	51,34356	0,000802	64019,4	Yes	australia	42,30759	0,000965	43842,07	Yes
germany	42,99512	0,000797	53946,2	Yes	new_zealand	35,63264	0,000619	57564,85	Yes
netherlands	41,62365	0,00075	55498,19	Yes	vietnam	9,40834	0,000581	16193,36	Yes
ireland	26,68119	0,001344	19852,08	Yes	malaysia	18,36148	0,000175	104922,7	Yes
italy	42,72924	0,000872	49001,42	Yes	philippines	20,4042	0,00048	42508,74	Yes
austria	32,88892	0,001435	22919,11	Yes	singapore	24,90769	0,000595	41861,67	Yes
belgium	22,54482	0,00076	29664,24	Yes					
portugal	34,1309	0,000533	64035,46	Yes					
spain	43,08335	0,00081	53189,32	Yes					

H_0: Constant Correlation ($\alpha = 1 - \beta$) and H_1: Dynamic Correlation. Critical value for Chi^2 at 5% level is 7,8, and at 1% level is 11,3. ‘Yes’ means it rejects CCC.

Table 4 – Results for AR(1) model

This table presents the results for the eq. 7 using the global crisis sample (1st September 2008-31st December 2009). The γ_0 is the constant term, γ_1 is the coefficient for the AR(1) for the DCC, and ▯δ ▯▯▯▯▯▯▯coefficient for the crisis dummy.

West European Countries					East European Countries				
Country	γ_0	γ_1	δ	R^2	Country	γ_0	γ_1	δ	R^2
AUSTRIA	-0,0004	0,96***	0,0030***	0,95	CROATIA	-0,0024*	0,92***	0,0085***	0,88
BELGIUM	0,013***	0,0000	2,8E-07*	0,00	CZECH REP.	-0,0006	0,95***	0,0033**	0,92
FRANCE	-0,0004	0,96***	0,0043***	0,97	ESTONIA	-0,0003	0,95***	0,0017***	0,94
GERMANY	-0,0006	0,96***	0,0051***	0,96	HUNGARY	-0,0018	0,90***	0,0075***	0,83
GREECE	-0,0002	0,96***	0,0018*	0,93	ROMANIA	-0,0015	0,95***	0,0052***	0,93
IRELAND	0,011***	0,16***	0,0098	0,03	RUSSIA	-0,0005	0,97***	0,0032**	0,96
ITALY	-0,0005	0,96***	0,0041***	0,96	POLAND	-0,0005	0,96***	0,0031**	0,94
NETHERLANDS	-0,0001	0,95***	0,0050***	0,98	SLOVENIA	-0,0014**	0,96***	0,0046***	0,96
PORTUGAL	-0,0004	0,97***	0,0032**	0,97	Nordic Countries				
SPAIN	-0,0002	0,96***	0,0048***	0,97	DENMARK	-0,0002	0,95***	0,0026**	0,93
SWITZERLAND	-0,0004	0,95***	0,0032***	0,93	NORWAY	-0,0013	0,95***	0,0064***	0,94
UK	-0,0002	0,98***	0,00073**	0,98	FINLAND	-0,0005	0,97***	0,0032***	0,97
MENA Countries					SWEDEN	0,0000	0,82***	-0,0001	0,68
TURKEY	-0,0001	0,98***	0,0011*	0,97	South and Central Asian Countries				
EGYPT	0,0026**	-0,0171	0,0049**	0,01	CHINA	-0,0005	0,96***	0,0024***	0,96
MOROCCO	-0,0013*	0,93***	0,0033**	0,89	HONG KONG	0,0010	0,0152	0,0084***	0,01
TUNISIA	-0,00018***	0,98***	0,00055**	0,98	INDIA	-0,00058***	0,97***	0,0023***	0,97
BAHRAIN	-0,0063***	-0,0040	0,0043*	0,00	KAZAKHSTAN	-0,0010	0,94***	0,0031**	0,90
ISRAEL	0,0004	0,94***	0,0015	0,88	KOREA	0,0028***	-0,0053	0,0026	0,00
JORDAN	-0,0008	-2,09E-04	0,0006	0,00	PAKISTAN	0,00051***	-0,0002	-3,83762E-08	0,00
KUWAIT	0,0002	-0,001	0,0003	0,00	SRI LANKA	0,0000	0,93***	0,0001	0,86
LEBANON	-0,00909939	-0,0116	0,0065	0,00	TAIWAN	0,0027***	0,0170	0,00095**	0,01
OMAN	-0,0009	0,0031	-0,0022	0,00	THAILAND	-0,0007	0,94***	0,0033***	0,92
QATAR	0,00057***	-0,0012	0,0002	0,00	Asian Pacific Countries				
UAE	-0,0001	0,97***	0,0025***	0,97	AUSTRALIA	-0,0009	0,97***	0,0037***	0,96
African Countries					INDONESIA	0,0037***	0,0035	0,0003	0,00
KENYA	-0,0027*	0,36***	0,0045*	0,13	JAPAN	-0,0009	0,33***	-0,0004	0,11
MAURITIUS	0,0029***	0,0000	0,0000	0,00	MALAYSIA	-0,0004	0,96***	0,0020**	0,94
NIGERIA	-0,00040***	-0,0004	0,0000	0,00	NEW ZEALAND	-0,0007	0,96***	0,0034**	0,95
SOUTH AFRICA	-0,0005	0,96***	0,0028**	0,95	PHILIPPINES	0,0040***	0,0099	0,0002	0,00
					SINGAPORE	-0,0006	0,97**	0,0029***	0,97
North American Countries					South American Countries				
CANADA	-0,0004	0,94***	0,0058**	0,91	ARGENTINA	0,0006	0,93***	0,0029	0,86
MEXICO	0,013***	0,19***	0,0088*	0,04	BRAZIL	-0,0003	0,95***	0,0037*	0,91
					CHILE	0,0000	0,97***	0,0021*	0,95
					COLOMBIA	0,0075***	-0,0224	0,0056*	0,00
					PERU	-0,0011	0,93***	0,0067**	0,89

Note: We use the DCC pattern from the eq. 1 and run the AR(1) including a dummy variable in the regression. Each model regression thus describes how the returns (fitted to the specific model) are correlated with the US returns over the sample period, and whether contagion has occurred in the markets depending on how we explain our underlying returns.

Table 5 – The five largest principal components of stock market returns in different regions.

This Table presents the five principal components of the different regions.

Western Europé	1st princ.comp	2nd princ.comp	3rd princ.comp	4th princ.comp	5th princ.comp
Eigenvalue	35,8	5,4	2,6	2,0	1,4
Cumulative eigenvalue	35,8	41,2	43,8	45,8	47,2
Variance proportion	0,712	0,107	0,052	0,039	0,028
Cumulative proportion	0,712	0,819	0,871	0,910	0,938

Eastern Europé	1st princ.comp	2nd princ.comp	3rd princ.comp	4th princ.comp	5th princ.comp
Eigenvalue	30,2	4,8	3,7	3,3	2,1
Cumulative eigenvalue	30,2	35,0	38,7	41,9	44,1
Variance proportion	0,618	0,098	0,076	0,067	0,043
Cumulative proportion	0,618	0,716	0,792	0,859	0,903

Nordic	1st princ.comp	2nd princ.comp	3rd princ.comp	4th princ.comp
Eigenvalue	13,8	5,8	1,5	0,8
Cumulative eigenvalue	13,8	19,7	21,2	22,0
Variance proportion	0,628	0,265	0,069	0,038
Cumulative proportion	0,628	0,893	0,962	1,000

MENA	1st princ.comp	2nd princ.comp	3rd princ.comp	4th princ.comp	5th princ.comp
Eigenvalue	12,2	7,4	3,2	2,9	2,4
Cumulative eigenvalue	12,2	19,6	22,8	25,8	28,2
Variance proportion	0,318	0,192	0,084	0,077	0,062
Cumulative proportion	0,318	0,510	0,594	0,671	0,732

Africa	1st princ.comp	2nd princ.comp	3rd princ.comp	4th princ.comp
Eigenvalue	5,9	2,9	2,6	2,3
Cumulative eigenvalue	5,9	8,8	11,4	13,6
Variance proportion	0,431	0,212	0,191	0,166
Cumulative proportion	0,431	0,642	0,834	1,000

South and Central Asia	1st princ.comp	2nd princ.comp	3rd princ.comp	4th princ.comp	5th princ.comp
Eigenvalue	20,7	7,3	4,0	3,5	2,5
Cumulative eigenvalue	20,7	28,0	32,0	35,6	38,1
Variance proportion	0,470	0,167	0,091	0,080	0,058
Cumulative proportion	0,470	0,637	0,728	0,807	0,865

Pacific Asian	1st princ.comp	2nd princ.comp	3rd princ.comp	4th princ.comp	5th princ.comp
Eigenvalue	15,1	2,9	2,1	1,7	1,3
Cumulative eigenvalue	15,1	18,1	20,2	21,9	23,1
Variance proportion	0,614	0,120	0,086	0,069	0,052
Cumulative proportion	0,614	0,734	0,819	0,889	0,940

North America	1st princ.comp	2nd princ.comp
Eigenvalue	7,6	1,4
Cumulative eigenvalue	7,6	9,0
Variance proportion	0,840	0,160
Cumulative proportion	0,840	1,000

South America	1st princ.comp	2nd princ.comp	3rd princ.comp	4th princ.comp	5th princ.comp
Eigenvalue	20,6	3,0	2,5	2,2	1,2
Cumulative eigenvalue	20,6	23,6	26,1	28,4	29,6
Variance proportion	0,695	0,102	0,086	0,076	0,042
Cumulative proportion	0,695	0,796	0,882	0,958	1,000

Table 6 AR(1) Model for the Regional Factor

This table presents the results for Eq. (9) using global crisis period (1st September 2008-31st December 2009). γ0 is the constant term, γ1 is the AR(1) coefficient, and δ is the crisis dummy. ***indicate 1% significane level.

Regional factor	**γ0**	**γ1**	**δ**
Western Europé	0,0523***	0,89***	0,020***
Eastern Europé	0,33***	0,39***	0,090***
Nordic	-0,022***	0,95***	-0,011***
MENA	0,024***	0,94***	0,0071***
Africa	0,026***	0,93***	0,010***
South and Central Asia	0,010***	0,96***	0,0086***
Pacific Asian	0,013***	0,95***	0,0083***
North America	0,14***	0,82***	0,0094***
South America	0,043***	0,93***	0,013***

Table 7: Results for the Granger Causality

This table present the bi-directional granger causality for the sample countries during global financial crisis (1st Sept. 2008-31st Dec. 2009).

West European Countries		**South and Central Asia**		**MENA**	
Direction of Causality	Test Statistics	Direction of Causality	Test Statistics	Direction of Causality	Test Statistics
US→Austria Austria→US	27,5707*** 0,97191	US→India India→US	7,26220*** 4,68704**	US→Egypt Egypt→US	32,4636*** 2,64318*
US→Belgium Belgium→US	9,10236*** 4,32366**	US→Pakistan Pakistan→US	1,26367 1,33818	US→Morocco Morocco→US	8,28527*** 0,30654
US→France France→US	41,9941*** 2,82096*	US→Sri Lanka Sri Lanka→US	3,20025** 5,63057**	US→Bahrain Bahrain→US	2,94033* 4,06820**
US→Germany Germany→US	21,9420*** 3,18402**	US→Kazakhstan Kazakhastan→US	43,9322*** 5,95000**	US→Israel Israel→US	9,93567*** 4,36229**
US→Greece Greece→US	20,0726*** 1,78820	US→China China→US	36,4215*** 3,32611**	US→Jordan Jordan→US	19,3542*** 3,18590**
US→Ireland Ireland→US	20,6609*** 3,19686**	US→Hong Kong Hong Kong→US	39,5398*** 4,4,74799**	US→Kuwait Kuwait→US	2,92437* 0,10408
US→Italy Italy→US	37,5518*** 0,01569	US→Korea Korea→US	31,2284*** 5,46066**	US→Lebanon Lebanon→US	12,3315*** 0,55539
US→Netherlands Netherlands→US	30,3250*** 2,54464*	US→Taiwan Taiwan→US	38,3099*** 5,52664**	US→Oman Oman→US	28,7711*** 0,32140
US→Portugal Portugal→US	32,7039*** 5,30927**	US→Thailand Thailand→US	15,1923*** 3,20822**	US→Qatar Qatar→US	32,6068*** 0,27508
US→Spain Spain→US	32,8802*** 3,26182**	**Pacific Asia**		US→UAE UAE→US	21,1070*** 0,22422
US→Switzerland Switzerland→US	40,4614*** 2.44439*	US→Indonesia Indonesia→US	31,9130*** 4,87319**	US→Turkey Turkey→US	15,3088*** 6,01649**
US→UK UK→US	41,3580*** 0,49701	US→Japan Japan→US	106,072*** 2,02427	US→Tunisia Tunisia→US	15,4357*** 5,98147**
East European Countries		US→Australia Australia→US	119,891*** 4,39149**	**Nordic Countries**	
US→Croatia Croatia→US	57,7918*** 0,35896	US→New Zealand New Zealand→US	112,058*** 5,02185*	US→Denmark Denmark→US	36,6743*** 0,94602
US→Czech Republic Czech Republic→US	36,8568*** 3,87875**	US→Vietnam Vietnam→US	41,3734*** 3,44106**	US→Finland Finland→US	28,6825*** 0,24410
US→Estonia Estonia→US	38,2933*** 0,53231	US→Malaysia Malaysia→US	32,6825*** 3,68654**	US→Norway Norway→US	21,9463*** 1,44376
US→Hungary Hungary→US	19,0913*** 5,75883**	US→Philippines Philippines→US	106,515*** 5,59731**	US→Sweden Sweden→US	1,95031 4,34713**
US→Poland Poland→US	19,0809*** 1,38588	US→Singapore Singapore→US	21,1941*** 5,53825**	**North America**	

US→Romania Romania→US	18,2744*** 0,48160	**South America**		US→Mexico Mexico→US	6,97143** 5,46031**
US→Russia Russia→US	8,38921*** 4,34315**	US→Argentina Argentina→US	18,1183*** 7,11007***	US→Canada Canada→US	13,5651*** 8,96849***
US→Slovenia Slovenia→US	77,3146*** 1,17323	US→Brazil Brazil→US	13,4506*** 3,60040**	**Africa**	
		US→Chile Chile→US	11,3786*** 2,06011	US→Kenya Kenya→US	14,7920*** 1,08993
		US→Colombo Colombo→US	34,0754*** 6,55616**	US→Mauritius Mauritius→US	21,5109*** 3,90209**
		US→Peru Peru→US	8,20561*** 3,72594**	US→Nigeria Nigeria→US	2,13641 1,97374
				US→South Africa South Africa→US	44,2931*** 4,74506**

Note: The symbol → indicates no Granger Causality. A significant value (with Whilt's (1980) correction for heteroskedasticity) rejects no causation and implied that lagged variables can help explain or predict current movement in the other country. ***significant at the 1% level, **significant at the 5% level, and *significant at the 10% level.

Figure 1 - This figure presents the dynamic conditional correlation between USA and rest of the global countries for the period of 2006-2010. The correlation intensifies during global financial crisis.

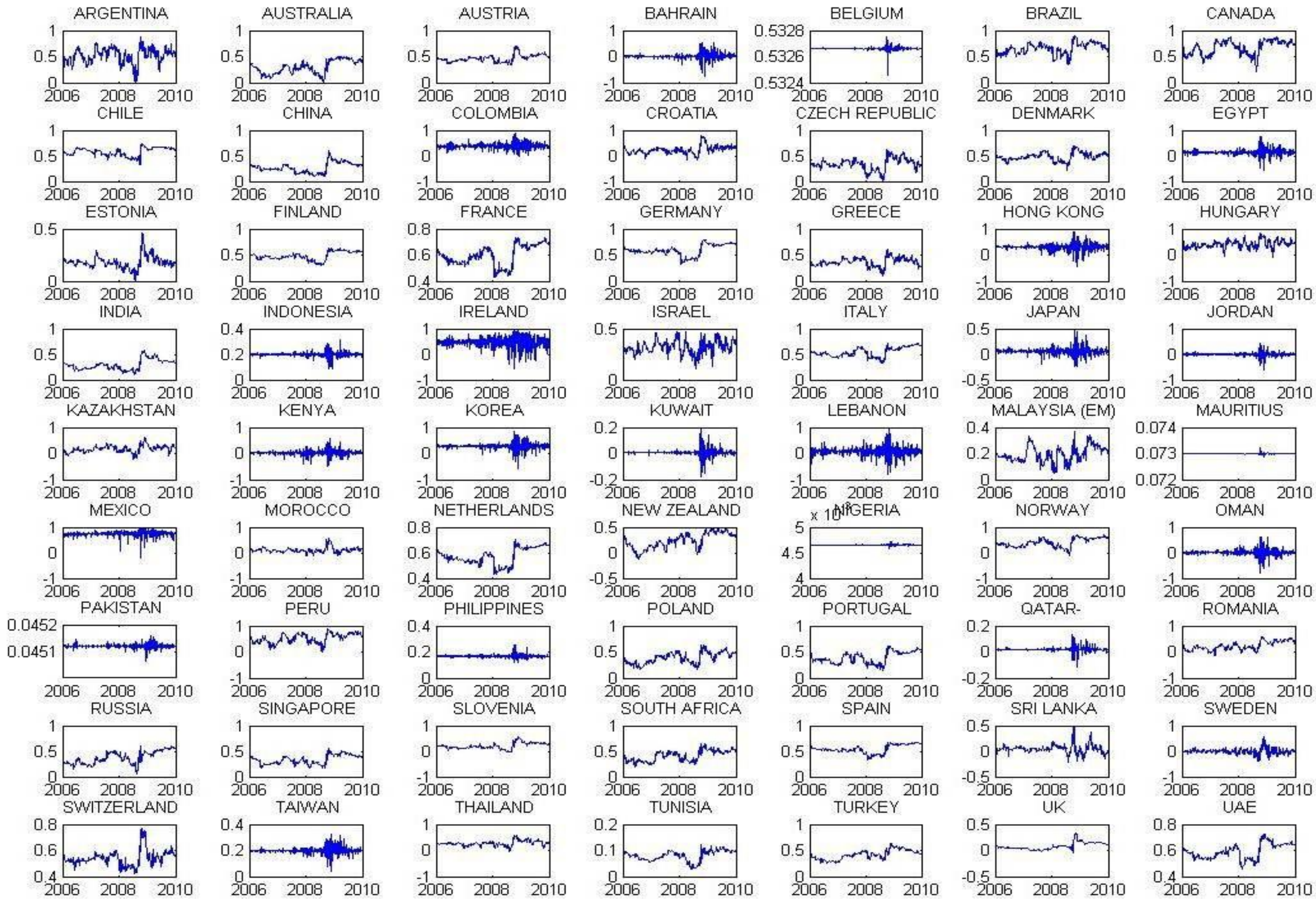


Figure 2 - This figure presents the DCC between the regional common factor and the USA.

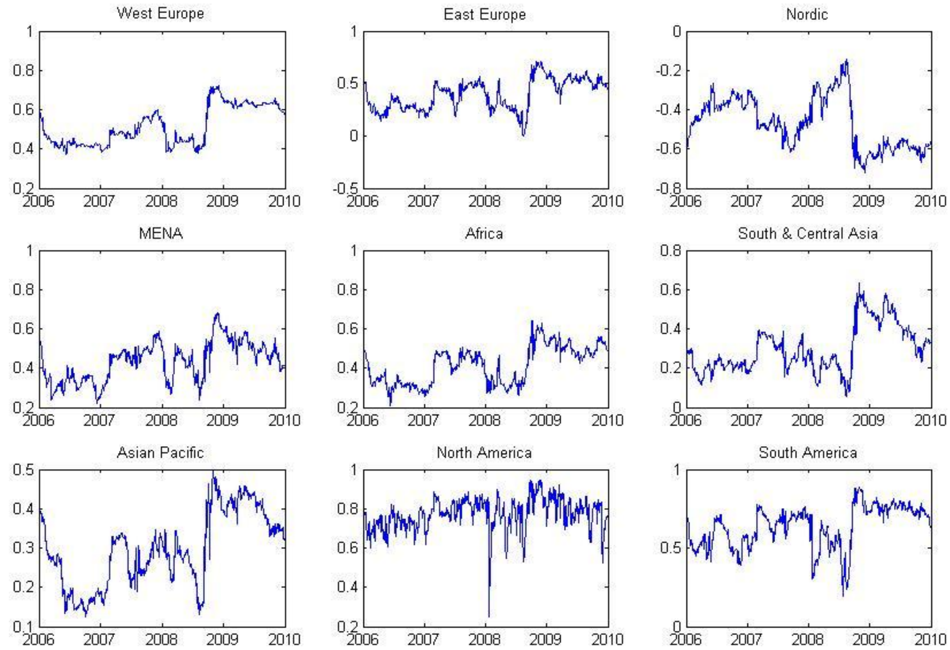
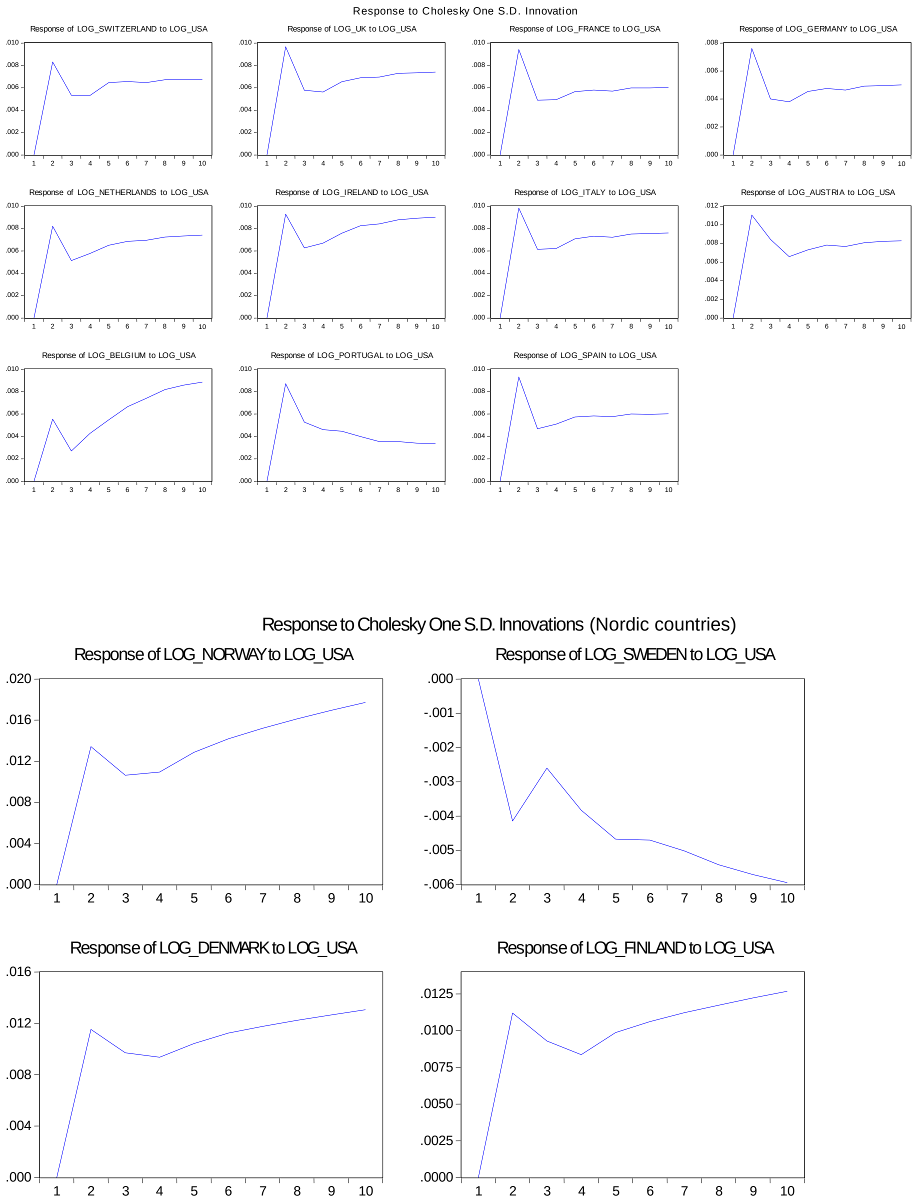
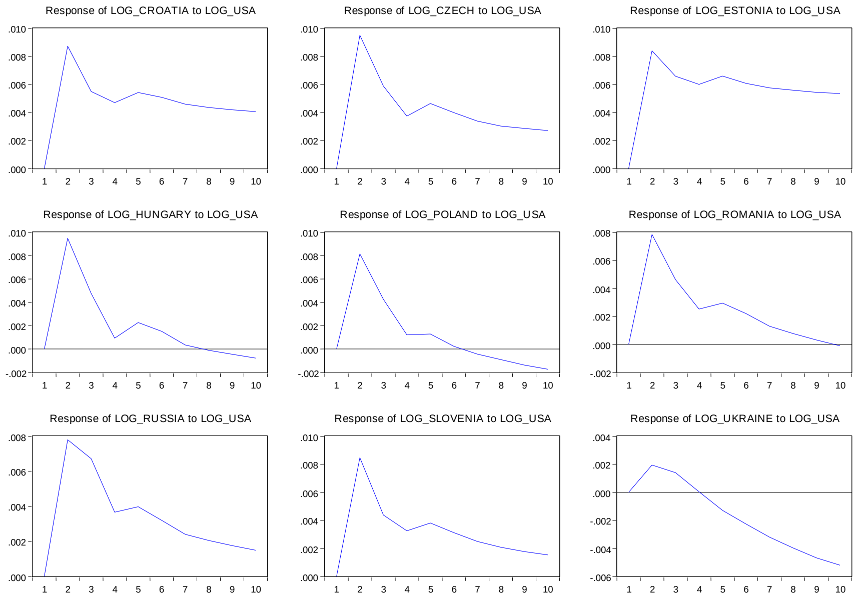


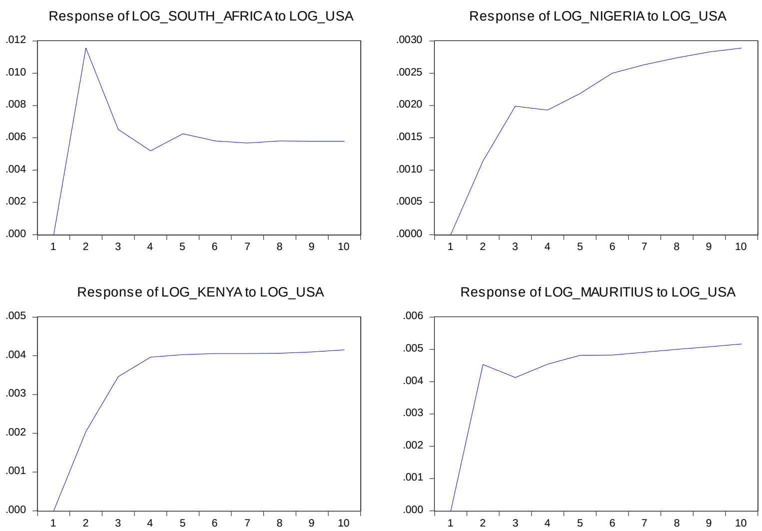
Figure 3 - Response to Cholesky's One standard deviation innovations of US to other countries through impulse response function. This figure presents the impulse response from the USA to different regions.



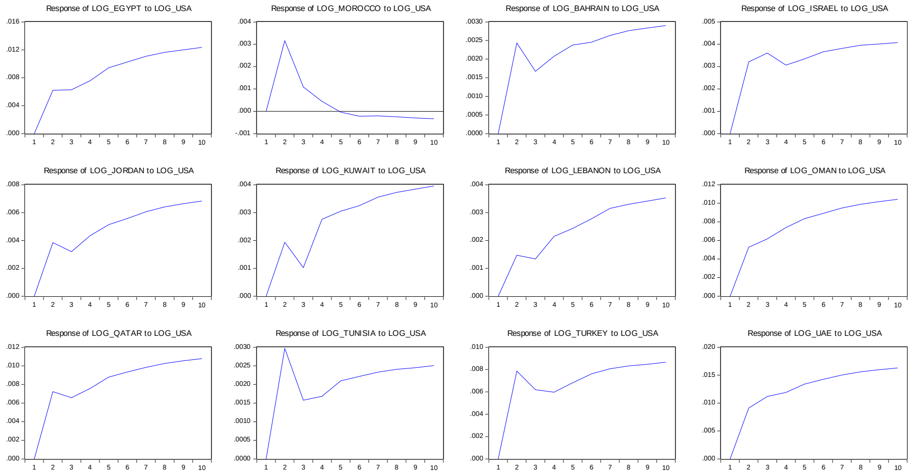
Response to Cholesky One S.D. Innovations (East-Central Europe)



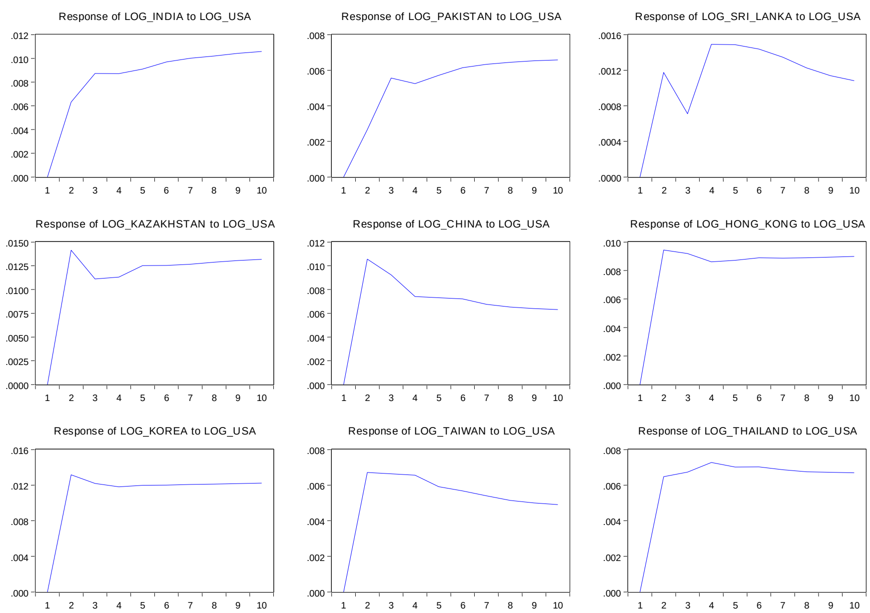
Response to Cholesky One S.D. Innovations (Africa)



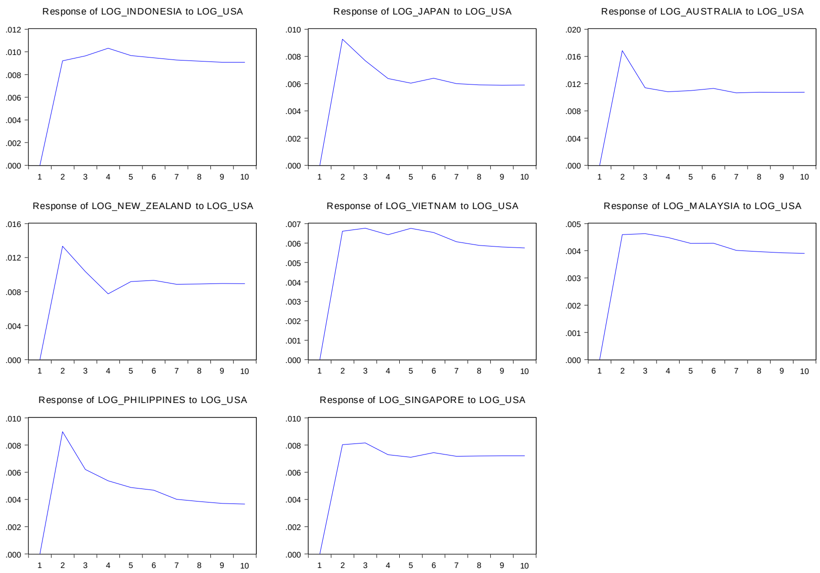
Response to Cholesky One S.D. Innovations (MENA)



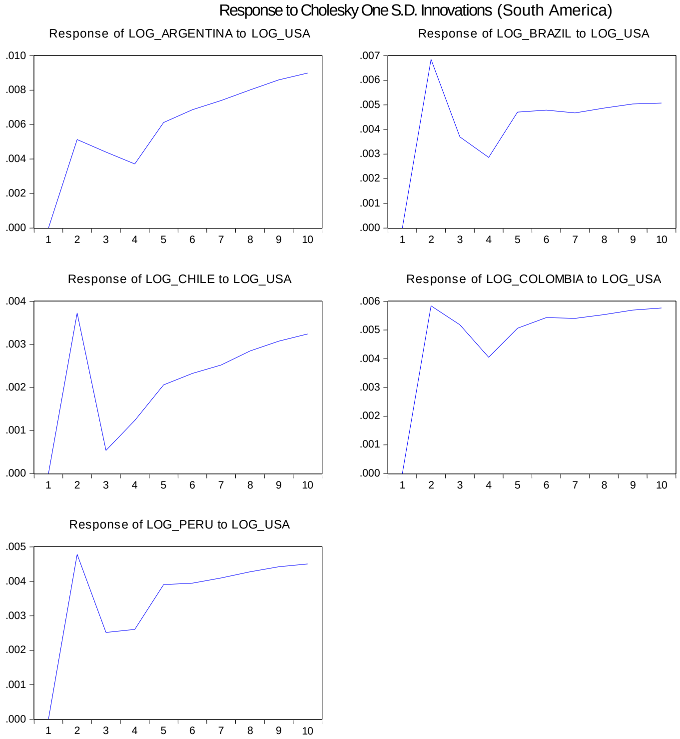
Response to Cholesky One S.D. Innovations (South –Central Asia)



Response to Cholesky One S.D. Innov ations (Pacific Asia)



Response to Cholesky One S.D. Innovations (South America)



Response to Cholesky One S.D. Innovations (North America)