# Testing the Conventional and Islamic Financial Market Contagion: Evidence from Wavelet Analysis

Saiti, Buerhan and Bacha, Obiyathulla and Masih, Mansur

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# Testing the Conventional and Islamic Financial Market Contagion: Evidence from Wavelet Analysis*

**Buerhan Saiti**
Universiti Kuala Lumpur Business School, Kuala Lumpur, Malaysia

**Obiyathulla Ismath Bacha and Mansur Masih**
INCEIF – The Global University of Islamic Finance, Kuala Lumpur, Malaysia

Corresponding Author: Buerhan Saiti
Mailing Address: B-8-13A, Putra Villa, Taman Melati, 53100, Kuala Lumpur, Malaysia
Email Address: borhanseti@gmail.com, Phone Number: +60-123904640

**Abstract**

A major issue facing the investors in the financial markets of the contemporary world is to identify whether the observed stock market fluctuations are due mainly to contagion or fundamentals. This is due to the fact that if the fluctuations are mainly due to a contagion, then it is something like a 'virus' which would disappear after a few days. In contrast, if the fluctuations are mainly due to fundamentals, then it is something like a 'pneumonia' which is likely to continue for a long time.

This study is the first attempt at testing whether there has been any contagion among the *Shari'ah*-compliant stock indexes during the most recent international financial crisis: the US subprime crisis of 2007-2009 and the Lehman Brothers collapse in 2008, with the application of a time-frequency decomposition technique known as 'wavelet approach' both in discrete and continuous forms recently imported to finance from engineering sciences. We analyze the daily data covering the period from June 2005 to December 2011 for the 18 MSCI conventional and Islamic stock market indexes of the Islamic (Malaysia, Indonesia, Turkey, GCC ex-Saudi) and non-Islamic countries (Japan, China, Korea, Taiwan and Hong Kong). Our study is focused on investigating the following empirical question: are the co-movements of selective stock markets normal (interdependent) or excessive (contagious) during the first and the second wave of the financial crisis?

Our findings based on the time-frequency decomposition of wavelet approach are as follows: i) The wavelet correlation analysis indicates that, there is no clear evidence of contagion at any time-scales during the subprime mortgage crisis in USA; ii) However, during the collapse of Lehman Brothers, in all conventional stock indexes of non-Islamic countries except Japan, the wavelet correlation coefficients changed significantly at the first time-scale implying that there was a clear evidence of contagion at the first time-scale iii) But the conventional stock indexes of Islamic countries did not suffer from contagion excepting Indonesian MSCI stock index due to overlapping of confidence intervals iv) In all Islamic stock indexes in both Islamic and non-Islamic countries excepting China and Hong Kong Islamic MSCI indexes, the wavelet correlation coefficients changed insignificantly at all scales. Therefore, we fail to reject the null hypothesis implying that there was no clear evidence of contagion at all time-scales excepting China and Hong Kong. Additionally, for robustness, we studied the dynamic correlations between two continuous wavelet transforms through wavelet coherency analysis. The findings whether the stock comovements triggered by the financial crises were showing interdependence or contagion are plausible and intuitive and have implications for both the conventional and *Shari'ah*-compliant stock markets in terms of asset allocation strategy of risk managers and for policymakers' optimal policy response to crises.

**Key words:** Wavelet time-frequency decompositions, Contagion, Interdependence, Wavelet Correlation, Wavelet coherence, conventional and *Shari'ah*-Compliant Stock markets

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## 1. Introduction

The cross-market transmission of financial crisis has been a major interest over the last decade. The financial systems have witnessed numerous financial and currency crises, where most of them with regional or even global consequences, such as the 1987 Wall Street crash, the 1992 ERM collapse, the 1994 Mexican pesos crisis, the 1997 "Asian Flu", the 1998 Russian bond default, the 1999 Brazilian asset markets crisis, the 2000 dot-com bust, the default crisis in Argentina from 2001 to 2005. Recently, the US subprime crisis 2008 that considerably hit the markets all over the world has raised a critical question on the capacity of the global financial system to maintain its financial stability in a meaningful way.

The recent international financial crash that began with the meltdown of the US sub-prime mortgage market in July 2007, was preceded by a 20-year growth in debt and leverages, in the context of rising world financial linkages, low real interest rates and growing U.S. external deficits. No one can deny that this recent financial crisis was one of the most unpredicted economic events in the recent history, particularly the severity with which it melted markets and economies around the world. There were two waves of crises. Firstly, countrywide $11.5 billion drew from credit lines by commercial banks and Bank of America topped $2 billion of equity capital up into countrywide by August 2007 (Guo et al. 2011). Such events resulted in a widespread loss of confidence in the banking system in the mind of investors. Consequently, another round of credit crisis resulted, due to tightened lending standards of banks. The crash reached a crucial point in September 2008 when the Federal Housing Finance Agency placed Fannie Mae and Freddie Mac in government conservatorship, Bank of America bought Merrill Lynch, Lehman Brothers filed for Chapter 11 protection, and the American International Group borrowed $85 billion from the Federal Reserve Board. Financial organizations and companies hastened to deleverage to minimize their risk exposures; therefore, selling massive assets at discounted rates.

Up until the recent episodic financial crises, a major focus of the policy makers and investors in general was to find out the extent of integration of the financial markets with a view to taking advantage of the diversification benefits. However, the recent financial crisis-induced excessive transmission of shocks from the crash in origin country into others has now raised a critical question as to whether this new phenomenon in the financial markets is due mainly to contagion or fundamentals. This excessive comovement of stock prices is generally found to occur during a financial crisis and is related to investors' behavior during heightened uncertainty reflected in herding, financial panic, loss of confidence, market sentiment and so on. In contrast, a fundamental-based comovement of stock prices is generally related to financial market integration, normal interdependence of markets across countries and real linkages in both crisis and non-crisis periods.

A major issue facing the investors in the financial markets of the contemporary world is to identify whether the observed stock market fluctuations are due mainly to contagion or fundamentals. This is due to the fact that if the fluctuations are mainly due to a contagion, then it is something like a 'virus' which would disappear after a few days. In contrast, if the fluctuations are mainly due to fundamentals, then it is something like a 'pneumonia' which is likely to continue for a long time. This identification of the stock price fluctuations as to whether it is a contagion or not is critical for the decision of the investors to invest or not. It is mainly because of this uncertainty regarding contagion or not in the stock markets, the international investors in countries like the U.S.A. had rather invested in bonds even though the bond yield was lower than the inflation rates resulting in negative real returns.

One of the major objectives of this study, therefore, is to examine whether the stock price comovements are because of contagion or fundamentals. This study employs multi-time scale wavelet analysis to uncover the comovements and the dynamic linkages that are often unobserved during the non-crisis quiet periods between a set of stock markets. Attempts have been made in this study to further unravel the linkages across both lower and higher frequencies in the time-frequency space, since the financial volatility sparked questions on both the nature of the transmission mechanism across markets as well as whether the sources of such linkages were due to pure contagion effects or more fundamental underpinnings.

A related issue in order to help the investors get the diversification benefits is to investigate the comovements of the *Shari'ah*-compliant stock indexes hitherto unexplored. The advocates of *Shari'ah*-compliant investment argue that the Islamic stock indexes are better positioned due to the specific features of Islamic stock indexes such as, ethical and ratio screenings, exclusion of financial sectors, exclusion of highly leveraged firms, the limit of interest-based leverage, and, finally, exclusion of using complex and intensive structured financial products, derivatives, and other toxic assets. An Islamic stock index is argued to be more resilient to a financial crisis compared to a conventional stock index. In other words, it is generally argued that the characteristics of the *Shari'ah*-compliant stocks are indifferent compared to those of the conventional stocks in that the former entails a lower leverage, smaller size of firms and undiversified markets resulting in different risk-return portfolios. This requires an empirical investigation of the conventional and *Shari'ah*-compliant stock indexes. Hence another important objective of this study is to investigate whether there is a contagion or not in the comovements of the conventional and *Shari'ah*-compliant stock indexes during the financial crisis episodes.

The current trend for Islamic equity to move towards the global markets has encouraged a number of studies to address the performance of Islamic equity markets and funds. In the context of the recent subprime crisis, it appears to be important to evaluate the vulnerability of Islamic stocks. Our study, therefore, attempts to identify whether there is any financial contagion that occurred among the conventional and *Shari'ah*-compliant stock markets during the US subprime crisis of 2007-2009. Such a question is important because of the nature of *Shari'ah* rules, in particular the limit of interest-based leverage is likely to lead to a lower systemic risk during economic expansion and recession.

The analysis of the linkages of financial markets is a significant topic and of special interest in times of turmoil periods. International investors need to examine the benefits of portfolio diversification and the policymakers worry about the stability of the financial system. In a highly interdependent financial system, a crisis in one country is likely to spread to other countries which are associated with contagion. As a result of the transmission, the linkages between the markets become stronger resulting in (i) forming policies on the architecture of the international financial system; (ii) reducing diversification benefits of investors; (iii) understanding the role of institutions in transmitting crises; (iv) developing a country specific policies to mitigate crisis transmission by discriminating how previous unrelated stock markets are suddenly related; and (v) last but not least, identifying globally accepted framework to mitigate crisis transmission. It is important to analyze the linkages existing in tranquil and turmoil periods in order to formulate these policies.

This study contributes to the literature in three ways:

To the best of our knowledge, this is the first study to test resilience of Islamic stock indexes to the recent financial crisis by analyzing daily stock price data with the wavelet approach. This study is the initial attempt at testing whether there has been any contagion among the *Shari'ah*-compliant stock indexes during the most recent international financial crisis: the US subprime crisis of 2007-2009 and the Lehman Brothers collapse of 2008, with the application of a time-frequency decomposition technique known as the 'wavelet approach' both in discrete and continuous forms which were recently imported to finance from engineering sciences.

Most importantly the study shows the resilience of Islamic stock indexes to international financial shocks by showing that the Lehman Brothers collapse hit the conventional indexes, however Islamic stock indexes were not affected.

The study also shows the US subprime mortgage crisis did not have any heavy impact on indexes of the Far East and selective Islamic countries.

To sum up our findings: this paper studies the contagion effect of recent 2007-2009 international financial crisis on the conventional and Islamic stock indexes of the Islamic (Malaysia, Indonesia, Turkey, GCC ex-Saudi) and non-Islamic countries (Japan, China, Korea, Taiwan, Hong Kong). We used a wavelet analysis with the specification of Gallegati (2010) . We have defined two shocks during the crisis namely, subprime mortgage shock of 2007 and Lehman Brothers collapse in 2008. We have found there is no clear evidence of contagion during the first shock, however during the second shock we have found that the conventional stock indexes of the Far East countries displayed contagion, while the rest of the stock indexes including Islamic stock indexes do not show contagion effects.

A large number of studies have discussed the proper definition of financial contagion. Our study has followed the application of wavelet decomposition by Gallegati (2010) to detect the contagion as the excessive transmission of shocks above what should be expected by the fundamentals which are reflected in long horizon (high timescale). The paper is organized as follows. Section 2 reviews the basic condition of Islamic stock indices, while Section 3 presents some literature reviews associated with the issue of financial contagion. Section 4 introduces wavelet decomposition analysis and the notions of wavelet and multiscale analysis of correlation as well as wavelet coherency analysis. In Section 5, we will first describe the data used in this study and then present the results of the wavelet-based test for contagion. Finally, Section 6 provides some interpretations while we conclude with section 7.

**2. Islamic Investment Criteria**

Islamic investment is growing rapidly as an alternative investment class for all investors, both Muslim and non-Muslim, for its foundation in ethical business practices, social responsibility and fiscal conservatism. While Islamic investors may be mandated to invest only in a *Shari'ah*-compliant manner, other investors do so for the benefits they derive, including greater stability of returns, transparency and diversification[1].

In Islamic finance, any market is subject to *Shari'ah* constraint where the market is free from prohibited activities and elements such as *riba* (usury), *maisir* (gambling), *gharar* (ambiguity), and other prohibited activities like gambling, alcohol, and so on. To describe the Islamic principle in detail, *riba* technically is defined as the "premium" which should be paid by the borrower to the lender together with the principal amount as a condition in the contract of the loan or for an extension in the duration of loan" (Iqbal and Mirakhor, 2007). More specifically, both the premium and the principal are guaranteed regardless of the investment performance. Islamic stock indexes must not include firms that pay or receive interest of any form. However, the percentage of today's listed firms that are fully in compliance with the *Shari'ah* is in small number. Some degree of tolerance therefore is required.

The modern *Shari'ah* scholars have provided general rules for *Shari'ah*-compliant investors to evaluate or screen whether a particular company is *halal* (lawful) or *haram* (unlawful) for investment (Wilson, 2004; Derigs and Marzban, 2008).There are two types of stock screening approaches such as qualitative and quantitative screens. The first one is qualitative screen, the screening process that focuses on the activity of a company that is used as the main principle in Islamic investment criteria. For a company that does not comply with *Shari'ah* principles, for example, a company involves in production of alcohol for drinking, gambling, and *riba*-based financial institutions, then, investment in this type of company is prohibited. The second one is quantitative screen, where Islamic scholars have applied a principle of tolerance associated with filtering criteria, namely:

(1) Debt/equity ratio. If a company's debt financing is more than 33 percent of its capital, then it is impermissible for investment.
(2) Interest-related income. If interest-related income of a company is more than 10 percent of its total income, then it is not permissible for investment. This income, however, should not come from its main business activities but from placing its surplus funds in investments that could yield interest income (Abdul Rahman et al,. 2010).

[1]Case for Islamic Asset Management, by CIMB bank, June 30, 2010.

(3) Monetary assets. This parameter refers to the composition of account receivables and liquid assets (cash at banks and marketable securities) compared to total assets. Various minimums have been set for the ratio of non-liquid assets (assets that are not in the form of money) necessary to make an investment permissible. Some set this minimum at 51 percent while a few cite 33 percent as an acceptable ratio of non-liquid assets to total assets.

Chapra (2008) and Chapra, Ebrahim, Mirakhor, and Siddiqi (2008) who mention that there are four basic conditions in Islamic finance that may prevent the two main causes of crisis, which are excessive leverage and the formation of speculative bubbles in credit markets. Firstly, all transactions have to be based on real assets rather than merely fictitious or notional assets. This may discourage all speculative transactions which involve excessive ambiguity or gambling. Secondly, the transaction must involve the possession of exchange objects on the seller/lesser where this condition may guarantee that, to obtain certain return, the owner will share the risk with his partner. Thirdly, the transaction must be genuine with full intention to give and take delivery which in turn will prevent the excessive speculation using imaginary assets. Lastly, the credit risk must be borne by the creditor up to the maturity, which is subject to the rule of prohibition of selling the debt except at par value. This is to ensure that the creditor cannot transfer the risk by selling the debt to the market within a speculative and derivative transaction and prevents the excessive growth of the debt beyond reasonable limits.

**3. Literature Review**

The occurrence of turmoil in international financial markets has drawn a striking interest in the linkages between financial markets during times of crisis. Therefore, in crisis periods we discern an increase in cross-market linkages due to the propagation of shocks from one country to other countries as a result of the high integration of financial and goods markets. The increase in cross-market linkages from the pre-crisis period to the crisis period may take the form of interdependence or contagion.

Even though there are a lot of researches on financial market contagion, there is disagreement in the literature on the exact definition of what attributes contagion and how we could measure it. The economic meaning of contagion is not straightforward, as illustrated by the numerous definitions of contagion that can be found on the World Bank's website. Referring to the website, we can distinguish three definitions of contagion[2].

Pericoli and Sbracia (2003) provide an overview of the contagion literature by presenting five different classifications of contagion. The main distinction when defining contagion is between “fundamentals-based” and “pure” contagion (see Dornbusch et al., 2000; Kaminsky and Reinhart, 2000). The definition of “fundamentals-based” contagion provided by Calvo and Reinhart (1996) emphasizes the transmission of shocks among countries and/or markets resulting from real linkages and financial market integration in both crisis and non-crisis periods. These forms of co-movements reflect normal interdependence across markets and countries and are often called as spillovers. The term “pure” contagion (see among others Eichengreen et al., 1996; Bae et al., 2003) refers to the transmission of shocks from one country to another country in excess of what should be expected after controlling for fundamental factors. This kind of contagion is generally related to investors’ behavior such as herding, financial panic, loss of confidence, etc., and leads to excessive co-movements. Thus, during crisis periods, some co-movements across markets can be an implication of the effect of contagion rather than the interdependence. An important problem in testing for contagion is to conclude a distinction between “excessive” and normal interdependence across conventional and *Shari’ah*-compliant financial markets.

Some previous studies tend to argue that financial crises are characterized by financial contagion (e.g., Kyle and Xiong, 2001; Kodres and Pritsker, 2002). This issue therefore has become extensively discussed in theoretical and empirical studies in order to measure financial spillovers and to discover channels of transmission of shocks across borders. King and Wadhwani (1990) have mentioned that

[2]http://www1.worldbank.org/economicpolicy/managing%20volatility/contagion/index.html

economic fundamentals on each country have not provided a clear explanation as regards the shock transmissions, suggesting that a stock market reacted to stock price changes across border beyond what economic fundamentals suggest. In another study, Forbes and Rigobon (2002) also define contagion as an excessive transmission of shocks from the origin of crash to others beyond any idiosyncratic disturbances and fundamental linkages.

Beyond economic linkages, financial crashes and the contagion process in turmoil periods are explained by a variety of factors. Many researchers have focused on the issue of contagion by showing evidence of significant changes in cross-country correlations of stock market returns and/or volatility in the specific region (Sachs et al., 1996, Chiang, 2007). However, the existence of contagion in relation to crisis is still an unresolved issue. Some studies based on Asian financial crisis show a significant rise in correlation coefficients and conclude that there was a contagion effect (Baig and Goldfajn, 1999). Meanwhile, other studies found that there were no significant changes in correlation between asset returns in pairs of crisis-hit countries after making an allowance for heteroskedasticity, concluding that there was ‘‘no contagion, only interdependence’’ (Forbes and Rigobon, 2002; Bordo and Murshid, 2001; Basu, 2002). Furthermore, in order to test the financial contagion, Corsetti et al. (2005) employed a single-factor model, and found “some contagion, some interdependence.” Lastly, Froot et al. (2001) and Basu (2002) confirmed the existence of the financial contagion effect by focusing on different transmission channels. Therefore, the evidence on financial market contagion is not conclusive.

There are several limitations and drawbacks in existing literature on empirical research of financial contagion (Chiang, 2007). First, measuring the correlation is associated with the heteroskedasticity problem which is caused by the fact that volatility rises during crisis periods. Second, on top of a lagged dependent variable, an omitted variable problem appears in the prediction of cross-country correlation coefficients. Third, since contagion is expressed as a significant increase in cross-market comovement during a crisis period, any prolonged market correlation, even though at high levels, is diagnosed as interdependence (Forbes and Rigobon, 2002). The presence of contagion must provide evidence of a dynamic increase in correlation. Therefore, the dynamic nature of the correlation of stock markets needs to be sorted out. Fourth, a common problem faced by these studies is, as pointed out by several researchers (Baig and Goldfajn, 1999; Ait-Sahalia et al., 2010, Gallegati, 2012, Reboredo and Rivera-Castro, 2013, 2014), that the transmission of shocks because of contagion in international financial markets is very fast and dies out quickly after a few days. Most such correlations tend to disappear in five days’ time or even less.

In particular, Forbes and Rigobon (2002) mentioned that past studies have found contagion because they did not appropriately correct the correlation measure for heteroscedasticity. By using a heteroscedasticity-corrected correlation measure, they therefore find little evidence of contagion during several recent major crises. Some other studies have attempted to follow the guidelines of Forbes & Rigobon, and they come up with similar conclusions (Collins and Biekpe, 2003). Nonetheless, the conclusions of Forbes & Rigobon (2002) have recently been criticized. Corsetti et al. (2005) has mentioned that the findings of Forbes and Rigobon are basically a result of an assumed model.

In this study, contagion is examined by using wavelet correlation and wavelet coherency analysis. A potentially useful different perspective on the empirical problem of identifying between contagion and interdependence can be solved by frequency domain analysis. By its ability to separate each variable into components of different frequencies, a frequency domain framework can provide a simple and intuitive way to identify between contagion and interdependence by associating each to its corresponding frequency component. This approach avoids the problems of the heteroscedasticity bias of Forbes & Rigobon (2002), because volatility should affect both short and long time scale correlations. Examples of studies testing for contagion by associating contagion and interdependence with distinct frequency ranges (high and low frequencies, respectively) are the recent papers by Bodart and Candelon (2009) and Orlov (2009). Gallegati (2010) by applying the wavelet analysis on the stock market indices of G7 countries plus Brazil and Hong Kong found that: (i) there is evidence for each country of international financial contagion during the US subprime crisis, and (ii) these contagion effects are scale dependent, in the sense that they do not display their effects uniformly across scales. In this paper, we will test the

contagion issue in both conventional and *Shari'ah*-compliant stock markets by following Gallegati's (2010) methodology.

## 4. Methodology

Wavelet analysis is a filtering method that provides a useful alternative to time series and frequency domain methods because it transforms the raw data into different frequency components with a resolution matched to its scale. This kind of method is useful in processing non-stationary signals, such as financial market data, that exhibit changing frequencies over time. The two important interesting features of wavelet analysis for the purpose of this study are thus: (i) its capability to decompose macroeconomic time series, and data in general, into their time-scale components, and (ii) its ability to provide representation of the variability and association structure of certain stochastic processes on a scale-by-scale basis from a different perspective. The multi-resolution decomposition property of the wavelet transform can be used to separately distinguish contagion and interdependence by associating each to its corresponding frequency component. Additionally, another wavelet transform property, namely ''energy-preserving'', which enables scale-based decomposition of the energy in a time series, can provide the basis for a wavelet-based test for contagion. Thus, after discriminating contagion and interdependence via wavelet and scaling coefficients, respectively, we test for the existence of contagion by using a simple graphical test based on non-overlapping confidence intervals of the estimated wavelet correlation coefficients in pre-crisis and crisis periods, as well as by employing wavelet coherency approach.

While acknowledging that the wavelet analysis is applied in many economics and finance fields, in this part, we only describe the fundamental methods that are useful for our research purpose. For a more complete and comprehensive development of the theory and use of wavelets, please see Percival and Walden (2000), Gencay et al. (2002), Gallegati (2010) and In and Kim (2013).

### 4.1 Wavelet Series Expansion

One of the most important properties of wavelet analysis, when applied to economic and financial data, is that this method can decompose the time series data into several components associated with different scales of resolution (Gallegati, 2010). Any function *f(t)* in $L^2(R)$ can be represented by the following wavelet series expansion:

$$f(t) = \sum_k \upsilon_{J,k}\, \phi_{J,k}(t) + \sum_k \omega_{J,k}\, \psi_{J,k}(t) + \sum_k \omega_{j,k}\, \psi_{j,k}(t) + \cdots + \sum_k \omega_{1,k}\, \psi_{1,k}(t) \qquad (1)$$

where the coefficients $\upsilon_{J,k} = \sum_k \phi_{J,k} f(t)$ and $\omega_{j,k} = \sum_k \psi_{j,k} f(t)$ respectively denote the underlying smooth behavior of the economic or financial data at the coarsest scale (the scaling coefficients), and the coarse-scale deviations from it (the wavelet coefficients), while $\phi_{J,k}, \psi_{j,k}$ are the so-called scaling functions. Finally, according to Gallegati (2010), the wavelet functions must fulfill the following conditions:

$$\int \phi_{J,k}(t)\phi_{J,k^*}(t)dt = \delta_{k,k^*},$$

$$\int \psi_{j,k}(t)\psi_{j^*,k^*}(t)dt = \delta_{j,j^*}\delta_{k,k^*},$$

$$\int \psi_{j,k}(t)\phi_{j,k^*}(t)dt = 0, \ \ \forall j,k,$$

where $\delta_{j,k}$ is the Kronecker delta. The scaling function is known as the "father wavelet" and can be defined as:

$$\phi_{J,k}(t) = 2^{-\frac{J}{2}}\phi(\frac{t-2^J k}{2^J})$$

Similarly, the wavelet function is known as the "mother wavelet", which can be represented as:

$$\psi_{j,k}(t) = 2^{-\frac{j}{2}}\psi(\frac{t-2^j k}{2^j})$$

The wavelet function in Eq. (1) depends on two parameters—scale (or frequency) and time. Here, the scale factor *j* controls the length of the wavelet (window), while parameter *k* refers to the location and indicates the non-zero portion of each wavelet basis vector. Based on the scale parameter, the wavelet function is stretched (or compressed) to obtain frequency information, whereby a wide window yields information on low-frequency movements, while high-frequency movements are derived from the narrow window. In order to obtain time information from the signal in question, it progresses through the timeline (from the beginning to the end).

The scaling function integrates to 1 and reconstructs the smooth and low-frequency parts of the signal. On the other hand, the wavelet function integrates to 0 and describes the detailed and high-frequency parts of the same signal (Gallegati, 2010). In this way, a complete reconstruction of the signal partitioned into a set of *J* frequency components can be obtained by applying a *J-level* multi-resolution decomposition analysis, whereby each component relates to a particular range of frequencies.

We can take advantage of this specific application, given that, owing to real and financial linkages, "fundamentals-based" contagion reveals normal interdependence. On the other hand, due to "pure" contagion co-movements over and above those linkages denoted by fundamentals, it is of particular interest for this work that the signal can be decomposed into two parts—a low-frequency part, which can be associated to interdependence, and a high frequency part, which remains after interdependence is accounted for, and represents contagion (Gallegati, 2010).

**4.2. Multiscale analysis of correlation**

The wavelet decomposition enables us to provide a different representation of the variability and association structure of certain stochastic processes on a scale-by-scale basis (Gallegati, 2010). The wavelet coefficients can be manipulated in a straightforward manner to achieve recognizable statistical quantities, such as wavelet variance, wavelet covariance, and wavelet correlation.

Whitcher et al. (1999, 2000) extended the notion of wavelet variance for the Maximal overlap discrete wavelet transform (MODWT) by introducing the definition of wavelet covariance and wavelet correlation between the two processes, along with their estimators and approximate confidence intervals. However, in order to determine the magnitude of the association between two series of observations *X* and *Y* on a scale-by-scale basis, the notion of wavelet covariance has to be used. Thus, in order to achieve the wavelet covariance, we followed Gençay et al. (2001) and Gallegati (2010).

The wavelet variance decomposes the variance of a time series into components associated with different scales (Percival, 1995; Gallegati, 2010), where the wavelet variance at scale *j*, $\sigma_X^2(\lambda_j)$, of a stationary stochastic process {X} with variance is given by the variance of *j-level* wavelet coefficients:

$$\sigma_X^2(\lambda j) = \mathrm{Var}(\omega_{j,t}^X)$$

In line with their classical counterparts, the wavelet covariance between two processes X and Y can be defined at wavelet scale *j* as the covariance between *scale-j* wavelet coefficients of X and Y, that is, $\gamma_{XY}(\lambda_j) = \mathrm{Cov}(\omega_{j,t}^X \omega_{j,t}^Y)$ ). In a similar way, the wavelet correlation between two time series $\rho_{XY}(\lambda_j)$ can be represented as the ratio of the wavelet covariance, $\gamma_{XY}(\lambda_j)$, and the square root of their wavelet variances

$\sigma_X$ ($\lambda_j$) and $\sigma_Y$ ($\lambda_j$) (see Whitcher et al., 1999, 2000; Gallegati, 2010). A standardized measure of the relationship between the two processes X and Y on a scale-by-scale basis can be obtained via the wavelet correlation coefficient $\rho_{XY}$ ($\lambda_j$). The correlation coefficient between two random variables, $|\tilde{\rho}_{XY}(\lambda_j)| \leq 1$ can be obtained in a similar way. In detail, given the unbiased estimators of the wavelet variances, $\tilde{\sigma}_X$ ($\lambda_j$) and $\tilde{\sigma}_Y$ ($\lambda_j$), and covariance, $\tilde{\gamma}_{XY}$ ($\lambda_j$), the unbiased estimator of the wavelet correlation for scale *j*, $\tilde{\rho}_{XY}$ ($\lambda_j$), may be achieved by:

$$\tilde{\rho}_{XY}(\lambda_j) = \frac{\tilde{\gamma}_{XY}(\lambda_j)}{\tilde{\sigma}_X(\lambda_j)\tilde{\sigma}_Y(\lambda_j)}$$

Based on Gallegati's methodology, we also employ a simple wavelet-based approach to test for contagion, starting from the unbiased estimator of the wavelet correlation for scale $j, \tilde{\rho}_{XY}(\lambda_j)$. Forbes and Rigobon (2002) defined contagion as a significant increase in cross-border linkages after a shock or a crisis. Adopting this view, we assess whether wavelet correlation coefficients on a scale-by-scale basis change significantly after a crisis, whereby the change is indicated by an upward or downward shift of the estimated wavelet correlation values. Similarly, the significance of the change can be identified by investigating approximate confidence intervals between crisis and non-crisis periods (Gallegati, 2010). Additionally, starting from spectrum $S_{\omega X,j}$ of scale j wavelet coefficients, it is possible to determine the asymptotic variance Vj of the MODWT-based estimator of the wavelet variance (covariance). This enables constructing a random interval that forms a 100(1 − 2p)% confidence interval. The expressions for estimating the 100(1 − 2p)% confidence intervals adopted in the robust MODWT estimator to non-Gaussianity for $\tilde{\upsilon}^2_{X,j}$ are provided in Gençay et al. (2002) and Gallegati (2008). Indeed, according to Whitcheret al. (2000), here we can consider a visual method—non-overlapping approximate confidence intervals of estimated wavelet correlation coefficient values—to statistically test the hypothesis of equality of wavelet correlations at different scales between crisis and non-crisis periods. Specifically, based on Forbes and Rigobon's (2002) definition of contagion, if we represent the estimated wavelet correlation coefficient values for the non-crisis and crisis periods as $\tilde{\rho}^I_{xy}(\lambda_j)$ and $\tilde{\rho}^{II}_{xy}(\lambda_j)$, respectively, the null hypothesis of no contagion can be defined by:

$$H_0: \tilde{\rho}^I_{xy}(\lambda_j) = \tilde{\rho}^{II}_{xy}(\lambda_j)$$

The null hypothesis can be rejected when 95% approximate confidence intervals are non-overlapping (see Gencay et al., 2002 and Gallegati, 2010 for more details).

### 4.3 The Continuous Wavelet Transform

In the previous Sections, we have introduced maximal overlap discrete wavelet transform (MODWT) such as wavelet correlation in order to identify financial market contagion. More recently, continuous wavelet transform (CWT) has appeared in the literature review and several authors provide some examples of useful economic applications (Aguiar-Conraria and Soares, 2011; Vacha and Barunik, 2012, Madaleno and Pinho, 2012).

The maximum overlap discrete wavelet transform (MODWT) is the most common transform among economists. This tool – MODWT-can be considered as a kind of compromise between the DWT (discrete wavelet transform) and the CWT.

The CWT maps the original time series, which is a function of just one variable –time- separated into function of two different variables such as time and frequency. It is a redundant transform compared to DWT and MODWT. It has several advantages:

1) In the DWT and MODWT, we have to define the number of wavelets according to our objectives; however, CWT provides a large freedom in selecting wavelets according to the length of data.

2) According to Aguiar-Conraria and Soares (2011), the redundancy makes CWT much easier to interpret the results and to derive conclusions from the data.
3) If the purpose is to analyze data to discover patterns or hidden information, then the redundancy function of CWT is helpful.

According to Madaleno and Pinho (2012), there is contagion only if two markets display a significant rise in comovement during turmoil periods compared with tranquil periods. If in the case of cross-market, if the comovements do not increase appreciably after the crisis, then any sustained level of market correlation only implies the interdependence between the two economies.

In addition to the above MODWT, we have illustrated CWT as an example only for a few countries to analyze data to discover patterns or hidden information. The wavelet coherence method under CWT is used to study the presence of contagion effects which was introduced by Torrence & Compo (1998) and Grinsted et al (2004). Instead of the discrete wavelet transform, the estimator for interdependence is now based on the continuous wavelet transform.

The continuous wavelet transform (CWT) $W_X(u,s)$ is obtained by projecting a mother wavelet $\psi$ onto the examined time series $x(t) \in L^2(\mathbb{R})$, i.e.,

$$W_X(u,s) = \int_{-\infty}^{\infty} x(t) \frac{1}{\sqrt{s}} \psi\left(\frac{t-u}{s}\right) dt$$

the position of the wavelet in the time domain is given by *u*, while its position in the frequency domain is given by *s*. Therefore, the wavelet transform, by mapping the original series into a function of *u* and *s*, gives us information simultaneously on time and frequency.

**4.4 Wavelet Coherence**

To be able to study the interaction between two time series, how closely X and Y are related by a linear transformation, we need to apply a bivariate framework which is called wavelet coherence. The wavelet coherence of two time series is defined as:

$$R_n^2(s) = \frac{\left|S(s^{-1}W_n^{xy}(s))\right|^2}{S(s^{-1}|W_n^x(s)|^2 . S(s^{-1}\left|W_n^y(s)\right|^2}$$

where *S* is a smoothing operator, *s* is a wavelet scale, $W_n^x(s)$is the continuous wavelet transform of the time series *X*, $W_n^y(s)$ is the continuous wavelet transform of the time series *Y* and $W_n^{xy}(s)$is a cross wavelet transform of the two time series *X* and *Y* (Torrence & Webster, 1999; Grinsted et al. 2004; Ranta, 2010; Madaleno and Pinho, 2012).

The best wavelet for feature extraction purposes is the Morlet wavelet, since it provides a good balance between time- and frequency localization. Also for the Morlet wavelet the Fourier period is almost equal to the wavelet scale used (Grinsted et al. 2004). The smoothing operator is defined to be similar to the wavelet used. It is written as:

$$S(W) = S_{scale}\left(S_{time}\left(W_n(s)\right)\right)$$

where $S_{scale}$ denotes smoothing along the wavelet scale axis and $S_{time}$ smoothing in time (Grinsted et al. 2004; Madaleno and Pinho, 2012). It is natural to design the smoothing operator so that it has a similar footprint as the wavelet used. For the Morlet wavelet a suitable smoothing operator is given by Torrence and Webster (1998), Grinsted et al. (2004) and Madaleno and Pinho (2012).

$$S_{time}(W)|_s = \left( W_n(s) * c_1^{\frac{-t^2}{2s^2}} \right)\Big|_s$$

$$S_{scale}(W)|_n = (W_n(s) * c_2 \Pi(0.6s))|_n$$

where $c_1$and $c_2$are normalization constants and $\Pi$is a rectangle function. The factor of 0.6 is empirically determined and follows Torrence & Compo (1998). The statistical significance levels of the wavelet coherence are determined using Monte Carlo methods. The guidelines of Grinsted et al. (2004) are followed. Our assumption is that the lower scale high wavelet coherence is due to "contagion" and higher scale high coherence is due to "fundamentals".

**5. Data and empirical results**

In this section, we apply the wavelet-based approach proposed in the previous research (Gallegati, 2010) to test whether contagion occurred during the most recent international financial crisis: the US subprime crisis of 2007-2009. On the top of that, we have introduced continuous wavelet transform to detect financial market contagion.

**5.1 Data**

Since the subprime mortgage crisis originated in the U.S., the USA conventional MSCI index is assumed to be the volatility "originator," while the other 18 MSCI indexes are the volatility "recipients." The terms "originator" and "recipient" were introduced by Edwards and Susmel (2001).

We use close-to-close daily data in USD currencies for the stock market indexes of Far East and selective Islamic countries plus USA MSCI index as of originator: China, Japan, Korea, Hong Kong, Taiwan (5 conventional and 5 *Shari'ah*-compliant stock indexes) and Malaysia, Indonesia, Turkey, GCC-ex-Saudi (4 conventional and 4 *Shari'ah*-compliant stock indexes);

Data will be taken from the Datastream at INCEIF and cover the period from June 2005 to December 2011. These stock market indexes are transformed to compounded stock market returns by calculating the natural logarithmic differences of the daily stock prices, that is, *rt* = $\ln(\frac{p_t}{p_{t-1}})$, where $P_t$ and $P_{t-1}$ represent the stock price index at time t and t − 1, respectively. Consistent with others in the literature (Kasa, 1992; King et al., 1997, Masih and Masih, 2001), the raw indexes have been transformed to reflect real US dollars in order to adopt the perspective of the US investor.

Periods of financial turmoil are generally identified with a rise in asset price volatility. Figure 1 shows that the volatility of MSCI USA index started to increase after the occurrence of the US subprime mortgage bubble in August 2007 and peaked in September 2008 which is associated with collapse of Lehman Brothers. Based on these two fundamental events, we chose the end of July 2007 as the structural break date that separates the pre-crisis and crisis periods for the first wave of crisis – the outbreak of U.S. mortgage bubble; and we took middle of September 2008 as another structural break date for the second wave of crisis – the collapse of Lehman Brothers. In particular, i) the first wave of crisis period begins on 1 August 2007 and we took one year period data for crisis period. ii) The second wave of crisis begins on 15 September 2008 and also we took slightly more than one year period daily data in order to analyze similar length of data.

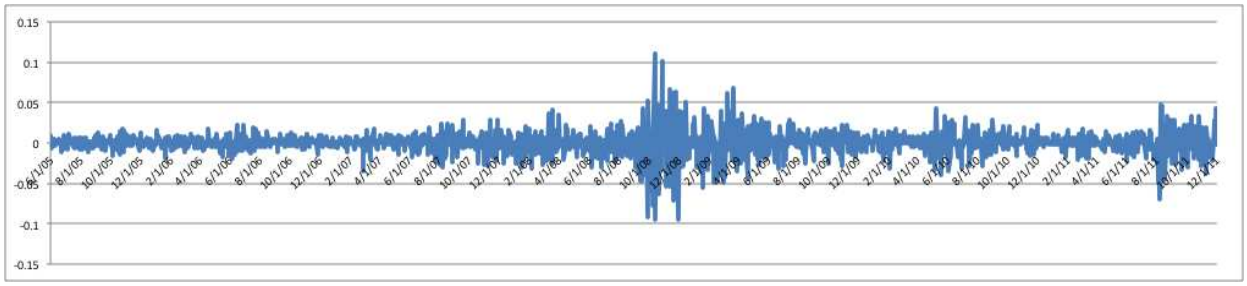



Figure 1: MSCI USA returns for the period from 1 June 2005 to 1 December 2011

Therefore, we have split the data into three periods such as before first wave of crisis [sample: 1 July 2006 – 31 July 2007], after first wave of crisis and before second wave of crisis [sample: 1 June 2007 – 12 September 2008] and after second wave of crisis [sample: 15 September 2008 – 31 December 2009]. Table 1 provides the number of daily observations for the bivariate series of conventional and Islamic indexes.

| | Periods | Conventional Indexes | Islamic Indexes |
|---|---|---|---|
| 1st wave of contagion | Before 1st wave of crisis | 282 | n/a |
| | After 1st wave and before 2nd wave of crisis | 336 | |
| | Total | 618 | |
| 2nd wave of contagion | After 1st wave and before 2nd wave of crisis | 336 | 336 |
| | After 2nd wave of crisis | 339 | 339 |
| | Total | 675 | 675 |

Table 1: Number of daily observations for the bivariate series of conventional and Islamic indexes

Note: The empirical evidence from the wavelet variance suggest that $N_j = 128$ is a large enough number of wavelet coefficients for the large sample theory to be a good approximation (Whitcher et al., 2000).

**5.3 Empirical Results**

The results from the application of wavelet correlation analysis to each bivariate system for the different sub-periods, crisis and pre-crisis periods, are presented in Figure 2, 3 and 4. All computations have been performed using the waveslim package developed by Whitcher (and available at http://www.cgd.ucar.edu/~whitcher) running under the R statistical computing environment (R Development Core Team, 2006) (Gallegati, 2010).The blue line deals with the wavelet correlation coefficient for the non-crisis period, whereas the red line corresponds to the wavelet correlation coefficient during the crisis period. The dashed lines denote the upper and lower bound for the approximate 95% confidence interval with the assumption of a non-Gaussian process (Gallegati, 2010).

We test whether the wavelet correlation coefficient on a scale-by-scale basis between two stocks are significantly different or not. The significant difference is identified by observing the confidence intervals between the two stocks. The null hypothesis of no significant difference is rejected when the 95% confidence intervals are non-overlapping. In other words, in the context of contagion, at a particular wavelet scale the 'null hypothesis of no contagion' is rejected when the two confidence intervals are non-overlapping. There are some interesting findings derived from various patterns which are presented by the wavelet-based "correlation-breakdown" test.

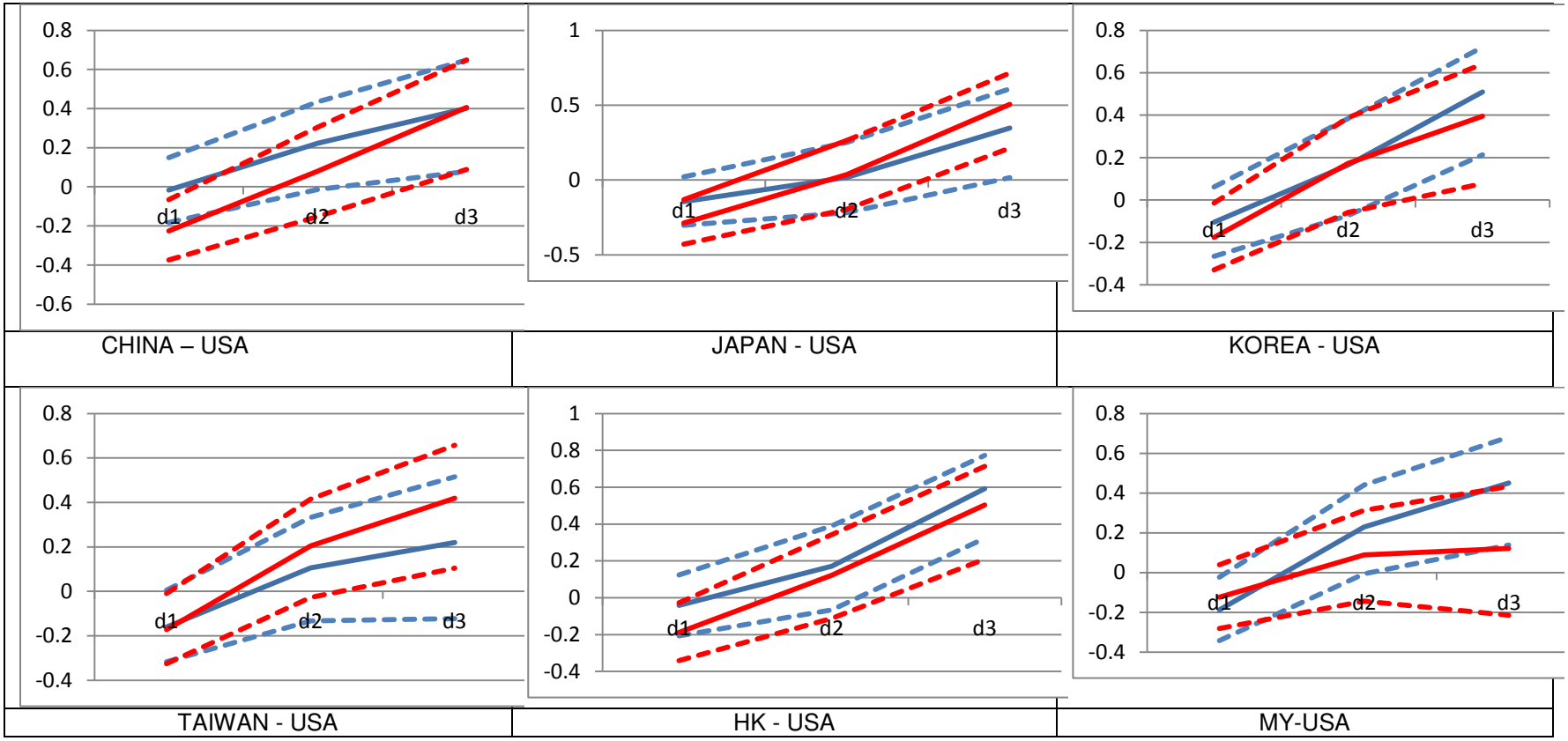
Firstly, the Figure 2 shows that in all cases of conventional stock indexes, the wavelet correlation coefficients change insignificantly at all scales during the outbreak of the US mortgage bubble. This

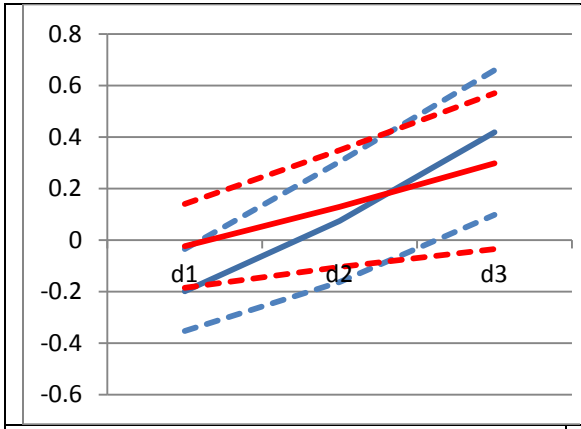
implies that there is no clear evidence for each country of international financial contagion during the outbreak of the US mortgage bubble regardless of Islamic or non-Islamic country. In some cases (China, Hong Kong, Malaysia), the wavelet correlations show a decrease in wavelet correlation that implies a weakening of the linkages between those markets and the US MSCI index. Zhou et al. (2012) found that the Greater Chinese stock markets (China, Hong Kong, Taiwan) were not greatly affected by the market volatility during the recent global crisis in July 2007. In the case of Japan, Korea, GCC ex-Saudi and Turkey, the wavelet correlation coefficients indicate that there is a very small change before and after the mortgage bubble. Finally, all other indexes display a slight increase in wavelet correlation coefficients, however, these increases are insignificant due to overlapping of confidence intervals; therefore we cannot reject the null hypothesis of no contagion. In summary, there is no clear evidence of contagion at all time scales or frequencies. In contrast, Gallegati (2010) found that all stock markets have been affected by the US subprime crisis by analyzing stock indexes of G7 countries plus Brazil and Hong Kong. These results indicate that during the outbreak of the US mortgage bubble, European countries were affected more by the US subprime crisis compared to the Asian and Middle East countries. This is very clear in the case of Hong Kong, where both studies found that there is a decrease in wavelet correlation that implies a weakening of the linkages between the Hong Kong index and the US index.

From Figure 3, we derive a very interesting finding in that all conventional stock indexes of non-Islamic countries excepting Japan, the wavelet correlation coefficients changes significantly at the first scale during the collapse of Lehman Brothers. This means that there is a clear evidence for each non-Islamic country of international financial contagion during the collapse of Lehman Brothers excepting Japan. These increases are significant due to the non-overlapping of confidence intervals; therefore, the significant decrease in wavelet correlation in the event of collapse of Lehman Brothers allowed us to reject the null hypothesis which implies that there is clear evidence of contagion at the first scale. These results are in line with the study of Neaime (2012), which found that the fallout of the global crisis in East Asia was devastating, measuring in some instances three times the impact on MENA countries, primarily because of greater financial and economic integration. Madaleno & Pinho (2012) also found the cycles of high coherence during the subprime crisis period at low scales. In another study by Nanta (2010), the results showed short time scale correlation increased during the crisis. Additionally, in the case of China, wavelet correlation coefficients increased significantly at time scale 1 which is associated with 1-2 days. Finally, the wavelet correlations in the markets of Korea, Taiwan and Hong Kong showed a significant decrease in wavelet correlation implying a weakening of the linkages between those markets and US MSCI index with negative values. The evidence of those markets is consistent with the hypothesis that contagion should not be limited to the hypothesis of stronger than normal linkages, because correlations can also fall at the outbreak of a crisis (see Corsetti et al., 2001, Gallegati, 2010). In the case of Japan, one can conclude that Japan presents, in general, a low comovement with US index. This particular feature of the Japanese stock index with other major stock markets has also been found elsewhere (Rua & Nunes, 2009).

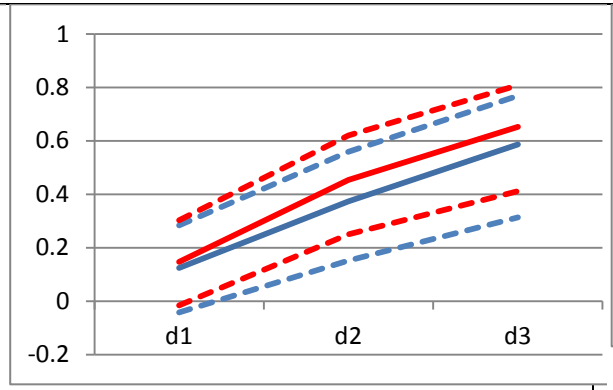
According to wavelet correlation analysis as far as the conventional stock indexes are concerned: (a) there was no dependence or no contagion effect between US conventional stock index and the other selected conventional index during the first wave of crisis – the US mortgage bubble; and (b) there was negative dependence between the same two indexes except Japan during the collapse of Lehman Brothers. Our results are consistent with the findings by Reboredo and Rivera-Castro (2013), by analyzing the relationship between crude oil price and exchange rate dependence they found that there was negative dependence between oil price and exchangers rates for all developed and emerging economies in the crisis period. The same authors (Reboredo and Rivera-Castro, 2014) also studied the impact of oil prices on stock returns by dividing the sample into two periods, namely, pre-July 2008 and post-July 2008; they identified that a structural breakpoint in linear dependence between July 2008 and September 2008 for all the return series.

**Figure 2: Conventional Stocks with USA index (the subprime crisis)**

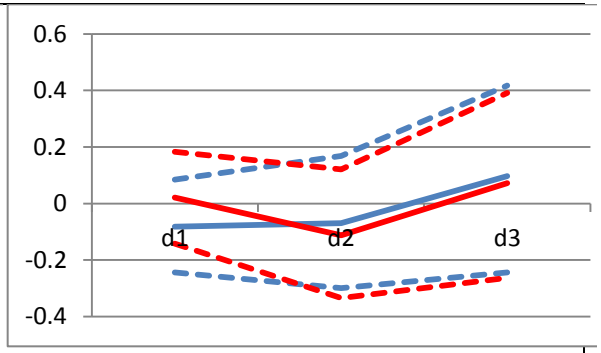





INDO – USA



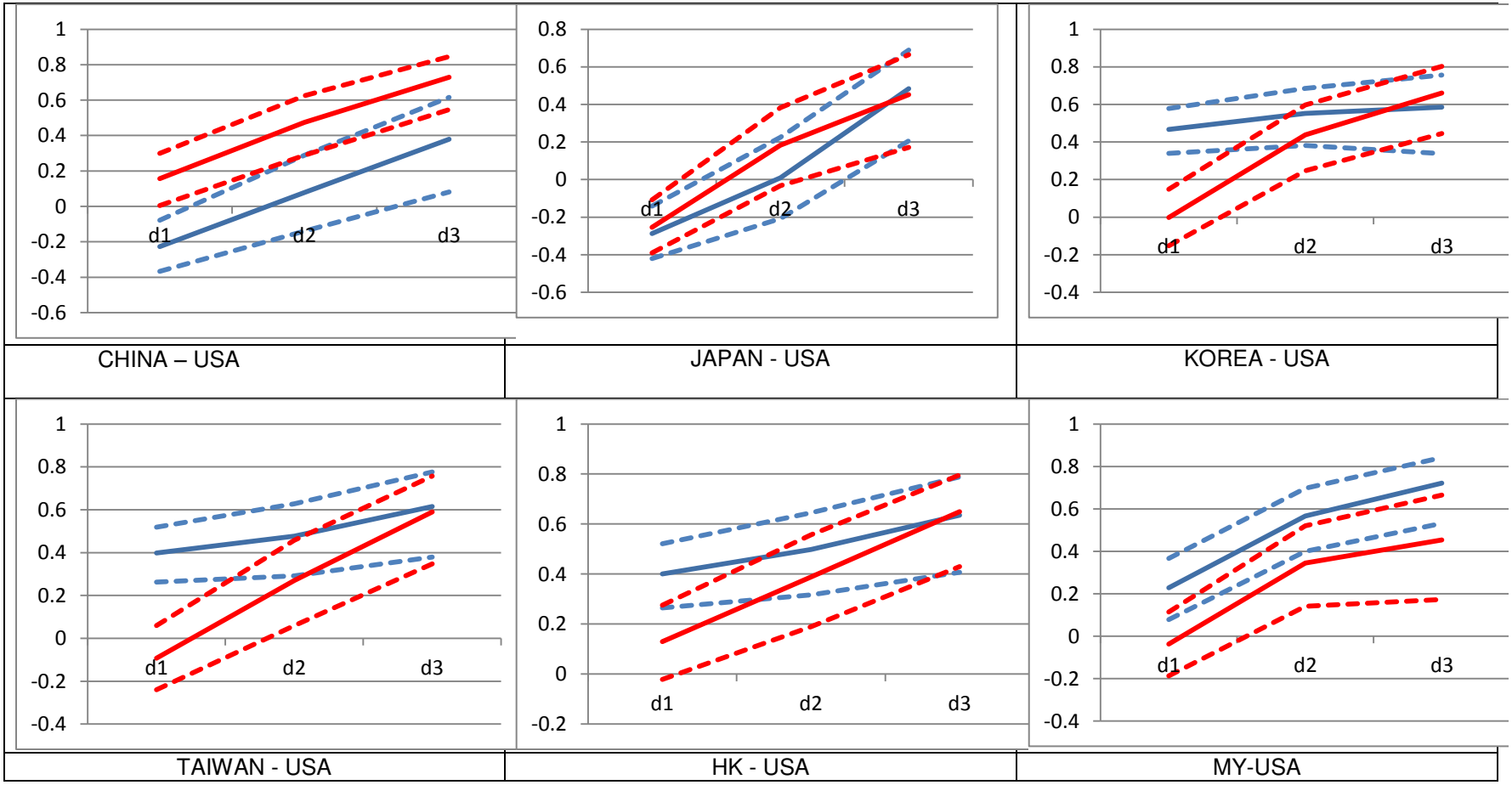

TURKEY - USA

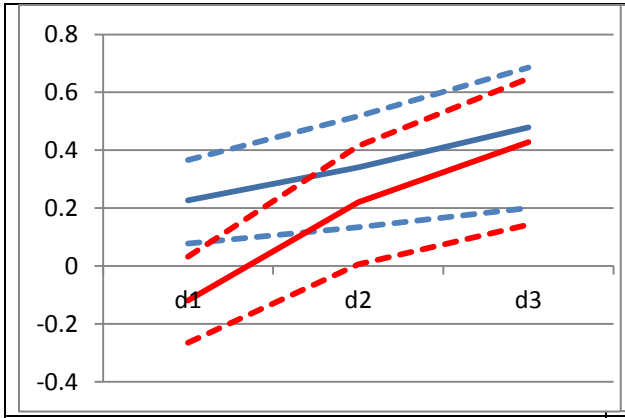



GCC - USA

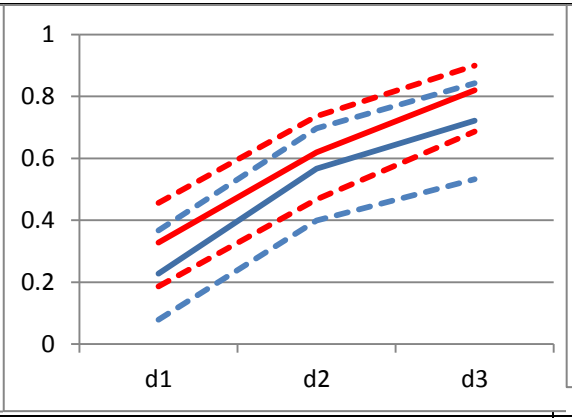
Note: Estimated wavelet correlation of USA MSCI with the returns of each other conventional stock index for pre-crisis (blue line) and crisis (red line) periods (for first wave of crisis). The dashed lines both blue and red denote the upper and lower bounds for the approximate 95% confidence interval. The null hypothesis of no contagion can be rejected when the confidence interval are non-overlapping.

**Figure 3: Conventional Stocks with USA index (the collapse of Lehman Brothers)**

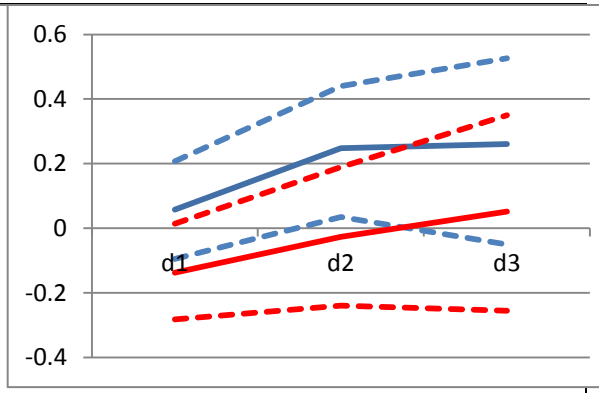





INDO – USA



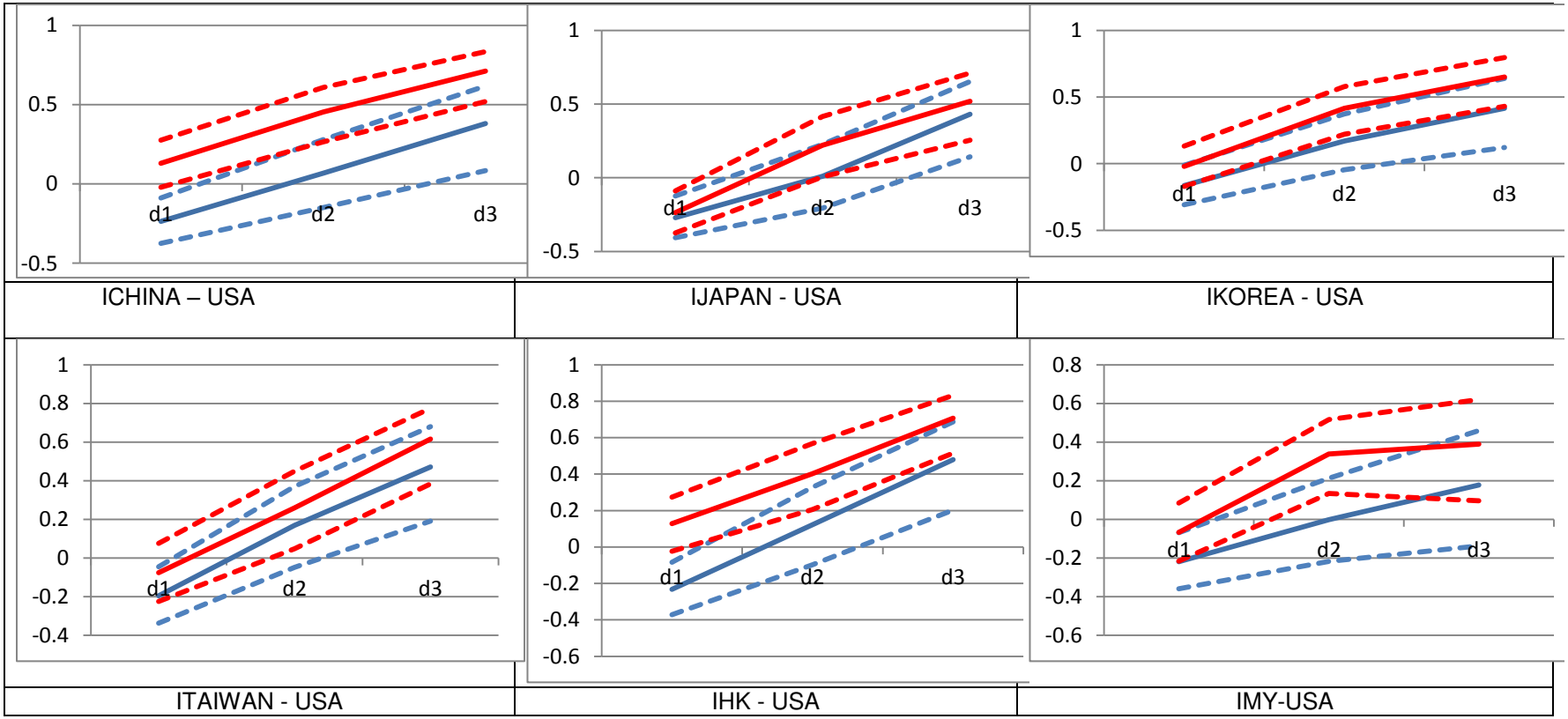

TURKEY - USA

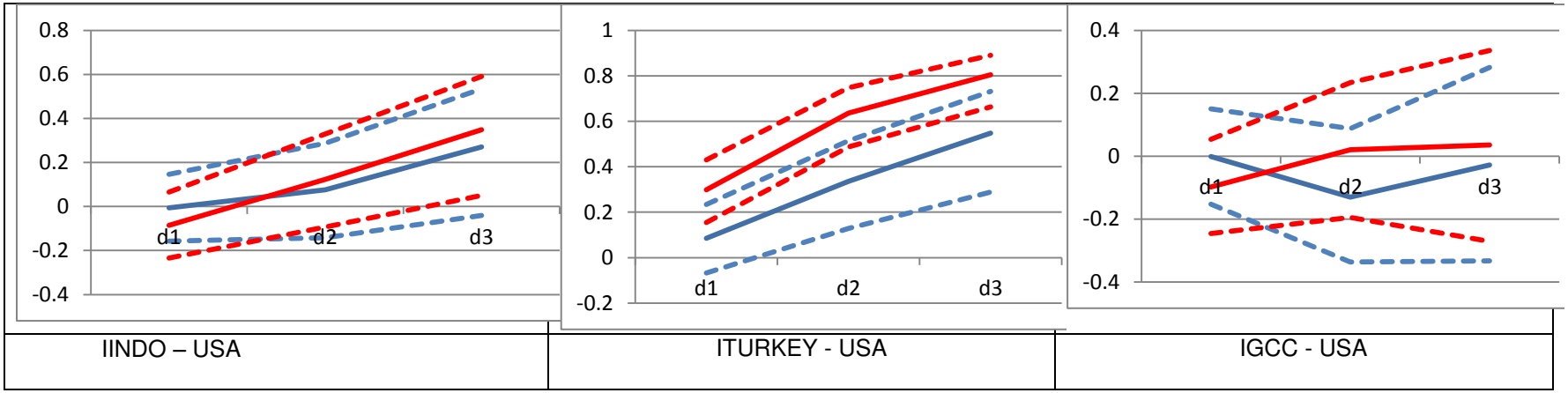



GCC - USA

Note: Estimated wavelet correlation of USA MSCI with the returns of each other conventional stock index for pre-crisis (blue line) and crisis (red line) periods (for second wave of crisis). The dashed lines both blue and red denote the upper and lower bounds for the approximate 95% confidence interval. The null hypothesis of no contagion can be rejected when the confidence interval are non-overlapping.

**Figure 4: Islamic stocks with USA index (the collapse of Lehman Brothers)**






| IINDO – USA | ITURKEY - USA | IGCC - USA |
|---|---|---|

Note: Estimated wavelet correlation of USA MSCI with the returns of each other Islamic stock index for pre-crisis (blue line) and crisis (red line) periods (for second wave of crisis). The dashed lines both blue and red denote the upper and lower bounds for the approximate 95% confidence interval. The null hypothesis of no contagion can be rejected when the confidence interval are non-overlapping.

In terms of Islamic countries, all MSCI conventional stock indexes do not suffer from contagion except the Indonesia MSCI stock index due to overlapping of confidence intervals. However, if we compare these wavelet correlations with the wavelet correlations which resulted from the mortgage bubble, the former shows slightly higher correlations. In the case of Indonesia, our results are consistent with the findings of Mulyadi (2009); the study used daily data for the period from January 2004 to December 2008 to investigate the stock market volatility spillovers between Indonesia, the US and Japan and found that volatility spillovers run unidirectionally from the US to Indonesia.

Figure 4 shows that, for all Islamic stock indexes of both the Islamic and non-Islamic countries excepting the China and Hong Kong indexes, the wavelet correlation coefficients change insignificantly at all scales during the second wave of crisis - the collapse of Lehman Brothers. These changes are insignificant due to overlap of confidence intervals; therefore, we failed to reject the null hypothesis which implies that there is no clear evidence of contagion at all scales excepting China and Hong Kong. In these two cases, wavelet correlation coefficients increase significantly with positive values at scale 1 which is associated with 1-2 days. These results are in line with the study of Neaime (2012), which finds that the fallout of the global crisis in East Asia was widespread, primarily due to the greater financial and economic integration.

**5.4 Data Description for Wavelet Coherency (in Continuous Form)**

As far as we are concerned, until now when wavelet transforms were applied to the analysis of stock market indexes, the use of the discrete wavelet transform or one of its variants dominated (Gallegati, 2008, 2011). More recently, Aguiar-Conraria and Soares (2011), Vacha & Barunik (2012), Madaleno & Pinho (2012) and Tiwari (2013) have introduced continuous wavelet transform (CWT) and provided some examples of useful economic applications. Our contagion analysis can be done more effectively and in a straightforward manner using the continuous wavelet transform.

Under the CWT, it is not required to find out the structural breaks since this wavelet transformation can capture all the dynamics of financial time series. For the conventional MSCI stock indexes, we examine the period from June 2005 to December 2011 and June 2007 to December 2011 for *Shari'ah*-compliant stock indexes. For illustration purpose, we conducted CWT for two extreme stock indexes such as the China and GCC-ex-Saudi conventional and *Shari'ah*-compliant MSCI stock indexes; while the former is more contagious compared to the latter.

**6.4.4 Empirical Results based on Wavelet Coherency**

A high wavelet coherence between two assets at the lower time scales tends to indicate 'contagion', whereas a high wavelet coherence at the higher time scales tends to indicate a fundamental theoretical relationship between assets. Coherency ranges from blue (low coherency between two assets) to red (high coherency between two assets). We use wavelet coherency (in continuous form) within bivariate framework with a view to observing the comovements between two markets at different time scales for identifying the nature of relationship between them (contagious or interdependent) and, therefore, we expose the time-frequency patterns in the relationship as well as the structural breaks in the relationship (Tiwari, 2013).

Figures 5 and 6 present the estimated wavelet coherency of two conventional MSCI indexes and two *Shari'ah*-compliant stock indexes with the US conventional MSCI index from scale 1 (one day) up to scale 9 (approximately two market years - 512 days) for conventional indexes and from scale 1 (one day) up to scale 8 (approximately one market year - 256 days) for *Shari'ah*-compliant stock indexes.

Time is shown on the horizontal axis, while the vertical axis refers to frequency (or time scales); the lower the frequency, the higher the time scale. Values for significance are obtained from Monte Carlo

simulations at 5% significance level. In the pictures, color code for power ranges from blue (low coherency) to red (high coherency).

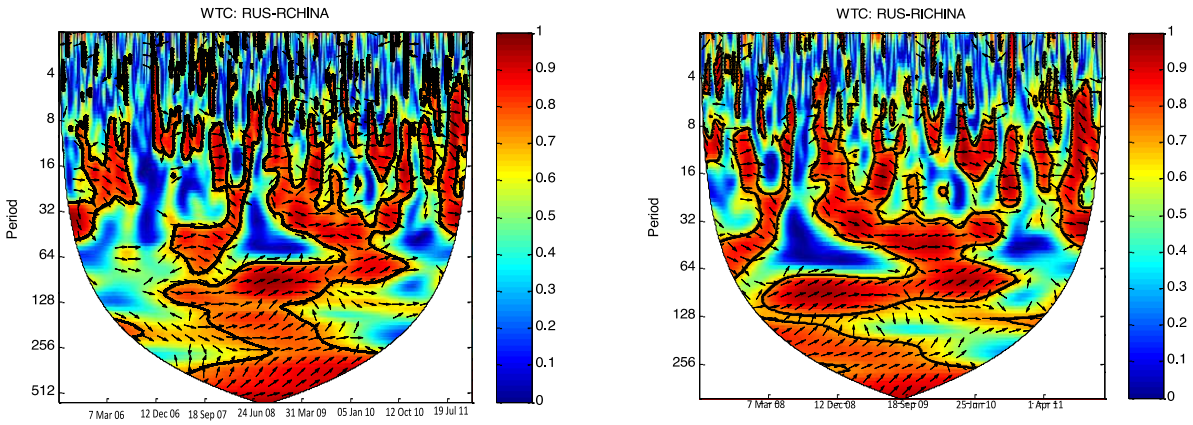



Figure 5: Wavelet coherence of both the China conventional and *Shari'ah*-compliant MSCI stock indexes with the US conventional MSCI index.

From the analysis of the wavelet coherence, we can observe very interesting results. A first glance confirms our findings from the previous MODWT analysis which shows that both the China conventional and *Shari'ah*-compliant MSCI stock indexes are more contagious compared to both the GCC-ex-Saudi conventional and *Shari'ah*-compliant MSCI stock indexes; which indicates that the fallout of the global financial crisis in China was widespread, primarily due to the greater financial and economic integration with US market.

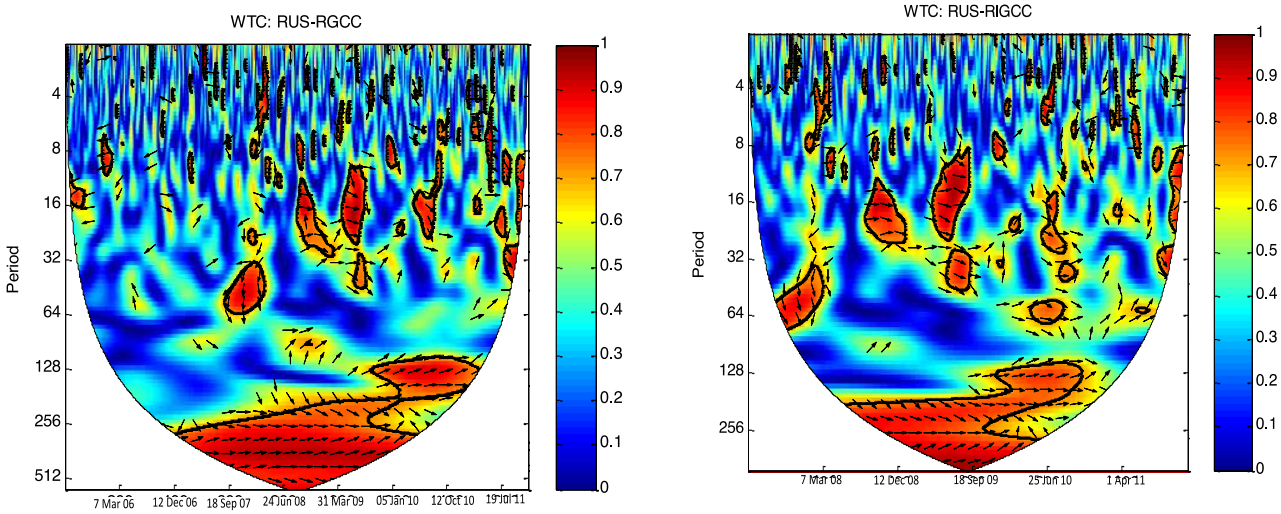



Figure 6: Wavelet coherence of both the GCC-ex-Saudi conventional and *Shari'ah*-compliant MSCI stock indexes with the US conventional MSCI index.

As we mentioned earlier, we are able to test contagion effect for conventional MSCI indexes during the two subsequent crises such as the outbreak of the mortgage bubble (July-August 2007) and the collapse of Lehman Brothers (15 September 2008). However, we test contagion effect for *Shari'ah*-compliant stock indexes only for the latter (the collapse of Lehman Brothers) due to the lack of data.

As far as the China conventional MSCI stock index is concerned, the degree of wavelet coherency indicates that the collapse of Lehman Brothers is more contagious compared to the outbreak of the mortgage bubble. For example, around September 2008, these two indexes (China and US conventional MSCI indexes) were very closely related at almost all scales; however, there seems to be no dependency except the time scale of 8-16 days around July 2007. In terms of the GCC-ex-Saudi conventional MSCI index, we cannot find any evidence of contagion effect during both periods of crises due to the lower coherency at lower scales. Still, there is high coherency among the stock indexes on the daily time scale bands of 128-512 days in both cases due to the "fundamentals". These results are consistent with our findings in the previous MODWT section.

In the case of *Shari'ah*-compliant MSCI stock indexes, it is very clear that the China *Shari'ah*-compliant stock index is highly correlated with the US conventional index compared to the GCC-ex-Saudi *Shari'ah*-compliant stock index. For example, around September 2008, the China *Shari'ah*-compliant stock index is very closely related to the US conventional stock index at almost all scales; however, in the case of the GCC-ex-Saudi *Shari'ah*-compliant stock index, there is no high wavelet coherence again excepting the time scale of 16-32 days. This implies that the GCC-ex-Saudi *Shari'ah*-compliant stock index is less contagious relative to China *Shari'ah*-compliant stock index during the collapse of Lehman Brothers in September 2008.

**6. Interpretations**

We argue that there should be some factors to explain: i) why does the US subprime mortgage crisis not have any heavy impact on indexes of Far East and selective Islamic countries? ii) Why are the conventional indexes contagious, while the Islamic stock indexes show insignificant wavelet correlation changes during the collapse of Lehman Brothers in USA?

Many economists (Kawai, 2008) have argued that the contagion effects of the US subprime mortgage crisis on the Asian financial activity have been relatively limited, and that the growth prospects of Asian economies will remain robust. Lee and Park (2008) documented that the Asian financial institutions possess relatively lesser direct exposure to US subprime mortgages and other structured credit products. This spillover on the Asian financial markets has been relatively limited; the banks in Asia remain little affected and short-term credit markets display few signs of stress; domestic funding conditions have been generally positive, therefore, and capital inflows to the region remain strong. Even though Asia has experienced a fast development towards global financial integration, the use of securitization and auxiliary markets is currently far more modest than that in advanced countries. The study documents that more advanced markets in emerging Asia show higher global integration, while less advanced countries like Indonesia and Philippine possess lower sensitivity, with the spillover from the US to Thailand being modest. South-East Asian countries are relatively different compared to the advanced counterparts like China and Korea that experienced a sharp increase in portfolio investment outflows in the past few years (mainly US debt securities), indicating the higher exposure of these Asian countries to any shock from the US.

The strong growth prospects, sound external positions, and improved policies in Asia also have supported investor confidence in the regional economies during subprime mortgages. Lee and Park (2008) describe the healthy condition of Asian financial system, which are the stronger regional banking systems and prudential, better risk management practices, more flexible exchange rate regimes, broader corporate financing sources, increasing integration at the global level, fiscal budgets consolidated, and so on.

However, they also stated that these positive factors do not guarantee the complete protection of the Asia's financial markets and systems from global financial turbulence, especially in the case of worsening. Asia still remains open to further contagion given underlying weaknesses in the region's financial systems due to several important channels such as heightened risk perception, declining investor confidence, a sudden change in liquidity conditions, unsophisticated financial institutions. As they rightly forecasted, there are contagion effects in MSCI indexes of Far East countries during the collapse of Lehman Brothers in USA which have more heavier global consequences.

When Lehman Brothers and other important financial institutions failed in September 2008, the crisis hit a key point. This event resulted in a near collapse of banking industry, stock market crashes, a large decrease in liquidity on the credit market especially money market.

Many Asian financial markets have suffered sharper losses, even the banks in the region were relatively less affected by this crisis compared to those in North America and Europe (Yiu et al., 2011). When the U.S. government let Lehman brothers go bankrupt, a massive world-wide sell-off financial assets started and the asset prices fell throughout the world. The Asian equity markets also plunged. Similar to our result, Yiu et al., (2011) also found that the contagion effect of the U.S. equity market on the Asia is apparent in the 2008 crisis episode.

In terms of Islamic MSCI stock indexes, we argue that the insignificant impact can be due to the specific features of Islamic stocks. The excessive leveraging and credit growth in the U.S. market are the fundamental factors that have ignited the subprime crisis (Haneef and Smolo, 2010). The application of *Shari'ah* principles would prevent excessive leverage and the formation of speculative bubbles in credit markets, thus it will in turn mitigate the adverse impact of the subprime crisis for Islamic finance industry (Chapra, 2008); Chapra, Ebrahim, Mirakhor, and Siddiqi, 2008) due to the limit of leverage in Islamic finance, Islamic firms would absorb lesser impact from the crisis.

For another explanation, the limit of interest-based leverage would also lead to lower systemic risks of Islamic stocks, both during expansion and recession. During credit expansion supported by low interest rate, every company may benefit by taking higher leverage which will consequently boost their expected return. This is unlikely to be found in Islamic stocks. *Shari'ah* screening in the form of the twin screen of ethical and financial ratio filters will lead the Islamic index to take highly leveraged firms out of the index. For instance, DJIMI was able to detect the corporate troubles of Worldcom and Enron, due to increasing high leverage, and remove these companies from the DJIMI indices a year before the stock value of these companies became worthless (Hassan, 2002; Hussein, 2004). The leverage limit may lead the performance of individual firms to be less influenced by interest rate movement and would not fluctuate in the same fashion as overall markets. This may conform to study of Askari et al (2010) who argue about the lower correlation of individual stock price with other assets as well as whole market.

In addition, other conventional studies also have found the positive relationship between level of leverage and systemic risk. Hamada (1972) and Rubenstein (1973) have decomposed the beta into financial risk and operating risk while Mandelker and Rhee (1984) have provided an alternative way. They suggest that a company's beta have to increase if the company finances more heavily with debt. Hamada (1972) derives the Modigliani and Miller propositions within a portfolio theoretic framework and have found that firms with the same asset risk but different degrees of leverage must have different costs of equity, with the market requiring higher returns on the more highly levered firm. In other words, the levered beta therefore will contain the financial risk of leverage.

The Final reason can refer to the complexity and intensive use of structured financial products, derivatives, and other toxic assets with uncertain fundamentals which played an important role in triggering crisis (Haneef and Smolo, 2010). On the other hand, the evidence above is unlikely to be found in Islamic financial sector. Firstly, Islamic Financial Institutions (IFIs) did not have any exposure to toxic assets (largely debt-based). In Islamic teachings, selling the debt at discount or premium is prohibited with the rule of *bay ad-dayn*. The debt should only be traded at par value which has made it impossible for IFIs to purchase these kinds of assets. Secondly, IFIs cannot purchase CDSs and interest rate swaps to cover risks. Given the presence of *gharar* in the contract, the validity of any kind of conventional

derivatives is still a debatable issue among Islamic scholars. However, majority of scholars argue that trading derivates is not allowed with the reason that they are neither tangible assets nor intangible assets. It cannot be the subject matter of the sale and purchase. Thirdly, we can refer to the study done by Beck, Demirgüç-Kunt and Merrouche (2010) who mentioned that Islamic financial institutions particularly banks were more resilient to the subprime crisis than their conventional counterparts mainly due to their capital and liquidity buffers before the inception of the crisis in the summer 2007. For these three reasons, Islamic financial sector was not possibly directly affected by the subprime financial crisis.

## 7. Concluding Remarks

In this research paper, we analyzed the issues of contagion and interdependence by using a wavelet-based time-frequency framework. We investigated whether contagion occurred during the US subprime crisis of 2007-2009 by applying wavelet correlation analysis on a scale-by-scale basis through a simple visual method based on approximate confidence intervals of estimated wavelet correlation coefficients in pre-crisis and crisis periods. Additionally, we have applied wavelet coherency approach to check robustness of the results.

The key results of this research were that there was no contagion effects among all MSCI conventional indexes during the subprime mortgage crisis in USA; However, we failed to test contagion effects for MSCI Islamic stock indexes due to the lack of data; Secondly, during the collapse of Lehman Brothers, generally, the MSCI conventional stock indexes of Far East countries display contagion effects while the rest of MSCI stock indexes which including Islamic stock indexes do not show any contagion effects.

The presence of contagion has significant implications for participants in financial markets and for all participants in the world economic system. The ultimate objective of this research is to find whether there are any contagion effects during recent financial crisis that can be used to reduce uncertainty about the transmission of financial crisis, and to help plan regulatory structures and inform portfolio and financial system management. So these correlations are significant inputs for international portfolio management and risk assessment, monitoring the changes of the correlations is crucial in international investment.

Contagion effects are expected, according to historical knowledge and existing relationships between stock markets. If policy is formulated to mitigate contagion effects, then knowledge of the presence and extent of contagion effects is important. In terms of information usage, it is meaningful to make an examination of the existence of contagion during crises with the help of more advanced techniques. Therefore, it is essential to provide policy makers with timely and appropriate measures of correlation changes and contagion.

More importantly, investors may avoid contagion effects by alternative investment channels: across different assets such as *Shari'ah*-compliant assets, across different countries such as emerging markets.

In short, this study shows that wavelet analysis can provide a valuable alternative to the existing conventional methodologies in testing international financial contagion, since wavelets can appropriately discriminate between contagion and interdependence effects.

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