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What econo-physics can tell us about Korean equity market co-movements?

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Abstract

Purpose – The purpose of this paper is to derive crucial insights from multi-scale analysis to detect equity return co-movements between Korean and emerging Asian markets.

Design/methodology/approach – Wavelet correlation, wavelet coherence and wavelet clustering measures are used to uncover Korean equity market interactions which are hard to see using any other modern econometric method and which would otherwise had remained hidden.

Findings – The authors observed that Korean equity market is strongly integrated with Asian equity markets at lower frequency scales and has a relatively weak correlation at higher frequencies. Further this correlation eventually grows strong in the interim of crises period at lower frequency scales. The authors, however, do not found any significant deviation in dendrograms generated in data clustering process from wavelet scale 2 to 6 which are associated with four and 64 weeks period, respectively. Overall the findings are relevant and have strong policy and practical implications.

Originality/value – The unique contribution of this paper is that it introduces wavelet clustering analysis to produce a nested hierarchy of similar markets at each frequency level for the first time in finance literature

Keywords Asian markets, Wavelet coherence, Wavelet correlation, Wavelet clustering, Dendrogram

Paper type Research paper

1. Introduction

Econophysics is seen as a quantitative approach using models and concepts derived from physics Rickles (2007, 2008), Lux (2008). It is rather a new way of modeling economic and financial systems based on the universality of statistical properties, emergence and complexity. The term "econophysics" was first introduced by Stanley *et al.* (1996) to describe the large number of papers written by physicists on problems relating to the stock market, the growth of companies and other economic questions. A comprehensive overview about this interdisciplinary field has been given by Yakovenko and Rosser (2009). In fact the relationship between physics and economics is not a new theme but has been widely acknowledged Bouchaud and Potters (1997). The analytical tools of physics and mathematics have been utilized to break the complex market behavior. One important factor in this development has been the availability of financial transaction data including high-frequency information which were not available earlier. Besides, there are few other similarities between financial markets and a complex system in physics in terms of the collective behavior of the whole system that arises from many individual events. Similarly finance deals with

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many interacting agents in the market. This supports the idea of treating markets as complex interacting systems. The analogy is further strengthened by the knowledge from statistical physics, that system with many interacting parts are capable of producing distributions with fat tails which are often seen in financial data. Apparently such association between finance and physics motivated many physicists to study various problems thrown up by social sciences in the light of their methods and models. Figure 1 shows some interesting observations extracted by Sinha and Bikas (2012). They emphasized how the number of papers appeared in *Physical Review E* with the word "market" in the title (when the term "econophysics" was coined) had increased over time and also those appeared in *Econometrica* with the words "physics" and "econophysics" anywhere in the text since 1999.

As explained by Gingras and Schinckus (2012), there is only one econophysics but physicists developed two different ways of dealing with statistical regularities characterizing the complexity of economic systems, that is, statistical econophysics and agent-based econophysics. While the first uses historical data with eventually zero-intelligent agents, the latter produces data through a complex modeling of self-evolving systems and deals with microscopic models applied to heterogeneous and learning agents. In recent times, many theories and methods from physics were tried to study financial markets and solve the problems relating to stochastic processes and non-linear dynamics. For example, in order to capture the frequency dynamics of the financial data, Fourier analysis Mallat (1999) was introduced in economics to quantify the importance of the various frequency components of the variable under investigation. Of late Fourier transformation (FT) turned out to be an increasingly popular tool in *Financial Economics* particularly when the statistical properties of a time series are time-variant. Econometrics factually failed to characterize financial markets as complicated dynamic systems to address the heterogeneous behavior of investors who operate at different time and frequency resolutions. It became apparent that econometric methods of analysis to deal with heterogeneous markets were

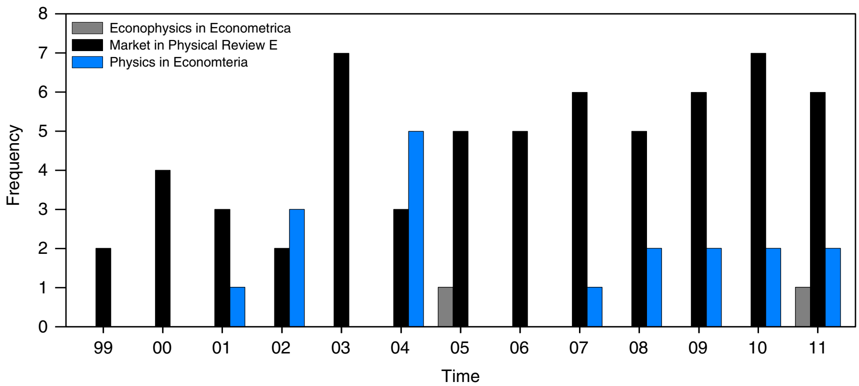

Figure 1. Advent of the discipline of econophysics since 1999-2011

Notes: The number of papers appeared in *Physical Review E* with the word "market" since 1995 (when the term "econophysics" was coined) and those appearing in *Econometrica* (published by the Econometric Society) with the words "physics" and "econophysics" anywhere in the text since 1999

Source: Sinha and Bikas (2012)

insufficient. For decades together, the analyses of financial and economic variables were carried out in the time domain and for the two time periods such as long run and short run. In recent times, however, economists realized that there were more time periods involved in economic decision making but the pedagogical advantages of just two periods dominated the relevance of many periods. Using Fourier analysis, Wen (2002) studied the cyclical nature of a time series in the frequency domain such as a Christmas effect and highlighted different relations among economic variables at distinct frequencies. On the other hand based on the interface between ecology and economics in the light of Fourier analysis, Brock (2000) emphasized the need for time-frequency analysis for economic time series data. In spite of its utility, however, under the FT, the time information of a time series is completely lost. Because of this loss of information it is hard to distinguish transient relations or to identify when structural changes do occur. The first modification to the FT to allow analysis of non-stationary signals came as the short-time Fourier transforms, henceforth (STFT). The idea behind the STFT was segmenting the signal by using a time-localized window, and performing the analysis for each segment. Since the FT was computed for every windowed (i.e. time-localized) segment of the signal, STFT was able to provide a true time-frequency representation. But the problem with the STFT is that it uses constant length windows. These fixed length windows give the uniform partition of the time-frequency space. When a wide range of frequencies is involved, the fixed time window tends to contain a large number of high-frequency cycles and a few low-frequency cycles which results in an overrepresentation of high-frequency components and an underrepresentation of the low-frequency components. Hence, as the signal is examined under a fixed time-frequency window with constant intervals in the time and frequency domains, the STFT does not allow an adequate resolution for all frequencies. Recently wavelet analysis has attracted attention in the fields of economic and finance as a means of filling this gap. The whole idea of wavelets manifests itself differently in many different disciplines although the basic principles remain the same, that is, they are localized in both time and scale and provide a convenient and efficient way of representing complex variables or signals into simultaneous time-frequency components.

As we mentioned earlier that the pedagogical advantages of just two periods in economic analysis were dominated merely by short and long-run domain. It is understandable that the study of economic and market interdependence which hold important implications for international portfolio diversification have been pursued within the scope of these two domains until recently. Nevertheless an obvious possibility is that the linkages among markets might show a different tune at different frequencies in view of diverse nature of market participants. With this background, the paper characterizes a multi-scale representation of the co-movements between Korean and emerging Asian equity markets in simultaneous time-frequency domain analysis and explains why and how it can be used to enhance the more conventional time domain analysis. The findings suggest that the integration of Korean market with the emerging Asian markets increase monotonically with the increase in the wavelet scale. This in turn implies time varying diversification opportunities for Korean investors. Further, with the financial crises, the integration of Korean market with those of Asian markets rises initially but grows strong as the time passes. This implies that investors have some time in the beginning for portfolio diversification even in crises period. Thus, investors, fund managers and regulators can use our insights in crafting effective portfolio diversification strategies. Finally clustering analysis shows how increasing participation in diverse markets could result in low-risk investments.

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The remaining part of the paper is organized as follows. Section 2 discusses about related literature in stock market co-movements. Section 3 documents economic prospects about the Korean and emerging Asian markets. Section 4 explains correlation, risk and diversification in the light of equity return co-movements. Section 5 describes the wavelet multi-scale decomposition. Section 6 gives details about data, sample structure and discussion of results and finally, Section 7 brings together the key findings and makes some concluding marks.

2. Literature review

According to Markowitz (1952) the portfolio risk can be reduced through international portfolio diversification provided the returns in different markets are weakly or negatively correlated. Since the first empirical work on the advantages of well internationally diversified portfolio by Grubel (1968), there has been a substantial debate in international finance on the linkages between stock markets and their effects on diversification. A large number of studies have emerged on the co-movement among international equity markets over a period of time (Levy and Sarnat, 1970; Shiller, 1989; Kasa, 1992; Richards, 1995; Forbes and Rigobon, 2002; Johnson and Soenen, 2003; Brooks and Del, 2004; Syriopoulos, 2007 and so on). Initially the investigations on stock market linkages were pursued through simple correlation Granger and Morgenstern (1970). Recently more advanced tools like co-integration methods (Arshanapalli and Doukas, 1993); switching regimes (Hassler, 1995); rolling window correlation (Brooks and Del, 2004) have also been used. In Asian markets, empirical works based on co-integration of equity markets have examined the extent to which such markets in the region are correlated (Mills and Mills, 1991; Huang *et al.*, 2000; Masih and Masih, 2001; Ratanapakorn and Sharma, 2002). Additionally Corhay and Urbain (1993), Chung and Liu (1994), Raisul (2014) incorporated vector auto-regression, vector error correction model, impulse response analysis, forecast error variance decomposition and Granger causality techniques. Also, bivariate GARCH models have been utilized to investigate the degree of market integration (Kang and Yoon, 2011).

In relation to Korean capital market co-movements, Jeon and Jang (2004) applied VAR (VECM) approach and found that US stock market plays a leading role over the Korean stock market at every level of aggregation. They, however, failed to find reverse direction of influence from Korea to the USA. Whereas, Roca (1999) tried to find linkages between Australian equity market and the USA, the UK, Japan, Korea, Singapore Taiwan and Hong Kong using Johansen and Granger causality methods and suggested that Australian investors can reap portfolio diversification benefits in short run from Asian markets except Hong Kong. But in case of USA, he suggested long-run portfolio diversification benefits for Australian investors. In nut shell, a variety of econometric tools have emerged over a period of time. The idea was to bring different kinds of tools so as to capture an unambiguous relationship between potential markets. However, the methodological experimentations lead the authors to end up in two different schools of thoughts. Some propounded that there is essentially a long-run relationship (Kasa, 1992; Hung and Cheung, 1995; Choudhry, 1996; Gupta and Guidi, 2012) and while others argued the relationship is exclusively short term (Bekaert and Harvey, 1995; Ghosh *et al.*, 1999) and while others such as Masih and Masih (2001) and Arouri *et al.* (2008) suggested both short as well as long-term relationship. But the fact remain that the authors have overlooked that the problems hinged on co-integration, error correction techniques and the like. For instance, these models have been constructed to deal with not more than two time frequencies. However, the diverse

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trading and investment practices in equity markets result in participants operating at different frequencies (scales). Viewing this phenomenon from a portfolio diversification perspective, this means that market participants with short-term investment horizons are active at higher frequencies while those with medium and longer-term investment horizons operate accordingly. Therefore it is imperative to gauge co-movements in stock markets on multiple scales. Wavelet techniques naturally provide a multi-scale analysis of financial data. This new approach has the capability to characterize the multi-scale aspects of a return time series to serve as a protocol for various traders who view the market with different time horizons. One of the fundamental advantages of wavelet analysis is the capability to decompose time series into different components. Capobianco (2004) applied wavelet matching pursuit algorithm of Mallat and Zhang (1993) and argued how it can be used to uncover hidden periodic components. Ramsey and Zhang (1997) used wavelets to analyze foreign exchange data. Their results revealed that waveform dictionaries are most efficient with non-stationary data. Similarly Jensen (2000) showed how the wavelet transform have a sparse covariance matrix that can be approximated at high precision with a diagonal matrix. Additionally Gencay *et al.* (2001) decomposed the variance of a time series of returns and the covariance between two time series on a scale by scale basis through the application of wavelet transforms and showed that no unique scaling parameter can be adapted for these time series.

With regard to co-moments of equity return series using wavelet correlation Lee (2004), Fernandez (2005), Rua and Nunes (2009), Raghavan *et al.* (2010) concluded that diversification benefits could be exploited at higher frequency intervals. Our study is unique in at least two ways. First, we use both discrete and continuous wavelet transform to analyze the Korean market linkages simultaneously in time-frequency resolutions. Second, we introduce wavelet clustering to produce a nested hierarchy of similar markets for the first time in the finance literature.

3. Korea and emerging Asian economies

In the recent past, the economic growth as well as industrialization of many Asian countries has been phenomenal by any measure of performance (Bakker and Bryan, 2003). In the beginning, it was Japan that took the lead and attained high-economic growth in 1960s followed by newly industrialized economies like Korea, Singapore, Taiwan and Hong Kong in 1980s. In addition, China, India and Vietnam have remarkably developed since 1990s (John, 1994). Based on the OECD FDI Regulatory Restrictiveness Index, Korea was the biggest reformer of its policies toward FDI between 1997 and 2010 among a sample of 40 developed and emerging countries (Nicolas *et al.*, 2013). Over the past four decades South Korea has demonstrated incredible growth and global integration to become a high-tech industrialized economy. The Korean government began to terminate some regulatory policies in the 1980s and accelerated the liberalization process in the 1990 with respect to external sectors of the economy. In 1992, foreign investors were given permission to purchase Korean stocks up to 3 percent of the outstanding shares of each company per individual, but no more than 10 percent of a company in total. In June 1993, the Korean government put forth a blueprint for the liberalization and opening of the financial sector, aiming at substantial progress in the financial market deregulation. Further capital account liberalization became inevitable when Korea joined the OECD in 1996. All these financial opportunities contributed to strong improvements in market capitalization, liquidity and the efficiency of the Korean capital market. The country is currently witnessing an

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unprecedented level of economic interdependence with both developed and developing nations. It is active in various bilateral trade agreements with several countries and regional groups across Asia and Europe. Japan contributed the largest share of Koreas FDI in 2012 at US$4.54 billion followed by USA with US$3.67 billion of FDI in 2012. While as, EU contributed US$2.69 billion (Investment Climate Statement-Republic of Korea, 2013). Foreign portfolio investment has also been continued to increase. At the end of 2012, foreign shareholders owned 34.7 percent of Korean Stock Exchange stocks. The interdependence and integration of its market is clearly reflected in the rising volatility from spill over turmoil emerging from international markets. For example, in September 2008, national stock markets around the world declined hastily in the wake of Lehman Brothers collapse. The exchange rate depreciated from around 1,100 won/dollar to over 1,500 won/dollar, and foreign reserves declined from US$240 billion at the end of September to US$201 billion at the end of December. Other asset markets also responded. For example, stock values collapsed by approximately 30 percent by the end of the year 2008.

Following the great economic reforms, Korea has been trading more intensively with the rest of east Asia since the mid-1990 leading to a sharp decline in the relative importance of its other traditional partners such as the USA and EU. Nicolas (2012), documents that the combined shares of these two partners dropped from close to 40 percent in 1990 to about 20 percent in 2010. In contrast the share of Korea's trade with East Asia rose from 33.5 to 48.2 percent over the same period of time. In fact both the regions (East Asia and South East Asia) consider Korea as an emerging power in Asia and thus are keen to develop relations with it. In turn, Korea also acknowledges and understands that the East and South East regions of Asia comprise both developed and emerging economies which have achieved significant progress over past two decades. It is therefore in the interest of both sides to establish strong economic linkages so as to develop key partnerships. Figure 2 depicts weekly price fluctuations of Asian stock markets during the period starting from 1997 to 2014. These fluctuations are evident because the individual stocks that make up the stock market

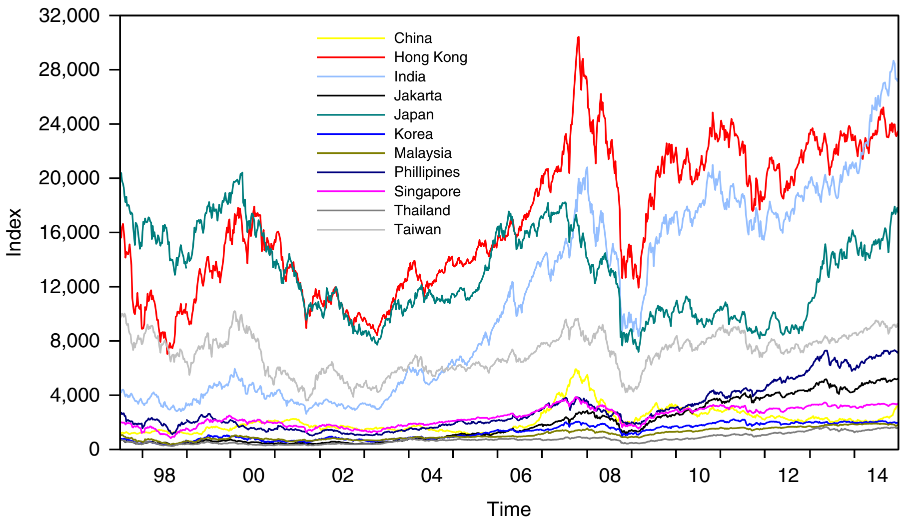

Figure 2.
Weekly price fluctuations of Asian equity markets since 1997-2014

fluctuates based on supply and demand. If stock markets are efficient, the prices must evolve randomly. The graph demonstrates that both Asian financial crises of 1997 as well as US subprime mortgage crises of 2008-2009 caused a sharp decline to Asian stock markets. According to International Monetray Fund Annual Report (2009) on economic growth slowdown, the GDP growth of Singapore reduced from (7.8 to 1.1), Hong Kong (6.4 to 2.5), Malaysia (6.3 to 4.6), Korea (5.1 to 2.2), (Philippines), (7.2 to 4.6), (China 13.0 to 9.0), Indonesia (6.3 to 6.1), Thailand (4.9 to 2.6) and (India 9.3 to 7.3). The spontaneous reaction of the markets to external shocks carries significant implications for both policy makers and market participants. For policy makers, these are important elements in assessing the potential costs from financial contagion and policy coordination. For market participants, these elements may imply reductions in the benefit of portfolio diversification.

4. Correlation, risk and diversification

Bekaert (1995) infers that part of the move toward greater integration is driven by the deregulation across most of the developing countries. When the two markets are correlated, the financial shocks to the larger country are spreaded to the smaller ones via assets-trading. An example of such kind of spillovers is the integration among Argentina and Uruguay capital markets. As a consequence of Argentina's (2001-2002) stiff crises and subsequent external debt default and currency devaluation, Uruguay was forced to devalue its currency. Second, trading partners and bilateral or multilateral trade agreements also elevate the transmission of shocks internationally. For instance, when the currency of a country depreciates, imports from its trading partners go down, and the trade balance of the country whose currency is devalued become worse. For example, the Brazilian devaluation of 1999 placed great pressure on its strong trading partner Argentina. The third reason which Chua (1993) emphasized the role of technological factors on economic growth which tend to occur as a result of ideas and capital flow across neighboring countries. The fourth reason is that spillovers or contagious crises may occur for institutional reasons according to the theories of Calvo and Reinhart (1996). It was Markowitz (1952) who went on to show analytically how the benefits of diversification depend on correlation. It implies that the benefits of international diversification truly arise when the returns of stock markets in a particular region say (Asia) are not perfectively positively correlated because there exists different industrial structures in different markets and because all economies do not follow the same business cycle. Investors therefore expect smaller return correlations between investments in differ countries than between investments with in a given country. Lessard (1973) argues that a significant part of risk that cannot be diversified within a single country can be diversified internationally. It is believed that an internationally diversified portfolio has a lower β. This infers that if the market gets integrated, it reduces the scope for reduction of β in international diversification. Therefore it is imperative for both investors as well as fund managers to be well acquainted with stock market co-movements. Similarly, policy makers need to understand the driving forces behind these linkages. Such an understanding will not only provide a better grasp of the functioning of the underlying stock markets but also allow investors and policy makers as how to bring significant benefits from such economic integration including lower costs of trading financial assets, diversified portfolios and more stable consumption patterns mostly during periods when the level of economic activity fluctuates widely. Thus a study on stock market integration, either theoretical or empirical carries a lot of significance for various stakeholders.

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5. Wavelet multi-scale decomposition

Wavelet analysis is relatively new in economics and finance although the literature on wavelets is growing rapidly. The term wavelets literally mean small waves, as they have finite length (compactly supported) and oscillatory behavior. They are particular types of basic functions that are used to deconstruct a function $f(t)$, i.e. a signal, a surface, a series, etc., in more elementary functions giving a detailed information about $f(t)$. Generally speaking, wavelet analysis is a refinement of Fourier analysis. The FT processes the raw signal (a time series) by using a mathematical transformation which transforms the signal from time domain into frequency spectrum. The processed signal tells us how many frequencies and how much energy of each frequency exists in the raw signal but it does not give us the time information (where a particular frequency appears in the time domain). The first modification to the FT to allow analysis of non-stationary signals came as the STFT. The problem with the STFT is that it uses constant length windows. These fixed length windows give the uniform partition of the time-frequency space. Hence, as the signal is examined under a fixed time-frequency window with constant intervals in the time and frequency domains, the STFT does not allow an adequate resolution for all frequencies. Of late, wavelet filters emerged as an easy vehicle to study the multi-resolution properties of a process both in terms of time and frequency. The concept of wavelets was initially introduced by Ramsey and Lampart (1998a), Ramsey and Lampart (1998b) into the analysis of economic and financial relationships between income and expenditure followed by Gencay *et al.* (2002) who examined the relationship between money growth and inflation. They also extended the wavelets to estimate the relationship between risk and return. To be precise, unlike conventional methods of decomposing data into weekly, monthly, quarterly or yearly periods, wavelet methods deconstruct data over simultaneous time-frequency resolutions without losing any data points. To illustrate diametrically the decomposition effect on return series, we choose weekly Korean equity return series and deconstructed it under conventional as well as under wavelet methods. It can be noticed in Figure 3 that when weekly return series is decomposed or reduced to monthly return series under conventional decomposition, the number of sample points decreases from 910 to 210, respectively, which results in loss of information. However, when the same return series is decomposed from weekly to monthly time periods under wavelet transformation, the observations or data points remains same and hence no loss of information.

Until recent times the integration of equity markets has been generally reviewed following typical time domain approach without taking notice on frequency domains. Nevertheless an obvious possibility is there that the relationship might show a different tune at different frequencies in view of diverse trading nature of market participants. The promising linkage amidst equity markets can therefore be unlike across frequencies and the underlying relationship can change over time. Given its ability to deconstruct the return series into different time scales and addressing the market heterogeneity, wavelet method is persuasive. The wavelet and scaling coefficients at the first level of decomposition are obtained by convolution of the data series with the father wavelets $\varphi(t)$ and mother wavelet $\psi(t)$:

$$\int \varphi(t)dt = 1 \quad \int \psi(t)dt = 0, \tag{1}$$

The father wavelets are meant for the low-frequency components of a return series and the mother wavelets are meant for the high-frequency components. In other words

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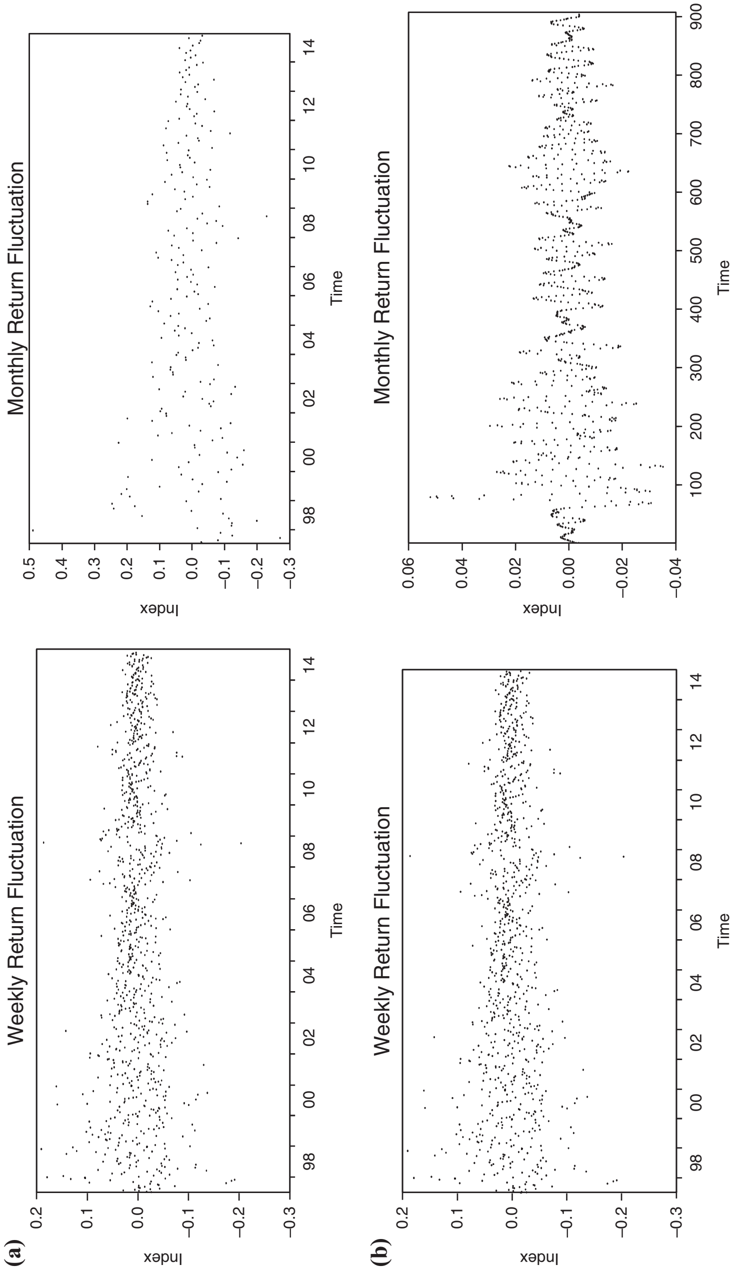

Notes: (a) Conventional decomposition and reconstruction of return series; (b) wavelet decomposition and reconstruction of return series

Figure 3.
Transformation of weekly return series into monthly return series

father wavelet deals with the trend components and mother wavelet characterizes all the variations from trend. This in turn means that a series of mother wavelets are used to represent a function while as only one father wavelet is accounted to represent a function. To continue the deconstruction of the return series into frequency components, one needs to resort to pyramid algorithm (Figure 4). Let $x(t)$ represents an original stock return series say (weekly). $w_1(t)$ denotes first level wavelet decomposition scale that captures (1-2) weeks stock return fluctuation in the market and $v_1(t)$ denotes smooth scale. Further in order to capture (2-4) weeks stock return fluctuation, smooth series, i.e., ($v_1(t)$) require decomposition which in turn will produce $w_2(t)$ and $v_2(t)$. Here $v_2(t)$ denotes smooth series for further decomposition and $w_2(t)$ is associated up to eight week stock return fluctuations.

The algorithm depicts that a time series $x(t)$ can be deconstructed by the wavelet transformation as under:

$$x(t) = \sum s_{j,k}\phi_{s,k}(t) + \sum d_{s,k}\psi_{s,k}(t) + \sum_k d_{J-1,k}\psi_{J-1,k}(t) + \ldots + \sum_k d_{1,k}\psi_{1,k}(t) \quad (2)$$

where J specifies number of multi-scale levels and k ranges from one to the number of coefficients in each level and $s_{J,k}$, $d_{J,k}, \ldots, d_{1,k}$ represent the wavelet transform coefficients and $\phi_{J,k}(t)$ and $\psi_{j,k}(t)$ denote the approximating wavelets functions. The wavelets decompositions can be expressed as:

$$s_{J,k} = \int \phi_{J,k}(t) f(t) dt \quad (3)$$

$$d_{j,k} = \int \psi_{J,k}(t) f(t) dt, \text{ for j} = 1, 2, \ldots J. \quad (4)$$

J is the maximum integer such that 2^J takes value less than the number of observations.

The detail coefficients, $d_{J,k}, \ldots, \mathrm{d}_{1,k}$, represents increasing finer scale deviation from the smooth trend and $s_{J,k}$ which represent the smooth coefficient capture the trend. Hence, the wavelet series approximation of the original series $f(t)$ can be expressed follows:

$$f(t) = S_{J,k}(t) + D_{J,k}(t) + D_{J-1,k}(t) + \ldots + D_1(t). \quad (5)$$

where $S_{J,k}$ is the smooth signal and $D_{J,k}$, $D_{J-1,k}$, $D_{J-2,k} \ldots D_{1,k}$ detailed signals. These smooth and detailed signals are expressed as follows:

$$S_{J,k} = \sum_k s_{J,k}\phi_{J,k}(t),\ D_{J,k} = \sum_k d_{J,k}\psi_{J,k}(t), \text{ and } D_{1,k} = \sum_k d_{1,k}\psi_{1,k}(t),\ j = 1, 2, \ldots, J-1 \quad (6)$$

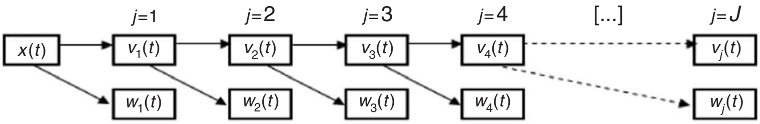

Figure 4.
Flowchart of the pyramid algorithm

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The $S_{J,k}$, $D_{J,k}$, $D_{J-1,k}$, $D_{J-2,k} \ldots D_{1,k}$ are listed in increasing order of the finer scale components. As is evident from the Figure 5 that as the wavelet scale is increasing, the wavelet coefficients become thicker and hence analyzing such patterns are a critical part of investment.

5.1 Wavelet coherence (power spectrum)

The measurement of wavelet correlation involves the computation of variances of $\{x_t, y_t\}$ and co-variances $\{x_t\}$ and $\{y_t\}$ at contrasting wavelet scales. Wavelet variance basically describes the substitution of variability against certain scales. For stochastic process say x, it is estimated using the maximal overlap discrete wavelet transform (MODWT henceforth) coefficients for scale $\tau_j = 2^{j-1}$ through: $\hat{\sigma}_x^2(\tau_j) = (1/\hat{N}_j)\sum_{k=L_j-1}^{N-1}(\hat{W}_{j,k})^2$ where $\hat{W}_{j,k}$ denotes the coefficient of MODWT wavelet variable x at scale and $\hat{N}_j$ is the number of coefficients unaffected by boundary, and L_j is the length of the scale τ_j wavelet filter. The wavelet covariance deconstructs the covariance between two stochastic processes at each scale. Given the wavelet covariance for $\{x_t, y_t\}$ and wavelet variances for $\{x_t\}$ and $\{y_t\}$, the wavelet correlation can be put across as follows:

$$\hat{\rho}_{xy}(\tau_j) = \frac{Cov_{xy}(\tau_j)}{\hat{\sigma}_x^2(\tau_j)\hat{\sigma}_y^2(\tau_j)}$$

Further in order to study the presence of contagion effects in simultaneous time-frequency resolutions, we use bivariate wavelet coherence. Wavelet coherence is similar to wavelet correlation. But it is calculated using the continuous wavelet transform instead of the discrete wavelet transform. In other words instead of the discrete wavelet transform, the estimator for interdependence is now based on the continuous wavelet transform. First, we define the cross-wavelet power of two return series $x(t)$ and $y(t)$ as $|W_{xy}(u,j)| = W_x(u,s)\overline{W}_y(u,j)$, where $W_x(u,s)$ and $W_y(u,j)$ denote the continuous wavelet transforms of time series $x(t)$ and $y(t)$, respectively. The bar on the other hand denotes complex conjugate. Parameter u allocates a time position whereas parameter j denotes the scale parameter. The cross-wavelet power uncovers areas in time-frequency space where the time series show a high common power. However, in the co-movement analysis we search for areas where the two time series in time-frequency space co-move, but does not necessarily have high power. Following Torrence and Webster (1999), we characterize the wavelet coherence of two time series as:

$$R_n^2(s) = \frac{\left|S\left(s^{-1}W_n^{XY}(s)\right)\right|^2}{S\left(s^{-1}\left|W_n^X(s)\right|^2 \cdot S\left(s^{-1}\left|W_n^Y(s)\right|^2\right)\right)},$$

where S represents smoothing operator. It could be noticed that this definition closely resembles that of a conventional correlation coefficient and it is useful to think of the wavelet coherence as a localized correlation coefficient in time-frequency space. We write the smoothing operator S as $S(W) = S_{scale}(S_{time}(W_n(s)))$. Where S scale denotes smoothing along the wavelet scale axis and S time smoothing in time.

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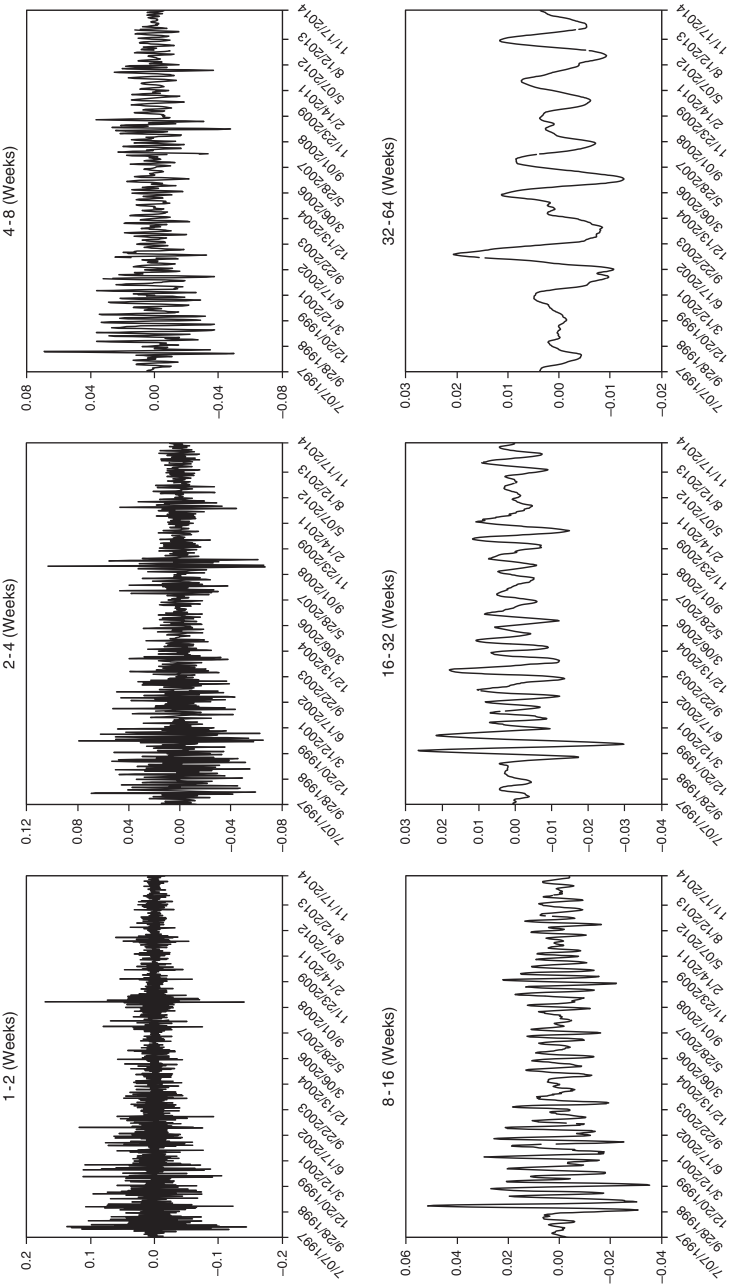

Figure 5.
Multi-scale decomposition of Korean equity returns

5.2 Wavelet clustering[1]

Since wavelet transform segregate features with different frequency content, it can be useful to identify, discriminate and localize clusters in multidimensional space. To find the clusters present in our data, we follow the procedure developed by Misiti *et al.* (2007) for clustering electrical data set. The series of steps are as follows:

(1) Carried out a deconstruction of each return series to calculate (cAJ, cDJ, …, $cD1$). Where cAJ denotes the coefficients of approximations at level j and cDJ represents the coefficients of detail at level j.

(2) Denoised individually each return series by wavelet coefficients thresholding leading to (cAJ, cDJ, …, $cD1$).

(3) Generated several hierarchies using common wavelet bases clusters (cAJ, cDJ, …, cDj) for $1 \leqslant j \leqslant J$.

(4) Selected the best hierarchy according to a quality index by selecting a level of decomposition $1 \leqslant j^* \leqslant J$ and a number of clusters C. The choice of the number of clusters is a classical issue and wavelets do not simplify the problem in the functional context. But, wavelets permit to avoid that noises corrupting a lot of signals, disturb the clustering process by creating extra clusters.

Finally to choose distance metric that is normally used to measure the similarity or dissimilarity between two data objects. We took the widely used Euclidean distance an extension of Pythagoras theorem for K-means and hierarchical clustering algorithm. K-means clustering is a method that aims to partition n observations into k clusters in which each observation belongs to the cluster with the nearest mean serving as the prototype of cluster. The Euclidean distance can be characterized in another ways. For example, it is nearly linked with cosine or scalar product. If we have cosine, or covariance, or correlation, we can always: transform it to (squared) Euclidean distance, and then generate data for that matrix of Euclidean distances (by means of Principal Coordinates or other forms of metric Multidimensional Scaling), input those data to K-means clustering. Therefore, it is likely to make K means "work with" cosines or such; in fact, such implementations of K-means clustering exist.

6. Data, results and discussion

Our data set consists of weekly stock indices from 11 emerging Asian equity markets including South Korean capital market between July 1, 1997 and December 30, 2014. The representative market indices[2] of each country were retrieved from the Bloomberg database. The data series were then expressed in logarithmic form. Since the return series has been dealt with wavelets, the stationarity condition is automatically fulfilled (Whitcher, 1998). The fundamental reason for this analogy is that wavelet transform yields a localized "instantaneous" estimate for the phase and amplitude of each spectral component in the data set which gives wavelet analysis an advantage in the analysis of non-stationary data series (Richard and William, 2014). To assess the distributional properties of return series, we begin with descriptive statistics[3]. The mean return of sample markets is found to be positive ranging between 0.01 and 0.03 percent. The standard deviation is observed with 3 percent for all markets except South Korea with 4 percent variations in its return series. Further the return data of Asian markets except China, Korea, Malaysia, Taiwan and Singapore are negatively skewed meaning that huge negative stock returns is more obvious than

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huge positive returns for these markets. While as Kurtosis statistics illustrated that all return series are leptokurtic with a large positive kurtosis value. The Jarque-Bera statistics on the other hand strongly disapproves the null hypothesis that the Gaussian distribution of returns is normal. Table I summarize Pearson correlation coefficients between Asian equity returns. It can be observed that Korean market is weekly correlated with the markets of China, Indonesia, Philippines, Thailand and moderately correlated with other markets. To what extent Pearson correlation would help in portfolio diversification decisions is basically the subject of interest for various market participants operating in the market. Of late efforts were made to measure correlations on different data sets like weekly, monthly and so on in view of the heterogeneous traders who make decisions over different investment horizons. But the question to be raised is that whether market consists of only daily, weekly, monthly or yearly traders? Econometric tools developed over time also could not analyze the financial data beyond short and long run. Recently wavelet analysis has attracted attention in the fields of economics and finance as a means of filling this gap. The wavelet transform uses local base functions that can be stretched and translated in simultaneous time-frequency resolutions. The whole idea of wavelets although manifests itself differently in different disciplines, but the basic principles remain the same, i.e., wavelets are localized in both time and frequency representation which allow one to assess simultaneously how variables are related at different frequencies and how such relationship has evolved over time.

With this background, the contribution of this paper is to characterize the Korean equity returns in terms of their co-movements with the returns of other emerging Asian markets in simultaneous time-frequency oscillations. In order to capture the basic knowledge as to how the Korean market move with other markets at multiple frequency resolutions, we proceed with wavelet correlation. In order to estimate the wavelet correlation of Korean[4] equity market with the rest of the Asian equity markets, we begin with deconstructing all return series in time = frequency localization using MODWT. This localization property makes wavelets useful because it allows for handling a non-stationary time series that may change quickly over time (Deo and Shah, 2012). We preferred MODWT to the discrete wavelet transform (DWT henceforth) because of some important reasons as mentioned by Percival and Walden (2000) like MODWT of level J is well defined by any sample size N and MODWT

→	CH	HK	IN	JK	JP	KR	ML	PH	SG	TH	TW
CH	1.00	0.20	0.14	0.12	0.14	0.13	0.15	0.12	0.14	0.10	0.19
HK	0.20	1.00	0.48	0.41	0.53	0.43	0.30	0.16	0.73	0.14	0.48
IN	0.14	0.48	1.00	0.34	0.40	0.37	0.29	0.21	0.48	0.31	0.36
JK	0.12	0.41	0.34	1.00	0.33	0.18	0.21	0.23	0.47	0.20	0.29
JP	0.14	0.53	0.40	0.33	1.00	0.42	0.21	0.17	0.51	0.22	0.45
KR	0.13	0.43	0.37	0.18	0.42	1.00	0.39	0.15	0.41	0.20	0.39
ML	0.15	0.30	0.29	0.21	0.21	0.39	1.00	0.25	0.38	0.25	0.31
PH	0.12	0.16	0.21	0.23	0.17	0.15	0.25	1.00	0.27	0.51	0.28
SG	0.14	0.73	0.48	0.47	0.51	0.41	0.38	0.27	1.00	0.15	0.48
TH	0.10	0.14	0.31	0.20	0.22	0.20	0.25	0.51	0.15	1.00	0.25
TW	0.19	0.48	0.36	0.29	0.45	0.39	0.31	0.28	0.48	0.25	1.00

Notes: CH, China; HK, Hong Kong; IN, India; JK, Jakarta; JP, Japan; KR, Korea; ML, Malaysia; PH, Philippines; SN, Singapore; TH, Thailand; TW, Taiwan

Table I.
Markets Pearson correlation matrix between Asian equity return series

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wavelet variance estimator is asymptotically more efficient than the same estimator based on DWT. Given the sample of 910 observations or roughly 17 years of data, the maximum decomposition possibility is given by [log2(T)]. However, for higher level decompositions, there is quite possibility that feasible wavelet coefficients get smaller and boundary conditions may get violated. A boundary is simply a character string indicating the boundary method used in the decomposition by assuming it either "periodic" or "reflection." According to Gencay *et al.* (2002), the most natural technique for dealing with the boundary is to assume the length N series is periodic and grab observations from the other end to finish the computations. Thus based on the periodic assumption, we restrict the decomposition process into six details (w_i1-w_i6) and one (v_i6) smooth component. The wavelet scales are such that scale 1 is associated with 1-2 weeks period, scale 2 = 2-4 weeks period, scale 3 = 4-8 weeks period, scale 4 = 8-16 weeks period, scale 5 = 16-32 weeks period, scale 6 = 32-64 weeks period and scale last represents smooth decomposition. Overall we generated 66 return series from 11 original raw return series (11 × 6) without losing any data point or information content. For several reasons, we do not report results for smooth series since it captures a long-term fluctuation where predetermined frequency component is not known. After decomposing the given series into details and smooth's, wavelet correlation between Korean and emerging Asian markets was measured. The wavelet correlation between Korean and rest of emerging Asian equity markets with upper and lower bounds of 95 percent confidence intervals is presented in Figure 6. Unlike Pearson correlation which suggests 13 percent association between Korean and Chinese market, the wavelet correlation reveals that this particular degree of correlation could be realistic with shorter intervals only. In particular, the coefficients from wavelet correlations bring out an interesting description. At higher frequencies (D1 and D2) the correlation between Korean and Chinese market is close to 0 but the two markets are moderately correlated at lower frequency scale (D6) with 40 percent association. Other than that of Chinese market, we also document weak correlation between Korean market and Philippines, Indonesian and Indian markets at higher frequency resolution components. However, all sample markets have strong linkages with Korean market at lower frequency scales with more than 50 percent inter-relationship. The highest integration of Korean market at lower frequency scales particularly at (D6) is observed with Japan, Malaysia, Indonesia, Singapore and Thailand with more than 70 percent association. These findings infer that lower frequency domains are essentially associated with strong linkages among markets which necessitate an attention of investors, fund managers and policy makers. This implies that the investors with short-term investment horizons can enjoy international portfolio diversification and also asset allocations. While portfolio diversification would help them in reducing the business risk, the asset allocation would facilitate them in stabilizing returns particularly over extended periods when market are relatively integrated. The results also suggest that higher frequencies (shorter intervals) are attractive for risk-averse investors. However, as the investment interval is increased from two weeks to four weeks to eight weeks and so on, the diversification opportunities are monotonically reduced. Therefore investors as well as fund managers must rebalance their portfolio with respect to different asset classes. The strong correlations over lower frequency intervals imply that Korean investors will seek less information asymmetry by demanding a better governance, larger quantity and superior information disclosure through security regulations and financial reports. This will in turn lead in the reduction of cost of capital. However, such kind of integration could also affect their expected returns or cost of capital.

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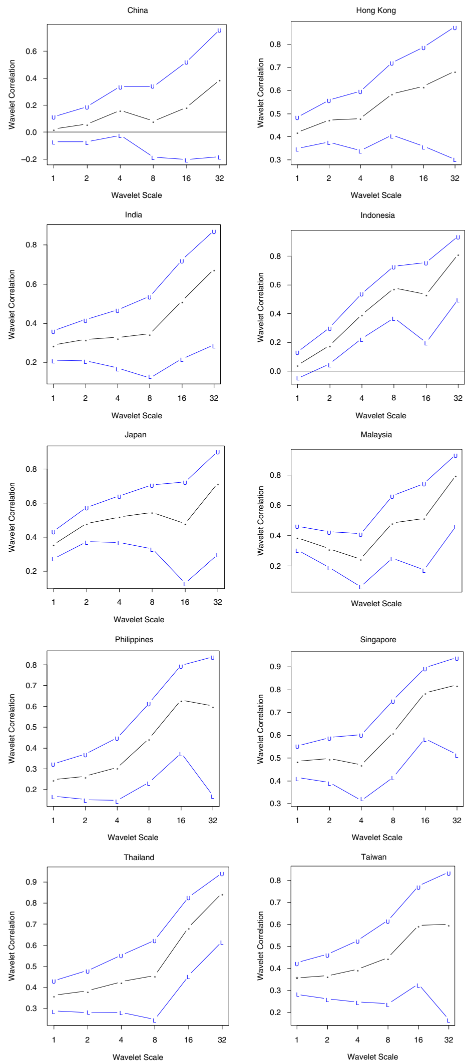

Notes: Wavelet correlation calculated with the MODWT estimator. 1,2,4,8,16,32 represent wavelet scales where scale 1 is associated with 1-2 weeks period, scale 2: 2-4 weeks period, scale 3: 4-8 weeks period, scale 4: 8-16 weeks period, scale 5: 16-32 weeks and scale 6: 32-64 weeks period

Figure 6.
Wavelet correlation scales between Korean and emerging Asian markets

For example, volatilities of stock market returns of developing markets like Korea is generally higher than those of developed markets like Japan and Hong Kong. As a result to keep the variance and covariance constant, the prices of market index should increase and expected returns should decrease. When Korean market becomes more

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integrated with Japan and Hong Kong, the sensitivity of its market return increases and so does the co-variances of its market with Japan and Hong Kong. When the increase in covariance is smaller than the increase in local stock variances, the prices are typically higher. Errunza and Miller (2000) describes the cost of capital of any security in the integrated market is lower because those traded on segmented markets are mostly held by local investors and their expected return depends on the local price risk and national covariance risk.

It is, however, imperative to mention that wavelet correlation is plagued with several issues. For instance, if the study period is 2000-2014, the coefficients would produce an average relationship between two markets over multiple frequency resolutions. However, an issue arises, when instead of an average, the market participants are interested to know this relationship in time-frequency localization at each year so as to be able to identify the contagion effect if any. Raisul (2014), documents that the Global Financial Crisis of 2007-2008, warrants much investigation. Thus keeping this vital concern into consideration, we resort to wavelet coherence (Power Spectrum) to map potentially interesting structures independently at each individual year. Figure 7 demonstrates the individual wavelet coherance plots between Korean and Asian equity markets. Time is recorded on horizontal axis and the vertical axis give us the periods and corrosponding scales. The spectrum of colors shows the strength of relationship between Korean equity market and rest of the Asian markets. The red shade represents the correlation about 80 percent. While as blue shade represents correlation about 20 percent and the yellow shade illustrates correlation about 60 percent. The black bounded lines describes the confidence band at 95 percent level. Year 1997-1998 and 2008-2009 denotes Asian and US crises period, respectively.

Overall the coherence analysis show clear signs of contagion effect among Asian equity markets. It can be noticed that except Chinese market, all other markets are strongly integrated with Korean equity market particularly during 1997 and 2008 financial crises period at lower frequency components. While observing the wavelet coherence plots of sample markets, it is clearly evident that the integration of Korean equity market appeared statistically significant immediately following the occurrence of the bad events and with the passage of time, this integration grows stronger. Although the bad event of 2008 gave rise to correlation between Korean and Chinese markets initially but their co-movements disappeared just after eight weeks period. By and large our results contradict with Forbes and Rigobon (2002) who observed that the impact of a crisis on correlation will often be a short term and result in short-lived spikes in correlation. But our findings are backed by Markwat *et al.* (2009) who suggested that Global contagion events can be relatively long and drawn out process as they are often preceded by a series of local regional crashes. Overall the results imply that the Asian markets become more vulnerable to financial crises for Korean investors over lower frequency resolutions. This implies that portfolio diversification opportunities could be grabbed at higher frequency resolutions even during crises period. Finally Figure 8 shows dendrogram a (branching diagram) for (D4) details and coefficients which is associated with 16 weeks period. We do not found any significant deviation in dendrograms generated in data clustering process from wavelet scale 3 to scale 6 which are associated with eight and 64 weeks period, respectively. Hence we report only one dendrogram at (D4) which reveals at what similarity levels, the clusters are formed – either by joining two individual markets or pairing an individual market with an existing cluster. Overall the dendrogram has produced two clusters comprising

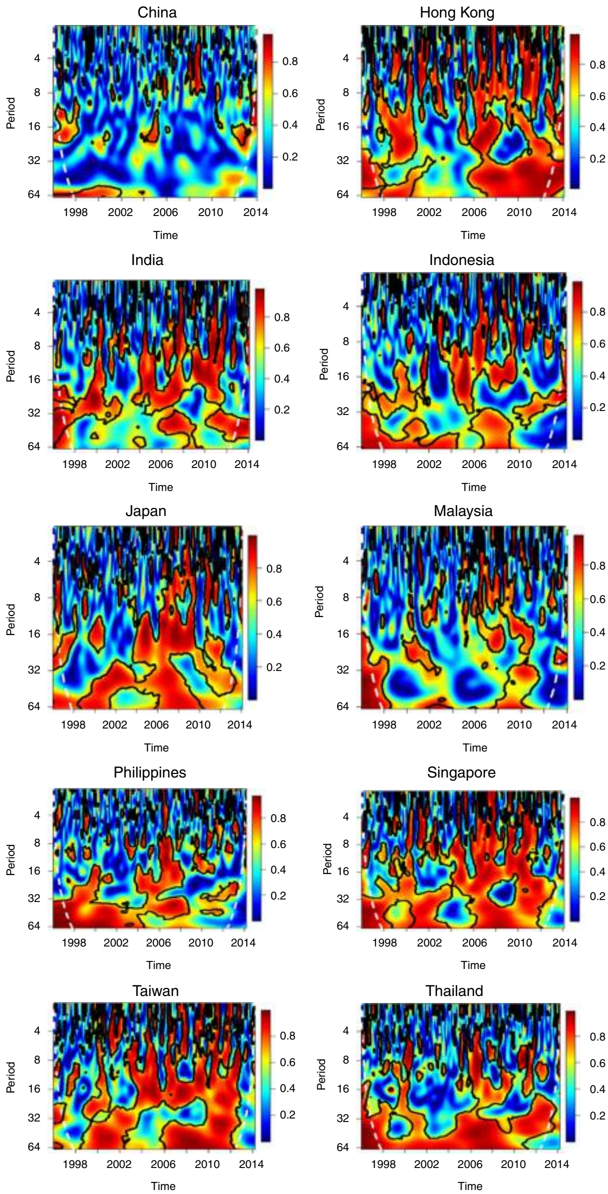

Figure 7.
Wavelet coherence (power spectrum between Korean and emerging Asian markets)

Notes: Wavelet power spectrum using the Morlet wavelet. The spectrum can be set to dog or paul but significance test is available for Morlet wavelet only

nine markets in first cluster and two markets in the second. There is no single isolated market or (an outlier). The vertical axis of the dendrogram represents the distance or dissimilarity between clusters. The horizontal axis represents the sample markets. The distance measure between two clusters is calculated as $D=1-C$.

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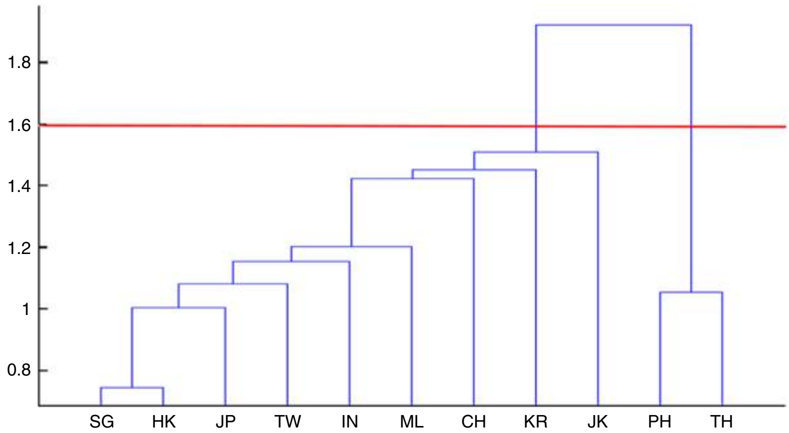

Figure 8. Wavelet clustering of Asian equity markets during 16 weeks period

Where, $D=$ distance and $C=$ correlation between object clusters. If markets are highly correlated, they will have a correlation value close to 1 and so $D=1-C$ will have a value close to 0. Therefore, highly correlated clusters are nearer the bottom of the dendrogram. The vertical line in red indicates the number of clusters in each dendrogram. The clustering plot shows that the distance metric between Singapore (SG) and Hong Kong (HK) markets are very close to 0. However, the inclusion of Japanese market in "two markets group" causes a slight increase in distance metric or fusion value to 1. Taiwan (TW) is the next market that joins in the "three markets group." It is clearly evident that with the involvement of Taiwan, the distance metric increases further to 1.5 and the correlation between these four markets become rather weak. Similarly Korea (KR) represents the eighth market that joins the "seven member group" at 1.42 fusion value which is further increased to 1.45 with the inclusion of Jakarta (JK) market. The second cluster consists of Philippines (PH) and Thailand (TH) markets which coincide with the markets of Singapore, Hong Kong and Japan in the first cluster although their matching analogous change at varying fusion values. However, it is interesting to observe that the two clusters (SG, HK, JP, TW, CH, KR, JK, IN, ML) and (PH, TH) are linked at increasing levels of dissimilarity. Assume that an investor "A" has an investment in all nine markets in cluster first for portfolio diversification. Also assume that investor "B" has invested exclusively in Singapore and Hong Kong markets in the given cluster. According to portfolio diversification theory, the investment of the investor "B" could be risky since both markets look identical. However, as soon as the investor "B" would extend his investment to Japanese market, there will be a slight decrease in his total risk. The dendrogram clustering plot shows that with the inclusion of every new market, the investor "B" can realize the benefits of portfolio diversification and by the time his investment is transmitted to all nine market, he can realize the advantages of portfolio diversification as realized by the investor "A." However, for higher frequency scale (D1) that is associated with one to two weeks period, we have retrieved three clusters (SG, HK, JP, TW, CH, KR, JK), (IN, ML), (PH, TH). Figure 9 demonstrates that the markets of Singapore, Honk Kong, Japan and Taiwan coincide with Indian and Malaysian market at 0.88 metric distance. The dendrogram shows that no portfolio diversification could be achieved by investing exclusively in Singapore and Hong Kong; Malaysia and India; Philippines and Taiwan during two weeks period.

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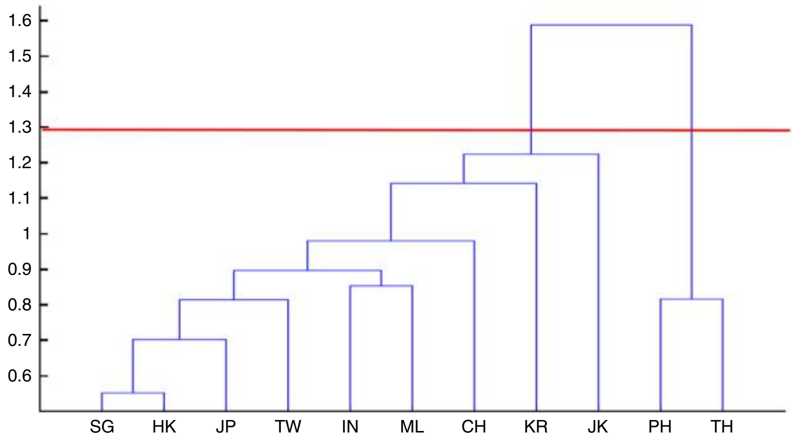

Figure 9.
Wavelet clustering of Asian equity markets during 2 weeks period

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7. Conclusion and policy implications

The degrees of capital market integrations are crucial for both policy makers and market participants. For policy makers, these are important elements in assessing the potential costs from financial contagion and policy coordination. For market participants, these elements may imply reductions in the benefit of portfolio diversification. Markowitz (1952) and Tobin (1959) agreed that the expected returns and risk of a portfolio largely depends upon the correlation among stock returns. If correlation does not exist among stock returns, portfolio diversification can reduce risk. If market correlations are weak, then international diversification can really be indisputably beneficial (Forbes and Rigobon, 2002). Therefore correlation has to be considered as a decisive factor in risk estimation of financial and real portfolios (Costa *et al.*, 2007). Against this background, our paper focussed on the simultaneous time-frequency localization to provide additional insights in dynamic linkages of Korean equity market with those of emerging Asian markets and the analysis of it is believed to contribute to the risk diversification process both for Korean as well as investors from sample countries. In particular the study tried to bring out the wavelet transformation method as a new analytic approach to review the scope of risk and portfolio diversification in view of the diverse investment horizons. The wavelet correlation exhibits that Korean market is correlated with Asian equity markets largely on lower frequencies implying that diversification opportunities for investors are more inclined at higher frequencies of returns. The results also suggest that higher frequencies (shorter intervals) are attractive for risk-averse investors. Additionally high-frequency intervals offer diversification opportunities also during crises time. However, as the investment interval is increased from two weeks to four weeks to eight weeks and so on, the diversification opportunities are monotonically reduced. This monotonic increase in correlations could lead to efficiency gains from domestic Korean firms because they have to compete directly with foreign rivals and this competition according to Kose *et al.* (2006) could lead better corporate governance. The clustering results imply that the highest portfolio diversification could be reaped by investing in all nine countries in cluster first during "16 weeks period." However, the diversification opportunities will be monotonically reduced by the time investors leaves out or with draws their investment from Jakarta, Korea and so on. The second dendrogram for "two weeks period" suggest three clusters and directs that no portfolio diversification could be achieved by investing exclusively in Singapore and Hong Kong; Malaysia and India; Philippines and Taiwan. Thus an important implication of our findings suggest that the degree of Korean market integration with those of Asian markets tends to change over time and because of the time varying nature of correlations, diversification benefits are also time varying. These findings are consistent with Bekaert and Harvey (1995), Goetzmann and Rouwenhorst (2005). There are also evidences that inter-asset correlations generally increase during financial crises. Such findings are consistent with Longin and Bruno (2001), Ang and Bekaert (2002). Over all the results are plausible for Korean investors and fund managers as when to increase/decrease participation in any specific Asian stock market. It also provides the information to foreign investors as when they ought to participate in Korean market. Our results showed that time series analysis in economic and financial research can gain new insight with wavelet analysis by separating processes on different time scales and repeating the traditional analysis on these different scales. Wavelets offer the possibility of going beyond this simplifying dichotomy by decomposing a time series into several layers of orthogonal sequences of scales which then be analyzed individually and compared across different series. Overall, adoption of simultaneous time-frequency analysis in present study although has facilitated comprehensive analysis of Korean equity market integration, but it would be further interesting to consider the linkages between Korean bond and derivative markets over multiple scales. The paper leaves this for further research.

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Notes

1. The comprehensive details of wavelet clustering is given by Michail Vlachos *et al.* (2003) and Quiroga *et al.* (2004), Cattani and Ciancio (2005). The clustering estimation was carried out using "mdwtcluster" package in Matlab tool box. While as, correlation and coherence estimations were carried out using "Waveslim" and "Bi-wavelet" packages in *R* statistical software.
2. SENSEX index for Bombay Stock Exchange (India), Hang Sang for Hong Kong, Shanghai Stock Exchange Composite Index for China, Bursa for Malaysia, Jakarta Stock exchange composite for Indonesia, Strait Time Index for Singapore, Philippines Stock Exchange Index for Philippines, Set Index for Thailand, KOSP for South Korea, Taiwan Stock Exchange Weighted Index for Taiwan.
3. To prevent the space, we did not report descriptive statistical figures of sample return series. Nevertheless, it would be available on request to corresponding author.
4. The Korea Composite Stock Price Index or KOSPI was launched in 1983 with the base value of 100 as of January 4, 1980. KOSPI is the major stock market index of South Korea. The index represents all common stocks traded on the Korea Exchange. The index calculation is based on market capitalization method. KOSPI replaced Dow-style KCSPI (Korea Composite Stock Price Index) in 1983.

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