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Abstract

This paper presents an empirical study in the dynamic causal relationships between each of national stock market of the East Asian economies (Hong Kong, Singapore, Korea (Rep. of), and Taiwan) and the U.S. stock market. This paper complements the existing studies by analyzing the dynamic causal relationship between the U.S. stock market and the East Asian stock markets at different time scales by employing wavelet analysis. Analyses of pre-crisis, East Asian financial crisis (year 1997-2000), inter-crisis and the subprime mortgage crisis (year 2007-2009) periods are conducted to compare the international transmission mechanism of stock market movements. The main empirical insight is that the causal relationship is stronger at finer time scales, whereas the relationship is less and less apparent at longer time horizons. The empirical evidence of the current study indicates that the U.S. stock market Granger-causes almost all the East Asian stock markets regardless of non-crisis periods or not, yet it applies only to the later two sub-sample periods. In general, the empirical results show that short-run causal linkages of the U.S. market to the East Asian economies are more dominant than the causal linkages of the other direction. The results also show that those stock markets are more integrated after the East Asian financial crisis period. Innovations in the U.S. market are transmitted to the stock markets of the East Asian economies in a similar fashion, whereas the degree of responsiveness of those East Asian stock markets differs between the inter-crisis period and the subprime mortgage crisis.

Keywords: Wavelet analysis; stock market; granger causality

JEL: G15; G29; C69 etc etc

1. Introduction

Understanding the degree of interdependence between national stock markets and the nature of their relationship (market dominance, transmission mechanism, and degree of responsiveness to information flows) have implications for market stability and international diversification (Eun and Shim, 1989; Chowdhury, 1994). The current study revisits the interrelationship between the US stock market and the national stock markets of each of the four East Asian economies (Hong Kong, Singapore, Korea (Rep. of), Taiwan) by investigating dynamic causal linkages between those markets using the concept of Granger causality. In this paper, wavelet decomposition is employed as an empirical methodology to help consider time-scale issues in studying the Granger causality of those national stock markets. In so doing, this paper lends itself to an understanding of the time-varying relationship of the two given variables, an issue which has not been addressed thoroughly in previous empirical studies.

The documented research on benefits of international diversification increased interest in the emerging markets among international investors along with the world capital market becoming increasingly international and with establishing greater integration since the 1980s. In addition to the benefits of portfolio diversification, the recurrence of financial crisis in the late 1990s spurred research on interaction between national stock markets; international transmission mechanism of stock prices movements and its spillover under the financial crisis were documented in numerous studies. Interdependence or contagion effects among national stock markets were investigated employing vector autoregression (VAR) analysis including Granger causality, impulse response functions and variance decompositions (Ghosh, Saldi, and Johnson, 1999; Sheng and Tu, 2000; Masih and Masih, 2001; and Dekker, Sen and Young, 2001). Contagion can be categorized into two kinds (Claessens, Dornbusch, and Park, 2001). One is based on fundamentals thus called fundamentals-based contagion (Calvo and Reinhart, 1996), which emphasizes normal interdependence among economies where a shock is spilt over to other countries through real or financial linkages. The other is the transmission mechanism that is beyond explanation based on observable factors. For example, a crisis in one country may be transmitted to other countries regardless of differences of fundamentals among the countries, which is caused by an increase in risk aversion among investors. This paper is not focused on identifying different types of contagion. However, causal linkages among national stock markets in the Granger sense are examined, whereby information transmission causing lead-and lag relationships among the national stock markets are tested.

While the above-mentioned interrelationship of equity markets focused on short-run relationships, long-run relationships are investigated as well using the notion of cointegration (Engle and Granger, 1987) with recognition of the nonstationary property of stock prices. Empirical findings of this branch of study are mixed, with some studies that have reported no cointegration (Chan, Gup, and Pan, 1992; DeFusco, Geppert, and Tseksekos, 1996) while other studies have found evidence of long run interdependence (Arshanapalli, Doukas, and Land, 1995; Masih and Masih, 1999; Chung and Liu, 1994 among others). Those studies that investigated long-run relationships have important implications to diversification potential in international stock markets by focusing on the degree to which national stock markets are integrated.

In the current paper, the Granger causality between the US stock market and those of the East Asian economies is examined at different time scales using wavelet decomposition. Wavelet analysis has become increasingly popular for analyzing economic time series due to its advantages of decomposing a time series into different time scales (Ramsey and Lampart, 1998; Almasri and Shukur, 2003 among others). In the wavelet decomposition of this paper, multiresolutionary analysis (MRA) for a discrete wavelet transform (DWT) is used to filter the data. Subsequently, Granger causality is tested using wavelet-decomposed series with a wild-bootstrapping prodecure. This method is chosen since the variance of the error terms in each studied regression are non-constant and follows an autoregressive conditional heteroscedasticity (ARCH) process or generalized autoregressive conditional heteroscedasticity (GARCH) process. The Granger-causal relationship will be investigated over different time scales to determine whether the US stock market has different impact on the East Asian stock markets during four different sub-sample periods: prior to Asian financial crisis, the Asian financial crisis that started in the year 1997, the inter-crisis period, and the financial crisis started in 2007. Finally in an attempt to gauge the extent to which the shocks from the U.S. stock market affect the East Asian economies, impulse responses are analyzed.

The four East Asian economies included in this paper were grouped as newly industrialized economies which had led the world in economic growth for about two decades by the middle of 1990s. These economies are categorized as among the emerging economies, albeit the list of the economies vary for different lists,[1] among which only these four economies are of interest in this paper since they are relatively at comparable levels in terms of macroeconomic indicators and financial competitiveness. Additionally, among the major stock markets in the world,[2] the effects of the US stock market on the individual East Asian economies is a matter of interest in this paper following the documented results on the leading role of the US market in the international stock market (Eun and Shim, 1989; Mashi and Mashi, 2001; Bessler and Yang, 2003).

The paper is organized as follows. In the next section data used in this study is described along with overview of each stock exchange included in this paper. In section 3 the econometric models used in this paper including theoretical foundations of wavelet filtering is explained, then in section 4 the results from the Granger causality tests and impulse responses are presented. Finally, in section 5 the conclusions drawn are summarized.

2. Data description and preliminaries

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[1] The MSCI list includes only Korea and Taiwan in the emerging market list while The Economist includes all the four east Asian economies – Hong Kong, Singapore, Korea and Taiwan in the emerging market list. FTSE list and the Dow-Jones list include neither of the four east Asian economies.

[2] In terms of market capitalization as of June 2010, The United States (New York stock exchange), Japan (Tokyo stock exchange), The United Kingdom (London stock exchange), Europe (Euronext), Hong Kong (Hong Kong stock exchange), Mainland China (Shanghai stock exchange), Canada (Toronto stock exchange), India (National stock exchange India), Germany (Deutsche Börse) and Spain (BME Spanish exchanges) are ten major markets (Source: World Federation of Exchanges, Year-to-monthly statistics, http://www.world-exchanges.org/statistics/ytd-monthly (4 August 2010).

The data, obtained from *Datastream*, are daily closing stock market indices for the sample period for the period September 23, 1994 to June 4, 2010.[3] The stock market indices are the Hong Kong Hang Seng index, Korea composite index (KOPSI), the Singapore Straight Times index, the Taiwan weighted index, and the S&P 500. All of these stock market indices are market-value weighted. All stock indices are expressed in both local currency and in U.S. dollar terms. Figure 1 provides time series plots of the each East Asian stock market index and the US stock market index over the sample period. Each of the five stock market indices is rebased to the index of the first day of the sample period, 23 September, 1994, for better comparability of different indices with different scales.

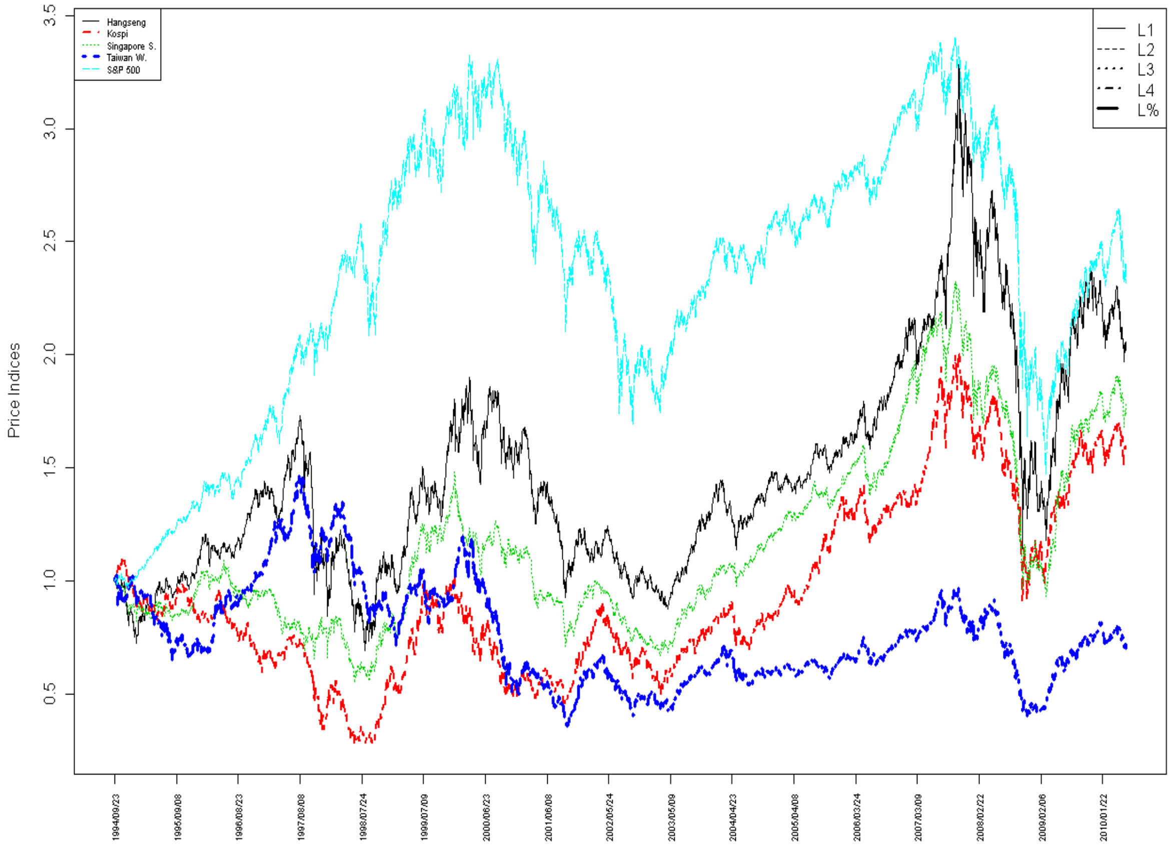

Figure 1. Daily closing stock market indices of the five economies (Hong Kong (Hang Seng), Korea (KOSPI), Singapore (The Singapore Straight), Taiwan (The Taiwan weighted), and the U.S. (S&P500). Indices are rebased on the starting day of the sample period.

The sample period is divided into four sub-periods: 1) before the Asian financial crisis (September 1994 - June 1997); 2) the Asian financial crisis (July 1997 - June 2000); 3) the inter-crisis period (July 2000 – June 2007); 4) the financial crisis (July 2007 – June 2009). The categorization into these sub-periods is to investigate if the impact of the US stock market on each of the East Asian stock markets varies between crisis and non-crisis periods. Particular attention will be made to the period of the global financial crisis started in 2007. Previous studies

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[3] The available data series range back to October 17th, 1989. However, the sample period could not cover the early five years from the available data set due to the methodology, discrete wavelet transform (DWT), used in this paper. Details of the methodology follow in the next section.

used first differences of the stock prices or log differences of the stock prices in keeping with the rationale provided by Fama (1965) to better model the random walk process. This study utilizes the level of the price indices with wavelet decomposition (further explanations follow in the next section) which transforms nonstationary series into stationary series. This allows avoidance of information loss that first-differencing entails.

Before moving on to the wavelet analysis, the unit-root tests (Augmented Dickey-Fuller test, ADF) with and without trends were performed for the daily closing stock market indices. The null hypothesis of a unit root was not rejected in all the cases. Due to the limiting assumption of the ADF test of involving the errors which are statistically independent with a constant variance, the Phillips and Perron (1988) test was also applied. The null hypothesis of a unit root was not rejected in all the cases either with Phillips-Perron test. After the tests for unit roots were done, it was proceeded to test for cointegration. The Engle-Granger and Phillips-Ouliaris tests for cointegration were employed, both of which did not reject, in almost all the cases, the null hypothesis of no cointegration of the each of the East Asian stock market price index and the S&P500.

As a second preliminary to the empirical study, it seems very useful to look into a brief summary of each national stock market (Table 1). Based on the market capitalization, the stock market of Hong Kong is the biggest among the stock markets of the four East Asian economies which is in turn followed by Korea, Taiwan and Singapore. Among the four East Asian economies, Hong Kong and Singapore have been the most open markets in Asia compared to the other two economies, Korea and Taiwan. The latter two economies, however, have taken deregulation measures and liberalized capital transaction procedures substantially since the 1990s. [4] Overall, the four East Asian economies have been through technological and organization reforms with expectations to encourage international participation. One thing to note is the different time zones in which each of the national stock markets of the East Asian economies and U.S. stock market (New York Stock Exchange, NYSE) are open. When NYSE is open, none of the stock markets of the East Asian economies are open, and when any of the stock markets of the East Asian economies is open, NYSE is not open. Non-overlapping trading hours between the stock markets of the East Asian economies and the NYSE does not pose a problem in the current paper for two reasons: 1) the main interest of paper is testing Granger causality of the US stock market to the East Asian national stock markets, not the contemporaneous correlation; 2) the methodology used in this paper, wavelet decomposition, is based on changes in weighted averages of the original observations.

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[4] In 1991, the Taiwanese government permitted Qualified Foreign Institutional Investor (QFII) to directly invest in Taiwan's stock market. General foreign juristic persons and natural persons were permitted for investment since the year 1996 with investment quotas (3 billion US dollars as the ceiling for QFII and 50 million US dollars for general foreign juristic persons). This rule on investment quotas for offshore institutional investors was removed in July 2003. Recently, changes in the review process (from the 'permit' system to the 'registration' system) for investment by overseas Chinese and foreign investors in domestic stocks consequently simplified the application procedures for the commencement of foreign investment in Taiwan's stock market. As for Korean stock market, investment in Korean securities by non-residents had been regulated by the foreign exchange transaction law. As of April 1, 1999, the law was abolished and capital transactions have been more liberalized.

Table 1. National stock market characteristics

	Hong Kong	Singapore	Korea	Taiwan	U.S. (New York Stock Exchange)
Market Capitalization ($ bil.)[a]	2,199	507	836	588	11,793
Value of share trading ($ bil.) [a]	697	133	779	403	9496
Number of listed firms[a]	1,344	775	1,768	759	2,321
Trading system[b]	Automatic order matching and execution system	OM[c]	Fully automated system (Periodic call auction)	A fully automated securities trading (FAST) system (call auction)	Floor Trading (Super Dot order routing and reporting system) Auction Market with specialists
Regulations for foreigners	None	None	Restrictions on emergent circumstances	Registration-based system for QFIT[e]	
Time zone[d]	GMT+7	GMT+7	GMT+8	GMT+7	GMT-4

[a]Source: World Federation of Exchanges (as of Jun, 2010).

[b]Information from each of the website of stock exchange: <http:www.hkex.com.hk>; <http:www.krx.co.kr>; <http:www.twse.com.tw>

[c]Orders to buy or sell are directed immediately to the screen-based trade matching system. If there is another order that matches the asking or selling prices, the trade will be executed immediately

[d] GMT(0) is Greenwich time

[e]Qualified foreign institutional investor (QFII) to directly invest in the stock market

3. The econometric models

3.1. Wavelet analysis[5]

Wavelets are mathematical tools that can localize data both in time and the frequency domain. With the theoretical foundation completed in the 1980s (Grossmann and Morlet 1984; Mallat 1989) , successful applications were made to economic research including frequency domain analysis, the study of long-memory process, and timescale decompositions. The wavelet

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[5] The presentation follows in large part the presentations in Gencay, Selcuk and Whitcher (2002) and Percival and Walden (2006).

decomposition for studying Granger causality between economic variables employed in this paper is decomposing a time series into several layers of orthogonal sequence at different scales. This method was used by Ramsey and Lampart (1998) where the causality relationship between output and money were examined at different timescales. Following Ramsey and Lampart (1998), three major properties of the wavelet analysis are the interests in this paper: handling nonstationary data; localization in time; and the resolution of the data at different timescales. This section is meant to introduce wavelets in an informal and non-technical manner.

The wavelet decomposition of a series of observations using wavelet transform provides a multi-scale analysis and bears a resemblance to the activity of a camera-lens. Zooming out the lens brings a broad landscape, while zooming in the lens allows you to find details which were not observable in the landscape portrait. In mathematical terms, "wavelets are local orthonormal bases consisting of small waves that dissect a function into layers of different scale" (Schleicher, 2002, p.1). This dissection of time series into different layers makes wavelet analysis a very useful tool in economics because most economic time series consist of different layers due to economic agents making decisions with different time horizons. For instance, in the stock market there are intraday traders, day traders, and long-term traders. It is the aggregation of the activities of all traders with different time horizons that generates movements of the stock market indices. By using wavelet analysis one can decompose the time-series (i.e. national stock market indices) into the different layers and thus zoom in on the activity of the traders at different time scales One can also zoom out and obtain the broad landscapes which correspond to longer-term trends of the time series.

More specifically, the method used in this paper is multiresolution analysis (MRA) using a discrete wavelet transform (DWT) based on a mother wavelet called least asymmetric class of wavelets with length 8 (in short LA(8)) developed by Daubechies (1992). Wavelet transformation is basically projection the function of interest onto a particular basis (wavelet) function, $\psi(t)$, by translating and dilating the basis function. A dilation of the function means that the basis function expands its range by s, $\psi(t/s)$, while a translation of the wavelet function denotes that the basis function changes its range by u units, $\psi(t-u)$. Through this wavelet transform, wavelet coefficients are obtained. If the minimum number of wavelet coefficients are selected, it is called a critical sampling with a discrete translation ($s=2^j$) and a discrete dilation ($u=k2^j$), where j and k are integers. All the information in the original function is not lost with the discrete choice of the wavelet coefficient, this is why it is called a discrete wavelet transform (DWT).[6] The DWT can be performed by using different wavelet functions such as the Haar wavelet, Daubechie family, the Least Asymmetric (LA) family, and the Mexican Hat (Percival and Walden, 2006). The Haar wavelet produces a simple difference between two adjacent observations (for this reason Haar filter has a length 2), which is repeated with the averages growing in length before being differenced. Although being easy to visualize and implement, Haar wavelet filter is not proper to apply to the real-world applications due to its characteristic of

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[6] The subsampling of the wavelet coefficient of DWT is decomposing a time series into orthogonal sequences of scales. An alternative wavelet transform is the maximum overlap discrete wavelet transform (MODWT) which gives up the orthogonality feature of DWT.

approximating ideal-band filter very poorly.[7] The level of approximation, however, improves as the length of the filter increases. The LA(8) filter is a much better approximation to an ideal band-pass filter (Gensay, Selcuk and Whitcher, 2002).

A quick way to calculate the wavelet coefficients is through a methodology introduced by Mallat (1989) referred to as multiresolution analysis (MRA), which also conveniently provides a rather intuitive interpretation of the wavelet decomposition. Briefly, it is simply a matter of finding (weighted) averages and differences from those averages, starting with values in the series closest to each other–the lowest scale–and repeating that process with the previous average series, gradually expanding how much of the original data is included in each successive average, i.e. increasing the scale.

Let $\mathbf{X}$ be a column vector containing T observations of a time series where T is an integer multiple of 2^J where J is a positive number. The discrete wavelet transform (DWT) of level J transforms the original series, generating vectors of wavelet coefficients as

$$\boldsymbol{\omega} = (\boldsymbol{\omega}_1, \boldsymbol{\omega}_2, _{\ldots,} \boldsymbol{\omega}_J, \mathbf{S}_J)' = \mathbf{WX} \tag{1}$$

where $\mathbf{W}$ is an orthonormal $T \times T$ matrix, i.e. $\mathbf{W}^{-1} = \mathbf{W}'$ and $\mathbf{W}'\mathbf{W} = \mathbf{WW}' = \mathbf{I}_T$. $\boldsymbol{\omega}_j = \{\omega_{j,u}\}$, $j = 1, 2, \cdots, J$ are $T/2^j \times 1$ vectors of wavelet coefficients at scale j and location u. Since $\mathbf{S}_J$ is a vector of scaling coefficients of $T/2^J \times 1$, T-$T/2^J$ elements of $\boldsymbol{\omega}$ are wavelet coefficients and last $T/2^J$ elements are scaling coefficients. The matrix $\mathbf{W}$ being orthogonal, it can be used to reconstruct the original time series $\mathbf{X}$ by using

$$\mathbf{X} = \mathbf{W}'\boldsymbol{\omega} \tag{2}$$

The columns of $\mathbf{W}'$ can be partitioned in the same way as $\boldsymbol{\omega}$ in (1) to obtain

$$\mathbf{W}' = [\, \mathbf{W}_1, \mathbf{W}_2, \ldots, \mathbf{W}_J, \mathbf{v}_J \,]$$

where $\mathbf{W}_j$ is a $T \times T/2^j$ matrix and $\mathbf{v}_J$ is a $T \times T/2^J$ matrix. Since the multiresolution (MRA) analysis is an additive decomposition of a series $\mathbf{X}$, $\mathbf{W}'\boldsymbol{\omega}$ is expressed as a sum of orthogonal sequence of series which is related to changes in the observation at a certain scale such that

$$\mathbf{X} = \mathbf{W}'\boldsymbol{\omega} = \sum_{j=1}^{J} \mathbf{W}_j\boldsymbol{\omega}_j + \mathbf{v}_J\mathbf{S}_J = \sum_{j=1}^{J} \mathbf{d}_j + \mathbf{s}_J \tag{3}$$

At every scale level j, the MRA for DWT produces: 1) a series of the weighted averages at that scale, referred to as that level's *smooth series*, $\mathbf{s}_J$, in which the averages are over values in the next-lower scale level's smooth series; and 2) a series of the weighted differences of the smooth series at the next-lower level from the current-level's smooth series, referred to as the *detail series*, $\mathbf{d}_j$, for scale level j. The zero-level smooth series is the original data series, since at the zero-level there is no smoothing of the data. As can be seen from (3), the original series can be obtained by summing up the level-1 to level-J detail series, where J is the highest considered scale level, and

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[7] An ideal band-pass filter of a time series is one that removes the frequency components which lie within a certain range. An ideal band-pass filter thus has a well-defined cut-off range. Further technical explanations are found in Gensay, Selcuk and Whitcher, 2002.

adding the result to the level-*J* smooth series. The variable's long-term trend at the scale level of *J* is given by s_J, which contains the non-stationary components of the original series if any exist. The original series' decomposition at various time scales is given by the detail series d_1 to d_J. MRA for DWT allows the wavelet basis function being used to represent the information contained in the time series of interest (Gensay, Selcuk and Whitcher, 2002).

In Figure 2 the raw data and the wavelet filtered data of the S&P 500 are shown, broken out into five different scale levels.[8] In our empirical presentation here and later, the convention of the software is followed, and have the level of a detail appended *d* not subscripted and removed the italics on *d*, e.g. $\mathrm{d}2 \equiv d_2$. Due to the construction of the scale levels, d1 is associated with a scale of one-period movement (changes can occur between consecutive periods), d2 with a scale of two-period movement (changes occurring every two periods), d3 with a scale of four-period movement, d4 with a scale of an eight-period movement, and d5 with a scale of a sixteen-period movement. The *wavelet scale* refers to these scales of the movement. For each variable, the variation of the detail series at each time scale tend to differ. Time series plots of the wavelet filtered data in Figure 2 shows that at the longer time scales the oscillations of the time series are longer; as the time scale increases the time between consecutive peaks and between consecutive troughs gets longer.

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[8] Since it would take too much space to present all time series only one is presented. Graphs over all wavelet filtered time series are, however, available from the authors upon request.

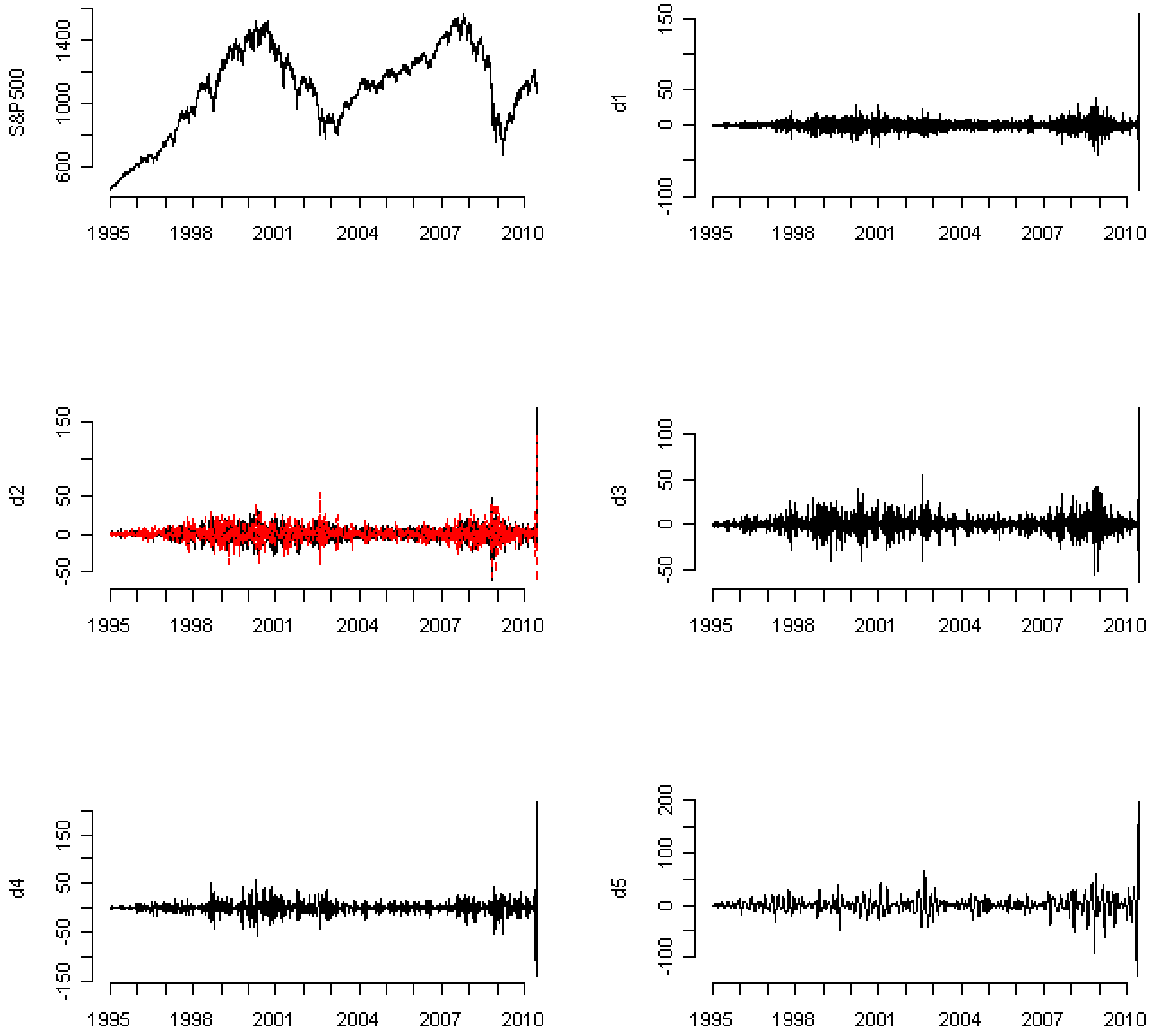

Figure 2. Time series plots of the S&P500 series and their different time scales.

3.2. Granger causality

For each country pair (one of the East Asian economies and the U.S.) Granger causality at each wavelet scale is tested by using wavelet details for the price indices of the national stock markets. Letting

$$y_t \equiv \begin{bmatrix} d_t^A \\ d_t^{US} \end{bmatrix}$$

where superscripts, *A* and *US*, represent the East Asian economies and the U.S, the subscript t being the time values. The vector autoregressive model of order *K*, VAR(*K*), is estimated as shown below:

$$\begin{bmatrix} d_t^{A} \\ d_t^{US} \end{bmatrix} = \begin{bmatrix} \beta_{01} \\ \beta_{02} \end{bmatrix} + \begin{bmatrix} \beta_{11}^{(1)} & \beta_{12}^{(1)} \\ \beta_{21}^{(1)} & \beta_{22}^{(1)} \end{bmatrix} \begin{bmatrix} d_{t-1}^{A} \\ d_{t-1}^{US} \end{bmatrix} + \begin{bmatrix} \beta_{11}^{(2)} & \beta_{12}^{(2)} \\ \beta_{21}^{(2)} & \beta_{22}^{(2)} \end{bmatrix} \begin{bmatrix} d_{t-2}^{A} \\ d_{t-2}^{US} \end{bmatrix} + \cdots + \begin{bmatrix} \beta_{11}^{(K)} & \beta_{12}^{(K)} \\ \beta_{21}^{(K)} & \beta_{22}^{(K)} \end{bmatrix} \begin{bmatrix} d_{t-K}^{A} \\ d_{t-K}^{US} \end{bmatrix} + \begin{bmatrix} u_{1t} \\ u_{2t} \end{bmatrix}$$

where the various β parameters are constants and $[u_{1t}\ u_{2t}]'$ is the error vector at time *t*. The number of lags of the regression models, *K*, is decided by using the Schwarz (1978) information criteria (SIC), the Hannan & Quinn (1979) criteria (HQ) and Akaike (1971) information criteria (AIC), along with testing for autocorrelation using the Rao F-test developed by Edgerton & Shukur (1999). In the first step the order of the VAR process is determined by using SIC, and by testing for autocorrelation. If any significant autocorrelation is detected, the lag suggested by HQ is used and autocorrelation is tested for again. If any significant autocorrelation is remaining when HQ is used the AIC criteria is used. Further diagnostic checking with the VAR model is performed. To check for GARCH effects and non-normality the Breusch-Godfrey LM-test for GARCH effects and the Jarque-Bera (1987) test for non-normality are used. The test results indicate GARCH effects and non-normality in almost every case.

According to Granger & Newbold (1986) one can test for Granger causality by evaluating a zero restriction in each of the single linear equations in the VAR model using ordinary least squares (OLS) at different time scales, *j*:

$$d_{j,t}^{A} = \beta_{01} + \sum_{k=1}^{K} \beta_{11}^{(k)} d_{1,t-k}^{A} + \sum_{k=1}^{K} \beta_{12}^{(k)} d_{1,t-k}^{US} + u_{j,t} \tag{4}$$

$$d_{j,t}^{US} = \beta_{02} + \sum_{k=1}^{K} \beta_{21}^{(k)} d_{2,t-k}^{A} + \sum_{k=1}^{K} \beta_{22}^{(k)} d_{2,t-k}^{US} + u_{j,t} \tag{5}$$

The interest of the current paper in testing for Granger causality is whether the U.S. stock market Granger causes the East Asian national stock market; the hypothesis that all of the $\beta_{12}^{(k)}$ parameters are zero can be statistically rejected.

Since GARCH process were found in the diagnostic checking, the wild bootstrapping is used for testing parameter restrictions of regression models with heteroskedastic disturbances.[9] Following Herwarts and Neumann (2005) and Hafner and Herwartz (2009), the bootstrapped time series for testing Granger causality are found according to the equations below:

$$d_{j,t}^{A*} = \hat{\beta}_{01} + \sum_{k=1}^{K} \hat{\beta}_{11}^{(k)} d_{t-k}^{A} + \sum_{k=1}^{K} \hat{\beta}_{12}^{(k)} d_{t-k}^{US} + \varepsilon_{j,t}^{*} \tag{6}$$

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[9] The bootstrap resamples from original data by randomly sampling *n* times, with replacement for doing statistical analysis without making assumptions on the distribution function. This method can be accurately done if the resampling process is following as closely as possible the true data generating process that generated the original (observed) data under the assumption that the null hypothesis is satisfied. It is however challenging to make the boostrap work well if the models have heteroskedastic errors of an unknown form. In order to handle the heteroskedasticity in regression models, the wild bootstrap was proposed by Wu (1986) and then developed by Liu (1988).

$$d_{j,t}^{US*} = \hat{\beta}_{02} + \sum_{k=1}^{K} \hat{\beta}_{21}^{(k)} d_{t-k}^{A} + \sum_{k=1}^{K} \hat{\beta}_{22}^{(k)} d_{t-k}^{US} + \varepsilon_{j,t}^{*} \qquad (7)$$

where $\varepsilon_{j,t}^{*} = \hat{u}_{j,t}\eta_{j,t}$, with $\hat{u}_{j,t}$ being residuals from the associated equations for (4) or (5), and $\eta_{j,t}$ are a sequence random variables with zero mean and unit variance being also independent of the variables occurring in the equations (4) and (5). From the bootstrapped time series the bootstrapped test statistic is calculated (F^{*}). By repeating this 10,000 times and each time calculating F^{*} the bootstrap distribution is found and the α -level critical value can be found from that distribution.[10]

4. Empirical findings

4.1. VAR estimation results

Table 2 contains results for testing the two hypotheses: the US stock market does not Granger cause each of the East Asian stock market (panel A of table 2); each of the East Asian stock market does not Granger cause the US stock market (panel B of table 2).[11] Looking at the very finest time scale, d1, during the first sub-period (before the financial crisis in 1997), none of the national stock markets of the East Asian economies responded to the US market. As for the Asian financial crisis period, the evidence shows that it Hong Kong which was Granger-caused by the US market (in panel A) and that Hong Kong Granger caused the U.S. stock market (in panel B). This feedback relationship is detected only for the national stock market of Hong Kong. These results of the two sample periods are associated with two features: 1) national stock market characteristics; and 2) the nature of the Asian financial crisis in the year 1997. Firstly, the national stock markets of the two economies, Taiwan and Korea, had been less liberalized in capital transaction, thus less integrated with the international financial markets in the 1990s. Additionally, a notable characteristic of the Taiwanese stock market is that it is very sensitive to the regional political environment, which was favorable during this time period, and Taiwan's stock market saw steady appreciation from the year 1994 to July 1997 (Ammermann, 1999). Secondly, the Asian financial crisis in the year 1997 hit hard those economies which had been growing rapidly. The crisis which was dubbed as 'crisis of success' was mainly caused by a sudden withdrawal of the foreign capital which flowed in by a substantial amount through international lending which flowed into those fast-growing economies during the period of their

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[10] As was explained above, Granger causality is tested for each country, which might bring about the issue of choosing a correct significance level in testing and making multiple comparisons. Although there are correction methods to address the issue, it was not employed in this study for the two reasons: 1) the data series used for testing Granger causality are filtered data through wavelet decomposition and that wildboostrapping was used to construct critical values; 2) the method of correcting significance value has a problem of reducing substantially a statistical power (Holm, 1979; Rice, 1989). Two kinds of methods for correcting significance level, Bonferroni procedure, were employed. The standard Bonferroni procedure divides α with k where k is the number of statistical tests conducted using the given data series. The other is the sequential Bonferroni procedure..

[11] Tests were performed both in local currencies and US dollar terms by using different wavelet basis functions such as Haar, Daubechies(4), Daubechies(6), Daubechies(8) and LA(8). Test results show, in general, qualitatively similar results with an exception of the Haar function which is a poor approximation to an ideal band-pass filter (Gensay, Selcuk and Wither, 2002).

economic boom (Radelet and Sachs, 2000). From the test result of table 2, it is shown that the US market did not Granger cause the Korean stock market during the Asian financial crisis period. This is due to the fact that the stock market plummet of Korea, one the economy which was hit hard during the financial crisis period, was caused by the withdrawal of the foreign capital, the nominal and real exchange rate depreciation, and the soaring interest rate rather than external shocks from major stock markets. As for Taiwan, stringent restrictions against foreign capital flows were kept in place during this time period with a relatively less pressure to open its financial market. This economy, thus, was not hit as hard as Korea by the financial crisis (Radelet and Sachs, 2000). Consequently, the national stock market in Taiwan was not Granger caused by the US market.[12] National stock market of Hong Kong is the only one which has a feedback relationship with the U.S. stock market among the east Asian stock markets included in this study.

The evidence during the inter-crisis period, however, indicates that the US stock market strongly Granger causes most the East Asia stock markets (with an exception of the Taiwan's stock market). Most of the East Asian economies also responded to the U.S. stock market during financial crisis period since July 2007 (still with an exception of the Taiwan's stock market). The lead-lag relationship between the individual East Asian national stock markets and the U.S. stock market, i.e. short-run (1-day to 2-day) causal linkages, from July 2000 to June 2007 is as strong as during the financial crisis period since July 2007. The causal linkages are also even stronger in the inter-crisis period than those during the Asian financial crisis period. These results are consistent with the findings of Cheng, Cheung and Ng (2007), although another previous study reported that short-run causal linkages among these markets have been strengthened during the Asian financial crisis (Yang, Kolari, and Min, 2003). In the next finest time scale, d2, the results overall show that the movement of the US stock market has an effect on the East Asian markets (slightly less compared to the finest time scale, d1). In both sub-sample periods of the inter-crisis periods and financial periods started in the year 2007, the Granger causality starts to be subtantailly less apparent from the time scale 3. At the most coarse time scale, d5, there was no Granger causality found in any of the sub-sample period. It suggests that the speed of transmission channels which Granger-cause the East Asian economies is fast and in most part finished within 24-48 hours, although it takes three-to-four days to complete the whole process. This finding was also noted by Jeon and Jang (2004), however, the finding was country- and industry-specific results. The current study extends the finding as a general phenomena in the four East Asian stock markets.

The statistically significant casual relations, in a Granger sense, from the East Asian national stock markets to the U.S. stock market, are not found as dominant as the Granger causality of the U.S. stock market to the each of the East Asian national stock market. With a couple of exceptions, the movements of the East Asian national stock markets in the past do not exercise much influence on the current U.S. stock market movements.

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[12] Financial crisis is the period during when national stock markets react to the information to an extreme degree, where contagion effects lead to a shock being transmitted to other economies (King and Wadhwani, 1990). The lead-lag relationship of the major stock market is, however, showing mixed results in the previous studies. Malliaris and Urrutia (1992), for example, found no lead–lag relationship among the major national stock indexes during the October 1987 crash period, while Cheng et al. (2007) asserts that the US market leads the four East Asian markets not only during the Asian financial crisis but also before and after the crisis.

Table 2. Estimated results (p-values in parenthesis)

Time scale	Stock market	Before crisis in 1997 (Sep.23, 1994-Jun.30,1997)	Financial crisis, 1997 (Jul, 1997-Jun.30,2000)	Inter-crisis period (Jul.30,2000-Jun.29,2007)	Financial crisis, 2007 (Jul.2, 2007-Jun16,2009)
A. The US stock market Granger-causes the national stock markets of the East Asian economies					
d1	HK	S&P500→Hang Seng (0.0641)	S&P500→Hang Seng* (0.0285)	S&P500→Hang Seng* (0.0262)	S&P500→Hang Seng* (0.0391)
	KR	S&P500↛Kospi (0.1236)	S&P500↛Kospi (0342)	S&P500→Kospi** (2.2e-16)	S&P500→Kospi* (0.0368)
	SG	S&P500↛Singapore S. (0.1709)	S&P500↛Singapore S. (0.138)	S&P500→Singapore S.* (0.0134)	S&P500→Singapore S.* (0.04267)
	TW	S&P500↛Taiwan W. (0.5436)	S&P500↛Taiwan W. (0.8031)	S&P500↛Taiwan W. (0.2422)	S&P500↛Taiwan W. (0.0761)
d2	HK	S&P500→Hang Seng* (0.0292)	S&P500↛Hang Seng (0.5076)	S&P500→Hang Seng* (0.0198)	S&P500→Hang Seng* (0.016)
	KR	S&P500→Kospi* (0.0267)	S&P500↛Kospi (0.1757)	S&P500↛Kospi (0.8196)	S&P500→Kospi* (0.0447)
	SG	S&P500↛Singapore S. (0.7496)	S&P500↛Singapore S. (0.351)	S&P500↛Singapore S. (0.2402)	S&P500↛Singapore S. (0.0985)
	TW	S&P500↛Taiwan W. (0.5545)	S&P500↛Taiwan W. (0.3884)	S&P500→Taiwan W.** (0.0014)	S&P500→Taiwan W.* (0.0415)
d3	HK	S&P500↛Hang Seng (06994)	S&P500↛Hang Seng (0.1316)	S&P500→Hang Seng** (8e-04)	S&P500↛Hang Seng (0.8725)
	KR	S&P500↛Kospi (0.2703)	S&P500↛Kospi (0.7786)	S&P500→Kospi** (9e-04)	S&P500↛Kospi (0.6191)
	SG	S&P500↛Singapore S. (0.3255)	S&P500→Singapore S.* (0.0285)	S&P500↛Singapore S. (0.8924)	S&P500↛SingaporeS. (0.6718)
	TW	S&P500→Taiwan W. (0.074)	S&P500→Taiwan W.* (0.0441)	S&P500↛Taiwan W. (0.1236)	S&P500→Taiwan W. (0.0326)
d4	HK	S&P500↛Hang Seng (0.1966)	S&P500→Hang Seng** (0.0088)	S&P500↛Hang Seng (0.8685)	S&P500↛Hang Seng (0.8242)
	KR	S&P500↛Kospi (0.5882)	S&P500↛Kospi (0.2281)	S&P500→Kospi* (0.0361)	S&P500↛Kospi (0.9558)
	SG	S&P500↛Singapore S. (0.826)	S&P500↛Singapore S. (0.8293)	S&P500↛Singapore S. (08711)	S&P500↛SingaporeS. (0.9954)
	TW	S&P500↛Taiwan W. (0.2492)	S&P500↛Taiwan W. (0.5399)	S&P500↛Taiwan W. (0.9944)	S&P500↛Taiwan W. (0.3627)
d5	HK	S&P500↛Hang Seng (0.9105)	S&P500↛Hang Seng (0.9999)	S&P500↛Hang Seng (0.6406)	S&P500↛Hang Seng (0.7064)
	KR	S&P500↛Kospi (0.9753)	S&P500↛Kospi (0.2232)	S&P500↛Kospi (0.9935)	S&P500↛Kospi (0.3449)
	SG	S&P500↛Singapore S. (0.9436)	S&P500↛Singapore S. (0.4098)	S&P500↛Singapore S. (0.7396)	S&P500↛Singapore S. (0.4124)
	TW	S&P500↛Taiwan W. (0.999)	S&P500↛Taiwan W. (0.9896)	S&P500↛Taiwan W. (0.9845)	S&P500↛Taiwan W. (0.36)
B. Each of the national stock markets of East Asian economies Granger-causes the US stock market					
d1	HK	Hang Seng↛S&P500 (0.4255)	Hang Seng→S&P500* (0.0322)	Hang Seng↛S&P500 (0.4983)	Hang Seng↛S&P500 (0.9989)
	KR	Kospi→S&P500* (0.0452)	Kospi↛S&P500 (0.4082)	Kospi↛S&P500 (0.3279)	Kospi↛S&P500 (0.8217)
	SG	Singapore S.↛S&P500 (0.2437)	Singapore↛S&P500 (0.2676)	Singapore S.↛S&P500 (0.6605)	SingaporeS.↛S&P500 (0.9999)
	TW	Taiwan W.↛S&P500 (0.7412)	Taiwan↛S&P500 (0.2127)	Taiwan W.↛ S&P500 (0.7763)	Taiwan W.↛ S&P500 (0.3056)

d2	HK	Hang Seng↛S&P500 (0.2936)	Hang Seng↛S&P500 (0.1042)	Hang Seng↛S&P500 (0.356)	Hang Seng→S&P500 (0.0909)
	KR	Kospi → S&P500 (0.0738)	Kospi↛S&P500 (0.1258)	Kospi→S&P500* (0.0406)	Kospi→S&P500 (0.0912)
	SG	Singapore S.↛S&P500 (0.2182)	Singapore S.→S&P500 (0.0784)	Singapore S.→S&P500 (0.0945)	Singapore S.→S&P500* (0.0498)
	TW	Taiwan W.↛ S&P500 (0.156)	Taiwan W.→S&P500 (0.0886)	Taiwan W.↛S&P500 (0.495)	Taiwan W.↛S&P500 (0.1212)
d3	HK	Hang Seng→S&P500* (0.0429)	Hang Seng↛S&P500 (0.1443)	Hang Seng→S&P500 (0.0709)	Hang Seng→S&P500 (0.072)
	KR	Kospi→S&P500* (0.0395)	Kospi ↛ S&P500 (0.7615)	Kospi ↛ S&P500 (0.2173)	Kospi ↛ S&P500 (0.4806)
	SG	Singapore↛S&P500 (0.6364)	Singapore S.↛S&P500 (0.5905)	Singapore S.↛S&P500 (0.1614)	Singapore .↛S&P500 (0.3443)
	TW	Taiwan W.→S&P500 (0.0728)	Taiwan W.↛ S&P500 (0.2724)	Taiwan W.↛ S&P500 (0.8954)	Taiwan W.↛ S&P500 (0.3131)
d4	HK	Hang Seng→S&P500** (0.0011)	Hang Seng→S&P500** (0.0033)	Hang Seng↛S&P500 (0.5653)	Hang Seng↛S&P500 (0.2694)
	KR	Kospi ↛ S&P500 (0.6592)	Kospi→S&P500* (0.0475)	Kospi ↛ S&P500 (0.986)	Kospi ↛ S&P500 (0.9989)
	SG	Singapore S.→S&P500* (0.047)	Singapore S.↛S&P500 (0.7074)	Singapore→S&P500* (0.0413)	SingaporeS.↛S&P500 (0.1295)
	TW	Taiwan W.↛ S&P500 (0.646)	Taiwan W.↛ S&P500 (0.9923)	Taiwan→ S&P500 (0.0953)	Taiwan W.↛ S&P500 (0.45)
d5	HK	Hang Seng↛S&P500 (0.0544)	Hang Seng↛S&P500 (0.988)	Hang Seng↛S&P500 (0.9947)	Hang Seng↛S&P500 (0.5423)
	KR	Kospi↛S&P500 (0.326)	Kospi↛S&P500 (0.6751)	Kospi↛S&P500 (0.9956)	Kospi↛S&P500 (0.1817)
	SG	Singapore↛S&P500 (0.433)	Singapore S.↛ S&P500 (0.5214)	Singapore S.↛ S&P500 (0.1364)	Singapore S.↛ S&P500 (0.1525)
	TW	Taiwan W.↛ S&P500 (0.5945)	Taiwan W.↛ S&P500 (0.9999)	Taiwan W.↛ S&P500 (0.9835)	Taiwan W.↛ S&P500 (0.7367)

Note: Shading in cells is to denote statistically significant results. ** and * indicate the significance level at 1% and 5% level, respectively.

4.2. Impulse responses

Impulse response function analysis was conducted to obtain additional insights into the transmitting mechanism of the stock market movements in the U.S. to the East Asian stock markets. The pattern of dynamic responses of each of the four Asian stock markets to a shock, i.e. positive residuals of one standard deviation unit in the U.S. stock market, was examined. One things to note is that a different ordering of the variables in the system may provide different results for Choleski decomposition of the innovation matrix, so the arbitrariness of the ordering can be subject to criticism. In the current study, the causal ordering of the variables is S&P 500 first and then the East Asian national stock market indices. Figures 3 and 4 provide plots of the time paths of the impulse responses for those four Asian stock markets to a U.S. stock market shock during the inter crisis period (Figure 3) and the financial crisis started in the year 2007 (Figure 4) at the finest time scale (d1). The solid lines plot the point estimates of the impulse responses of each East Asian national stock market index to a standard deviation shock of the U.S. stock market. The dotted lines are the two standard deviation bands around the points estimates.

As can be seen from figures 3 and 4, all the four East Asian national stock markets respond to the shock in a similar manner regardless of the characteristic of the sub-sample periods, i.e. whether it is non-crisis period between the year 2000 and 2007 (figure 3) or not (the financial crisis between the year 2007 and 2009, figure 4). A positive one standard deviation shock to the U.S. stock market index has a positive effect to the East Asian stock market indices after one period. After two periods, however, responses of the East Asian stock market indices take to the opposite direction, which again changes direction after three periods. The responses of the East Asian national stock indices tend to fluctuate with less magnitudes over time. Among these East Asian stock markets, the greatest impact of a shock to the U.S. stock market index is on the stock market index of Hong Kong (Hang Seng), followed by in turn the stock market indices of Korea (KOSPI), Singapore (Singapore Times Straight), and Taiwan (Taiwan Weighted). The difference between impulse responses of the East Asian stock markets in figure 3 and figure 4 is the magnitude of the responses. The responses of East Asian stock market indices to the hypothesized shock is much greater during the financial crisis period compared to the inter-crisis period.

The impulse responses of the East Asian stock markets to the shock during the same time periods as those of figure 3 and 4, but in the next finest time scale (d2), are presented in the figure 5 (inter-crisis period) and figure 6 (financial crisis, 2007).

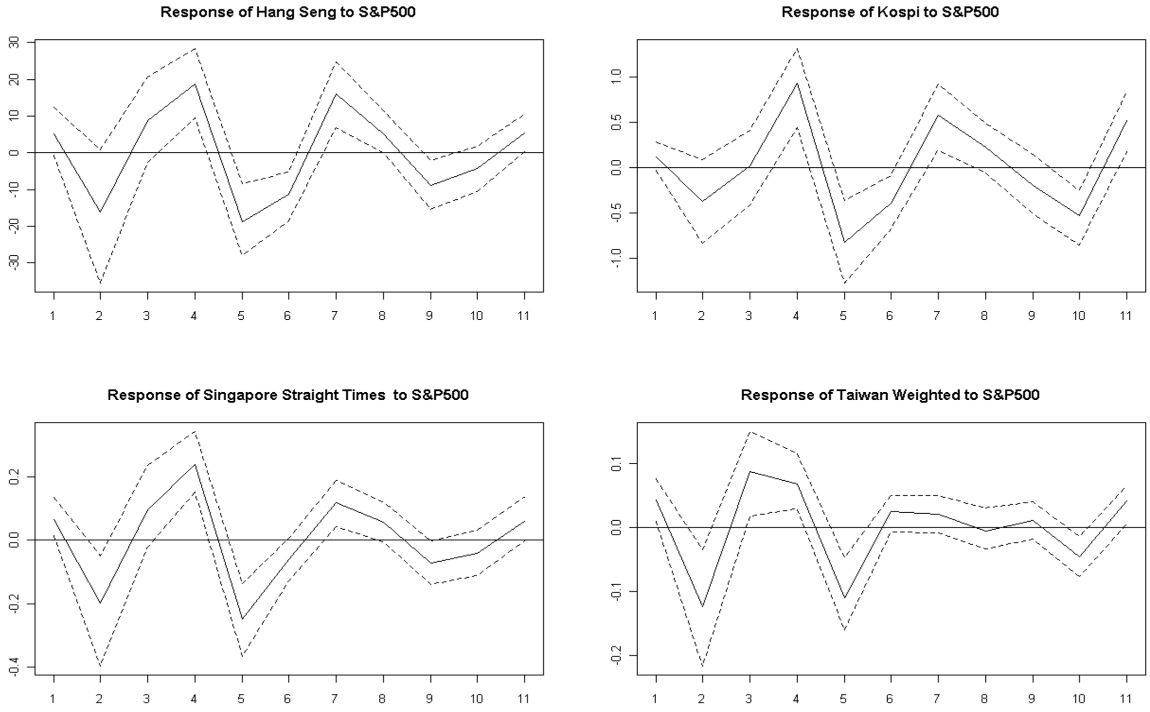

Figure 3. Impulse responses to a US shock
(3rd sub-period: the inter-crisis period at time scale 1, d1)

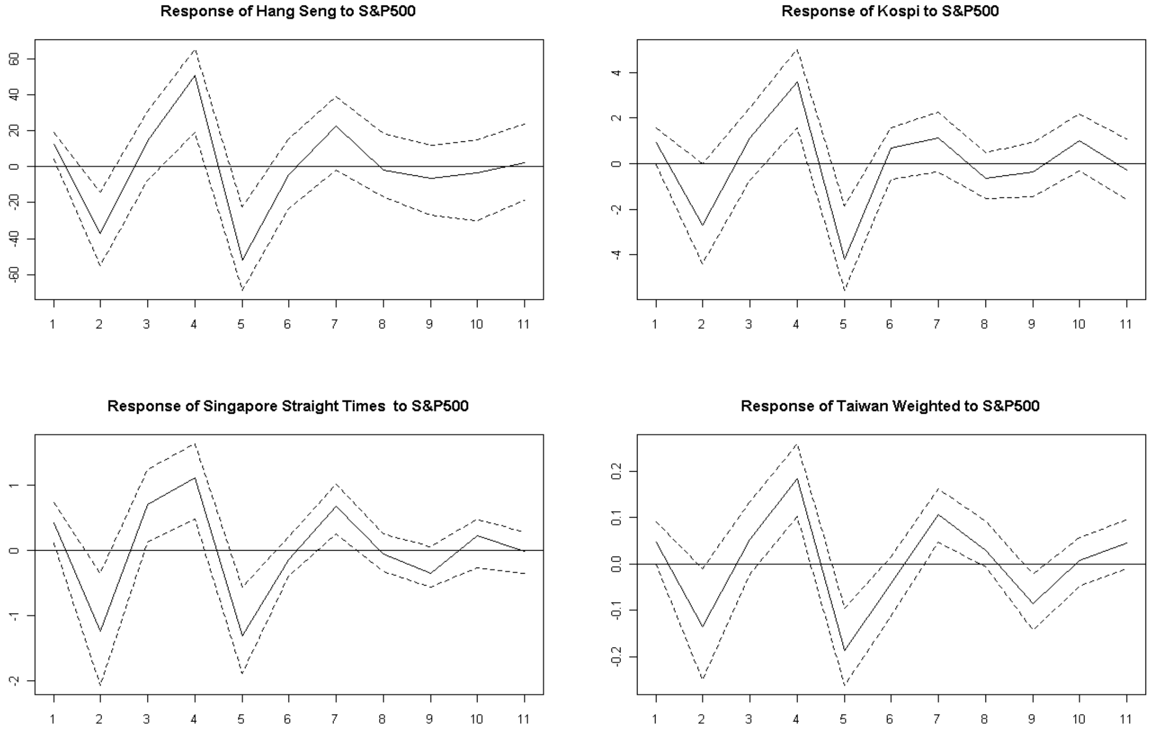

Figure 4. Impulse responses to a US shock
(4th Sub-period: the financial crisis started in the year 2007 at time scale 1,d1)

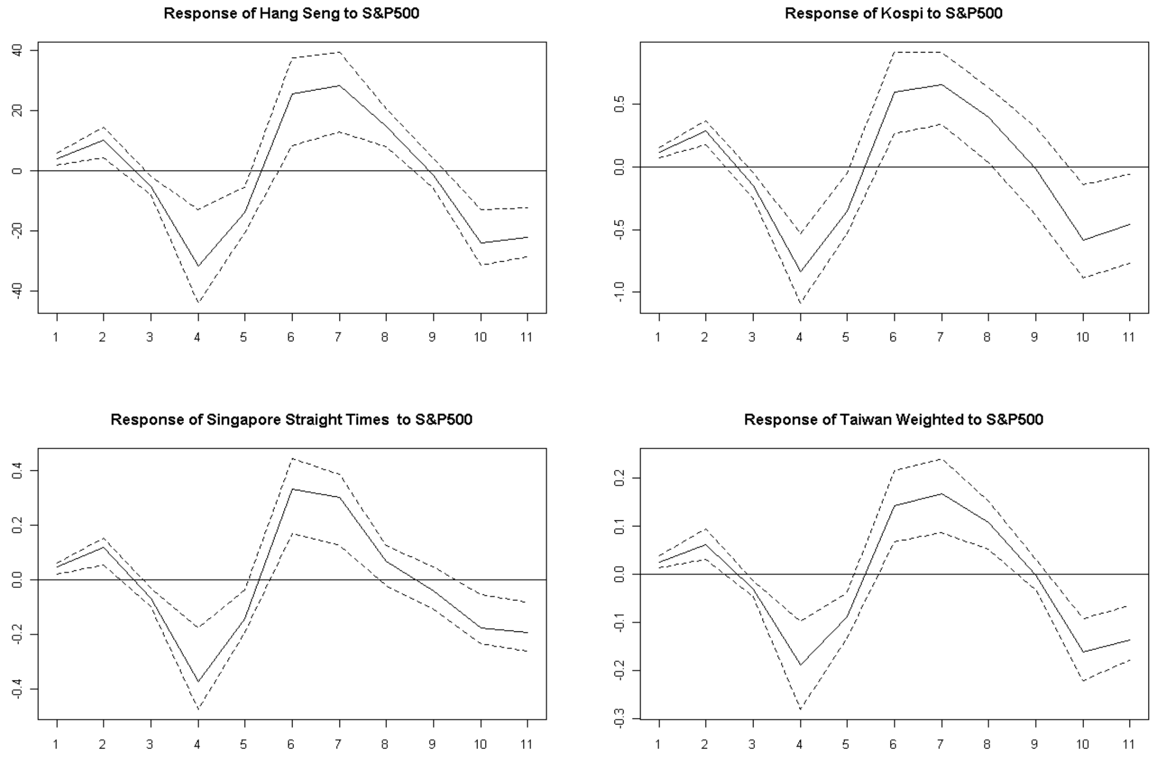

Figure 5. Impulse responses to a US shock
(3rd sub-period: the inter-crisis period at time scale 2, d2)

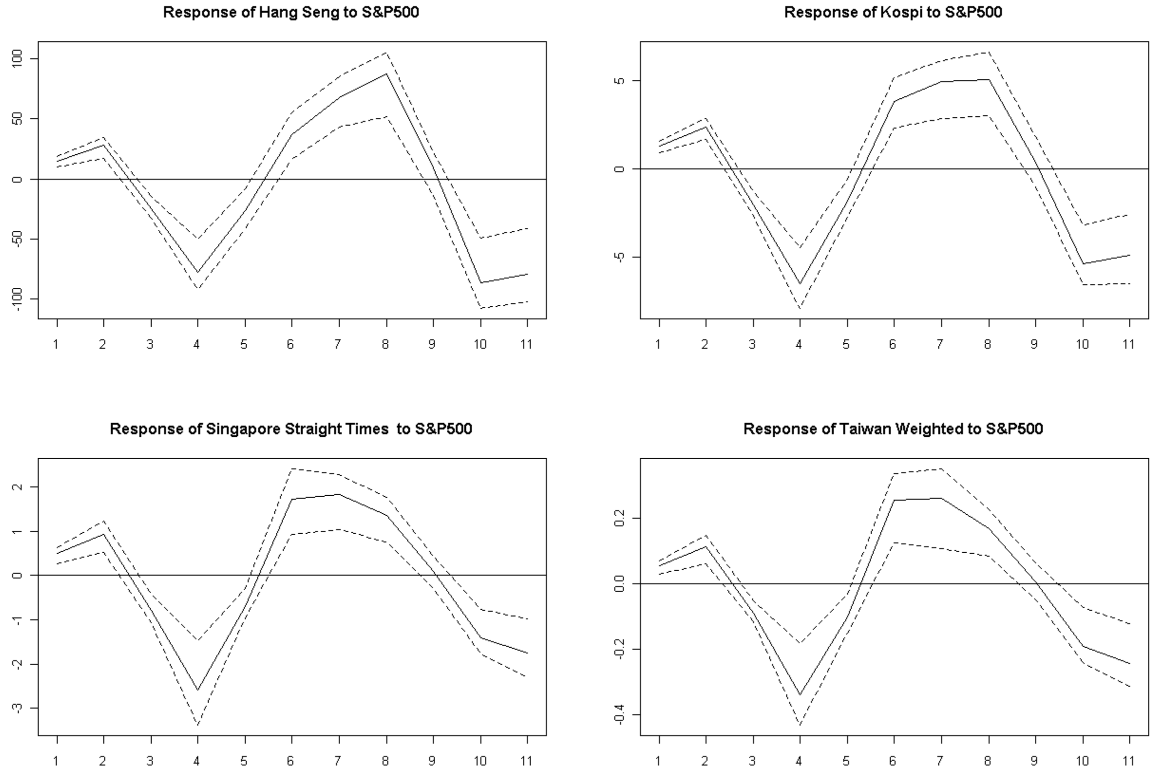

Figure 6. Impulse responses to a US shock
(4th Sub-period: the financial crisis started in the year 2007 at time scale 2, d2)

5. Summary and conclusion

The national stock markets of the East Asian economies (Hong Kong, Singapore, Korea, and Taiwan) have grown substantially over the last few decades with relaxation of control on capital movements and improved communication technology. Being more integrated with liberalization, the link of national stock markets of these economies and the most influential stock market, that of the U.S., has been extensively analyzed, especially with respect to the Asian financial crisis in the year 1997. This paper complements the existing studies by analyzing the dynamic causal relationship between the East Asian stock markets and the U.S. stock market at different time scales. The wavelet analysis which allows decomposition of time series data into different time scale was applied to the national stock market indices of the five national stock economies. The main empirical insight is that the causal relationship is strongest at finer time scales, whereas the relationship is less and less apparent at longer time horizons. However, unlike the other studies which focus on the contagion effect during the financial crisis periods, the empirical evidence of the current study indicates that the U.S. stock market Granger-causes almost all the East Asian stock markets regardless of the crisis and non-crisis period at the finest time scale. The impulse response functions show that innovations in the U.S. market are transmitted to the stock markets of the East Asian economies in a similar fashion, whereas the degree of responsiveness of those East Asian stock markets differ between inter-crisis and the financial crisis. The impulse response functions also reveal that the response of Hong Kong stock market is greater than the other East Asian stock markets. The impact of a shock to the U.S. market is greater during the financial crisis that started in the year 2007 than during the inter-crisis period (post-Asian financial crisis started in the year 1997). In general, at the finest time scale, a one standard deviation shock to the U.S. stock market index has a positive effect after one period on the East Asian stock market indices, which move in the opposite direction after two periods. After that the East Asian national stock markets fluctuate with less magnitudes over time.

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