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Integration between emerging market equity and global markets; is it fundamental or noisy? Evidence from wavelet denoised volatility spillover analysis in time and frequency domain

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ABSTRACT

The study investigates the integration between the five largest emerging stock markets, Morgan Stanley Capital Emerging Market Index, and global financial markets like the US S&P 500, Brent Crude Oil and Dollar Index based on wavelet denoised volatility spillover in time and frequency domain using forecasted error variance decomposition framework. It is found that the impact of noise on the connectedness is more pronounced in the short run and declines in longer term. Further, long-term connectedness which is much higher than that of short-term connectedness confirms the existence of fundamental (noisy) concernedness in the long (short) term. The impact of noise both varies by time and frequency. The policy implications are discussed.

KEYWORDS

Volatility spillover; wavelet denoising; time and frequency domains; emerging markets; global markets; US S&P 500

JEL CLASSIFICATION

C4; C5; C6; Q02 Q03



I. Introduction


With the rapid pace of economic reforms supplemented by technological innovation and financial engineered products, the financial markets linkages world over have been accelerated. As a result, the local financial markets are exposed to the global and regional risk factors. The impact of price changes in one market may be felt in another market (Liu and Gong 2020) resulting in volatility spillover between the financial markets. That means volatility from one market impacts the volatility of another market at a lag (Chang et al. 2013). The reasons of volatility spillover are wide-ranging such as arbitrage activities, emotional contagion related to herd behaviour (Liu and Gong 2020), common information and hedged portfolio rebalancing Fleming et al. (1998). Malik and Hammoudeh (2007) attribute portfolio diversification, cross market hedging and shared information changes to volatility spillover.

The implications associated with financial market integration are discussed in literature by Marshdeh and Shrestha (2010) who conclude that integrated markets aid in risk sharing across

markets, Chakrabarti and Roll (2002) talks about cross-market diversification. Tai (2007) concludes that market integration enhances financial markets stability by improving efficiency and competition in assets allocation, reduction in cost of capital and price changes. According to Levine (2001) financial markets integration plays vital role in stimulating investment and domestic savings which ends up affecting broader economic growth. Rizvi, Arshad, and Alam (2018) mention about efficient, stable, and integrated financial markets for sustainable economic growth in a study based on the tripartite relationship between volatility, efficiency, and integration in the context of emerging markets. Therefore, it is essential to study nature of transmission of volatility across markets and over time given the increased level of financial market integration. Although literatures are abundant studying the volatility spillover (see the literature section), our study investigates integration between emerging and global markets considering the importance noise in the financial market.

Noise trading, which is not based on economic fundamentals, is attributed to non-information

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and investor sentiment impacting asset prices (Black 1986). Now the important question to be addressed is as follows: Is the financial market integration fundamental or noisy? The observed volatility in emerging markets, which is usually higher than the developed markets, could be attributed to trading based not on economic fundamentals but on noise, according to Black (1986) and De Long et al. (1990). Markets systematically deviated from the Efficient Market Hypothesis (Shleifer and Summers 1990).

Further, individual investors are subject to behavioural biases like disposition effect and herding, and it is reported that their trades are based more on technical indicators than on fundamentals. Since noise trading leads to higher volatility and its spillover to other markets due to connectedness/integration, it subsequently affects the diversification strategy of the portfolio managers in terms of optimal weight and risk management of the hedge ratio. As far as the nature of the impact of fundamental and non-fundamental (noise) factors is concerned, it is more transitory in the case of the latter and permanent in the case of the former.

When asset prices are responsive to noise, they revert to the mean because the impact is transitory. The optimal investment strategy of a sophisticated (fundamental) investor is different in the presence of mean-reverting misperceptions of noise-traders (De Long et al. 1990). The impact of noise on Commodity Trading Advisors' (CTA) trading strategies like trend following and mean-reverting is discussed in a paper titled, 'Deconstructing Noise', by Kelonia Capital Management and published by the CME group. Therefore, the study aims at estimating the integration based on the denoised volatility spillover between emerging markets and global markets.

In this study, we have investigated the fundamental integration between emerging markets and global markets. Here, we have taken the U.S. S&P 500, Brent Crude Oil, and Dollar Index as a proxy for global markets. Emerging markets consist of the top five emerging markets based on market

capitalization¹ and MSCI Emerging Market Index², which is an investible portfolio of fastest-growing emerging economies.

The integration at the individual emerging market level is studied between the top five emerging markets in terms of market capitalization, such as KOSPI, SENSEX, TWSE, SHCOMP, and JALSH, and three global markets above. Because individual economies are different in terms their financial, regulatory, and economic fundamentals, that is why each country is getting impacted differently from the same external shock.

Since all the above financial markets function as system, we have followed the Diebold and Yilmaz (2014) volatility spillover methodology to uncover the structure and strength of integration/connectivity through volatility spillover.³

Dew-Becker and Giglio (2016) quantify the shocks to asset prices at different frequencies. They find that shocks having strong long-term (short-term) effect have high power at the low (high) frequency. As far as pricing of shocks in equity market is concerned, consistent pricing of low frequency shocks is reported. Furthermore, financial market participants are different in terms of their investment horizon, for example speculators are for short-term, portfolio/fund managers for medium term and institutional investors and policy makers are for long-term horizon Conlon, Cotter, and Gençay (2016), Baruník and Křehlík (2018). It is also a stylized fact that volatility and volatility spillover are time varying both in time and frequency domain. Time domain is an average representation of frequency-wise decomposed spillover of volatility. That is why to figure out which frequency dominates average time domain volatility; this study presents both Diebold and Yilmaz (2014) and Baruník and Křehlík (2018) volatility spillover in a comparative framework.

The major contribution of our study to the literature is that it estimates the denoised volatility spillover both in time and frequency domains using Diebold and Yilmaz (2014) and Baruník and

¹The four largest countries by market capitalization weight in the MSCI-EM Index over 20 years (i.e. by 2020) are China, South Korea, Taiwan, and India. South Africa carries around the same level of weight as Brazil. And over the 20-year period, the importance of South Africa in the MSCI-EM Index has been increasing, while on the other hand, it is opposite for Brazil. That is why we have used South Africa as the fifth emerging market in our study.

²MSCI-EM Index futures is the most popular multi-country and multi-currency futures in terms traded value and open interest (using multi-country, multi-currency futures in portfolio management, MSCI). It started trading in 2009 as an individual asset class in the NYSE LIFE US futures exchange.

³Measure of connectedness/integration is required for minimization of portfolio risk and optimal portfolio allocation Diebold and Yilmaz (2012).

Křehlík (2018) methodologies, respectively. Our study addresses for the first time ever one of the important aspects of financial market integration: whether integration is fundamental or noisy based on volatility spillover. Further, our set of data is unique in the sense that we have not classified financial markets as global or regional or emerging or developed or any other geographical block.

There are two ways foreign funds can invest in emerging markets. One is the direct way where foreign funds bet directly on individual emerging markets or through country-centric funds, and the other way is indirect where the foreign funds put money in emerging market funds where money is allocated across the countries and each country will get its share accordingly. The indirect way (emerging market basket) is mostly preferred by the foreign investors as putting money separately into individual markets is riskier than the former.

This is how the individual emerging markets are linked to MSCI Emerging Market as a block of the fastest-growing economies. Our sample market consists of the top five individual emerging markets and MSCI Emerging Market Index as an asset class. In addition, we have also considered the commodity and foreign exchange markets in the process of quantifying integration across financial markets because stock market integration is one the facets to economic integration. We find that long-term fundamentals and short-term noisy time vary the integration between emerging equity markets and global markets.

The remaining part of the paper is outlined as follows. [Section II](#) discusses the literature and explain the gap. [Section III](#) presents methodological techniques used in this paper. [Section IV](#) outlines our data while [section V](#) provides discussions on the results obtained. [Section VI](#) presents the conclusion.

II. Literature

Existing literature on financial markets comovement is very broad and comprehensive. On stock markets cointegration, the core body of prior study explores and document evidence of linkages among developed equity markets (Pukthuanthong and Roll 2009; Donadelli 2013) while other studies extended the scope to analyse the links between

developed and emerging equity markets (Phylaktis and Ravazzolo 2005). Chuliá, Guillén, and Uribe (2017) investigate the tail dependence of six Latin American stock markets with the US stock markets. They document weak dependence at the tail and the responses to US market shocks are asymmetrical. Hwang et al. (2013) investigate the comovements of 10 emerging and the US stock markets during US financial crises. They find different patterns of crisis spillover across emerging countries.

Moreover, another strand of prior studies focuses on the integration of markets at the global and regional levels. Gong, Tang, and Wang (2019) documented global stock markets' connectedness. Chevallier et al. (2018) studied the return spillover-based interdependence across the stock markets of Pacific Basin countries where they mention emerging stock markets interdependence with the US markets and regional cross market linkages. Bekaert and Mehl (2019) found a 'swoosh pattern' in the de facto global financial integration and no clear pattern for regional integration for 17 stock markets. Graham et al. (2012) reported a high degree of comovements between 22 emerging markets and the US markets at lower frequencies, although the strength of comovements differs by country. Similar long-term comovements are reported by Marfatia (2017) in his investigation of the comovement of risk across 22 leading stock markets at country and regional levels. He reported strong comovements of risk between the European and US markets in the long run, i.e. at a higher frequency. In the short term, a country's stock market risk is more connected at the regional level in comparison to other global markets including the US. Naeem et al. (2021) examined the connectedness between fear indices of stock markets and alternative assets. They found the global equity markets' fear index connectedness is driven by oil fear index. Nasir and Du (2018) studied the integration of global financial markets in the context of nine countries and three markets following the 2008 global financial crisis. They reported a shift in the integration among global financial markets after the global financial crisis.

However, in contrast to the above-mentioned literature, Chambet and Gibson (2008) mentioned

the decrease in financial market integration for 25 emerging stock markets and these still, to a large extent, remain segmented.

Our study examines the connectedness/integration in the context of a broader set of markets. It covers the top five emerging markets, India, China, Taiwan, Korea, and South Africa, in terms of market capitalization; MSCI Emerging Market Index as an asset class; developed markets proxied by the US S&P 500; and two more asset classes: Brent Crude Oil and an exchange rate represented by the Bloomberg dollar index.

Owing to the financialization of commodities (Qiang, Zhang, and Geng 2018), the commodities markets in recent years have become more cointegrated into the worldwide financial structure. Oil emerged as the most popular commodity with the increase in investment by the institutional investors (Basak and Pavlova 2016; Cheng and Xiong 2014; Tang and Xiong 2012). Arouri, Lahiani, and Nguyen (2011) found substantial returns and volatility spillover between world oil prices and stock markets of the Gulf Cooperation Council. Wang and Wang () reported short-term oil price risk for the Chinese sectoral equity market. Belhassine (2020) found time varying and heterogeneous mean and volatility spillover between oil market Eurozone super sector indices. Belhassine and Karamti (2021) reported price and volatility spillover between oil and stock markets, which are conditional on time scale and studied stock market. More importantly, long-run volatility spillover is found between the oil and stock markets, and it is homogenous for a group of oil importing and exporting countries.

As far as the exchange rate is concerned, while the flow-oriented theoretical model of Dornbusch and Fischer (1980) reported that exchange rates impact stock markets, the impact is reversed according to the stock-oriented model of Frankel (1984). Tiwari et al. (2018) in a global asset context reported foreign exchange markets as the net receivers of volatility from stock markets. However, comprehensive empirical literature and theoretical arguments on the relationship between exchange rate risk and stock returns remains inconclusive (Alagidede, Panagiotidis, and Zhang 2011; Kodongo and Ojah 2011; Koulakiotis, Kiohos, and Babalos

2015; Boako, Omane-adjepong, and Frimpong 2016). Notwithstanding mixed conclusion, the need for further related studies in emerging stock markets and exchange rate of developed economies cannot be overlooked due to the diversification benefits offered by emerging markets to the international portfolio investors.

Although prior literature on the dependency between stock markets, exchange rates and commodities have been extensive, the results remain mixed. Abakah et al. (2021) mention about the methodology that fails to capture dynamics in the data generating process of financial time series such as nonlinearities, thin trading, noise among others can affect results obtained.

Our study applies the forecasted error variance decomposition (FEVD) framework based on the Vector Autoregressive Model of Diebold and Yilmaz (2014) and Baruník and Křehlík (2018). Methods by Diebold and Yilmaz (2014) and Baruník and Křehlík (2018) measure the strength and structure of the volatility spillover between emerging markets and three major global financial markets: US S&P 500, Brent Crude Oil and Dollar Index in the time frequency domain. The significance of applying these methodologies lies in the fact that the financial markets function as a system. The measure of connectedness based on the FEVD volatility spillover would help in minimizing portfolio risk and optimizing the allocations in portfolios (Diebold and Yilmaz 2014). In addition, our study extends the extant literature on volatility spillover by considering the importance of noise in the volatility spillover in the time frequency domain.

According to Gencay et al. (2002), denoising helps improve the quality of signals and power of optimality. Further, according to Tiwari and Gupta (2019), the wavelet nonlinear denoising model is an appropriate and efficient method for denoising data. In the context of portfolio management, a stable hedge ratio and an optimal portfolio weight require low volatility (Olson, Vivian, and Wohar 2017; Belhassine and Karamti 2021). A stable hedge ratio and optimal portfolio weight lead to avoiding frequent portfolio rebalancing, which is costly, thereby saving costs and improving portfolio returns. Since noise impacts the financial markets' volatility,

our study investigates connectedness by denoising the data using the wavelet nonlinear denoising model.

Our contribution to the literature of volatility spillover lies in the application of the wavelet denoising technique and estimation of integration based on denoised volatility spillover across time and frequency domain. Our study is the first of its kind to address this important aspect the financial market integration, which is missing so far in the literature, i.e. whether integration is fundamental or noisy based on volatility spillover. Our study focuses on the noise, volatility, volatility spillover, and resulting connectedness between emerging markets, emerging markets as an asset class, and global factors like US equity market, oil, and exchange rate at different time scale. We find that the integration between emerging and global markets is fundamental in the long run and noisy in the short run.

III. Empirical methodology

The Diebold and Yilmaz (2014) and Baruník and Křehlík (2018) methodologies are used for estimation of connectedness in the time and frequency domain respectively. We use the wavelet nonlinear shrinkage model for denoising the data. All three methodologies are discussed in the Online Appendix 1.

IV. Data description

We have taken the top five emerging stock markets based on market capitalization such as India BSE SENSEX (SENSEX), China Shanghai Composite Index (SHCOMP), South Africa JSE Africa All Share Index (JALSH), Korea Composite Stock Price Index (KOSPI), and Taiwan TSEC Weighted Index – TAIEX (TWSE), and MSCI Emerging Market Index as an asset class of portfolios of emerging markets (MSCI). US S&P 500 (SPX), Brent Crude Oil Spot Price (BRENT), and Bloomberg Dollar Spot Index, a basket of 10 currencies (BBD) taken as global asset classes.

Daily closing price data are collected from 4 January 2005, to 10 November 2021, based on availability as a common pool of data. Return is

calculated as log difference between the closing price at t and $t-1$. Volatility is estimated using GARCH family of models based on normal errors. The descriptive statistics are presented through Table S1⁴ The highest (lowest) return emerging markets are SENSEX followed by JALSH (SHCOMP and TWSE. In terms risk measured by standard deviation, high (low) risk country is SHCOMP (TWSE). All the return series are negatively skewed except BBD, leptokurtic and non-normal. Further, heteroscedasticity and autocorrelation are reported. Based on conventional stationarity test, all the series are stationary. The nonlinearity test results in Table S2 indicate that all the series are non-linear except BBD. The unconditional correlation matrix of all the variables is presented in Figure 1.

As evident from Figure 1, while all the financial markets are negatively related to dollar index, they are all positively related to oil price. JALSH (SHCOMP) is the most (least) correlated market with global factors. It shows some kind of independence of Chinese market.

Further emerging market as a portfolio (MSCI) is highly correlated to global factors relative to individual emerging markets. However, this bivariate measure of correlation fails to explain the direction of connectedness, connectedness at different time scales. Diebold and Yilmaz (2014) and Baruník and Křehlík (2018) methodologies applied in this study would help us to find the answer to those questions.

V. Empirical results and discussion

The empirical results of DY and BK are discussed in two parts. In the first part, the static analysis is presented through spillover matrix indicating the total, pairwise and net volatility spillover in time and frequency domain. Total spillover indicates systemic integration of all the financial markets considered in the study, pairwise measures bilateral integration between two markets in the system and finally net spillover indicates net directional integration of a financial market as either a receiver or transmitter of volatility. Since, financial, and economic environments are dynamic, above spillover

⁴Online Appendix 2 report Table 1 (Descriptive statistics) and Table 2 (Non-linearity test)..

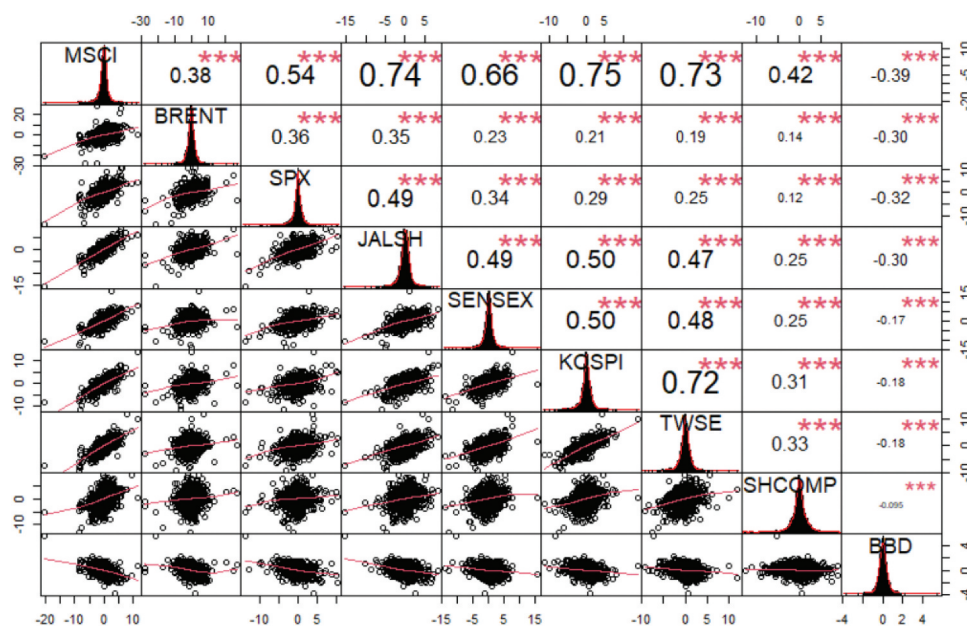


Figure 1. Unconditional correlation matrix between emerging equity markets and world financial markets such as Brent crude oil and dollar index. The size of the value of the correlation coefficient shows the strength of the relationship.

analysis is done in a time varying framework in the second part of analysis. The time varying parameters capture the non-linearity in volatility spillover Diebold and Yilmaz (2014). BK analysis is done at four different frequencies such as frequency 1, 2, 3, and 4 indicating a period of 1–2, 2–5, 5–15 and more than 15 days respectively. For brevity the results are discussed for frequency 1 (1–2 days) and 4 (more than 15 days) representing short and long run respectively. Results of other two frequencies are available upon request.

Static analysis of volatility spillover

First, the DY total, pairwise, and net volatility spillover analysis are presented and discussed through Table 1. Second, BK volatility spillover analysis are presented through Tables 2 and 3 for frequency 1 and 4, respectively. The spillover based on original, and denoised time series data presented through Panel A and Panel B will be called as raw and denoised spillover respectively henceforth.

A two-sample *t*-test with assumption of equal variance confirms that the raw and denoised volatility spillover are different in both time and frequency domain. Table 1 shows that, the total raw volatility spillover is 67.84%, which is less than the denoised spillover of 69.74%. The higher value of

total volatility spillover indicates the existence of systemic integration as 67% of the volatility of the markets in this study is due to their connectedness. As far as the impact of noise is concerned, the average systemwide connectedness is understated by 2.8% due to noise. It implies relatively less diversification opportunities for investment in the markets under study.

In the bilateral context, the connectedness of MSCI as an asset class with BBD and BRENT (SPX) is understated (overstated) due to noise. As far as individual emerging markets are concerned, a similar impact of noise on connectedness is observed, except in China where it is overstated across all the global factors. However, the Chinese market shows independence in providing portfolio diversification opportunities. Further, China is found to be more connected though MSCI rather than SPX, BBD, and BRENT. Overall, in the time domain, the impact of noise is relatively less on the connectedness of the financial markets under study.

The net volatility spillover presented through the last row of Table 1 indicates the net position of the individual financial market as a transmitter (net positive) or receiver (net negative) of volatility shock from the system. As far as global factors are concerned, SPX (BBD and BRENT) is the net transmitter (receiver) of volatility to (from) the

Table 1. DY volatility spillover matrix.

Panel A	MSCI	BRENT	SPX	JALSH	SENSEX	KOSPI	TWSE	SHCOMP	BBD	FROM
MSCI	25.09	3.21	15.33	15.18	5.78	10.31	12.36	7.49	5.26	8.32
BRENT	11.97	32.25	18.28	13.76	3.26	6.48	3.72	7.4	2.89	7.53
SPX	17.23	4.76	33.68	13.82	3.39	8.34	7.85	6.27	4.66	7.37
JALSH	18.52	4.47	18.95	23.8	6.79	8.29	8.41	7.12	3.66	8.47
SENSEX	16.62	1.65	15.42	12.82	23.73	7.83	10.3	9.13	2.51	8.47
KOSPI	20.31	1.81	19.89	13.31	5.74	18.72	11.13	5.94	3.15	9.03
TWSE	16.87	0.83	16.18	11.61	6.59	11.58	24.94	9.21	2.2	8.34
SHCOMP	6.28	0.85	0.86	1.42	4.52	4.02	5.92	75.85	0.27	2.68
BBD	15.79	4.58	17.16	13.73	1.96	4.99	6.12	4.31	31.37	7.63
TO	13.73	2.46	13.56	10.63	4.23	6.87	7.31	6.32	2.73	TSI=67.84
<i>NET</i>	<i>5.41</i>	<i>-5.06</i>	<i>6.19</i>	<i>2.16</i>	<i>-4.25</i>	<i>-2.16</i>	<i>-1.03</i>	<i>3.63</i>	<i>-4.89</i>	
Panel B	MSCI	BRENT	SPX	JALSH	SENSEX	KOSPI	TWSE	SHCOMP	BBD	FROM
MSCI	22.64	4.25	12.86	17.56	4.82	11.48	13.28	6.87	6.25	8.6
BRENT	12.5	28.45	19.59	17.15	2.22	6.41	3.31	7.54	2.82	7.95
SPX	16.88	5.52	28.95	15.97	2.89	9.64	8.64	5.78	5.74	7.89
JALSH	17.28	5.7	16.59	24.56	5.73	9.66	8.76	6.68	5.03	8.38
SENSEX	15.57	2.82	12.57	14.44	22.06	9.31	11.33	8.59	3.31	8.66
KOSPI	19.37	2.65	16.18	15.3	4.69	19.77	12.33	5.66	4.05	8.91
TWSE	15.37	1.49	11.92	12.58	6.35	15.2	25.96	8.45	2.69	8.23
SHCOMP	6.01	0.79	0.57	1.57	5.36	6.59	6.6	72.48	0.04	3.06
BBD	16.15	4.25	17.2	18.61	1	5.35	6.68	3.31	27.45	8.06
TO	13.24	3.05	11.94	12.57	3.67	8.18	7.88	5.88	3.33	TSI=69.74
<i>NET</i>	<i>4.64</i>	<i>-4.90</i>	<i>4.05</i>	<i>4.19</i>	<i>-4.99</i>	<i>-0.73</i>	<i>-0.35</i>	<i>2.82</i>	<i>-4.73</i>	

TSI indicates total spillover index, i.e. systemwide spillover. The diagonal values are spillovers from own market shock. The off-diagonal values are shocks from other markets. Panel A and Panel B present raw and denoised volatility spillover respectively.

system. MSCI as a portfolio of emerging market and two individual emerging markets, i.e. JALSH and SHCOMP are the net transmitters of volatility to the system. While SEXSEX, KOSPI and TWSE are the net receivers of volatility from the system. As far as the impact of noise evidenced from Panel B is concerned, a marginal over and understatement in the magnitude of the volatility spillover is observed, whereas their net positions in the system are not changed.

To understand the integration dynamics in the frequency domain, the BK volatility spillover results are presented and discussed through Tables 2 and 3. Tables 2 and 3 present the volatility spillover in the higher frequency (short run) i.e. freq1 and lower frequency (long run) i.e. freq4 respectively.

As evidenced by the short-term results in Table 2, the total connectedness based on denoised volatility spillover is 9%, which is 55% less than the connectedness based on raw volatility spillover at 20%. That means noise dominates the integration between the markets under study in the short run. Therefore, short-term players in these markets must consider noise in their investment strategy. This justifies our study of denoised-based volatility spillover.

However, long-term results in Table 3 show a marginal difference between raw and denoised

volatility spillover of 66.07% and 68.51%, respectively, and both are much higher than their short-term counterparts.

These results confirm the findings of Graham et al. (2012) and Marfatia (2017) who reported a high degree of comovement in the long run in the context of emerging and developed stock markets.

A few important things are implied from these findings. One, in the long run, more than 60% of the variation in emerging market return is system-dependent. However, in the short run, it is more idiosyncratic.

Second, long-term integration between the markets under study is fundamental and it is noisy in the short term. It also indicates the high-level persistence of volatility spillover among the financial markets (Baruník and Křehlík 2018).

Third, it is observed across time that the importance of noise declines in the long run. So, the financial markets in the long run are fundamentally connected, underscoring the synchronization of business cycle across the economy in line with the findings of Bordo and Helbling (2003).

Fourth, the time domain connectedness-based DY results reflect the long-term aspect of the connectedness. This again justifies our study of estimating the integration based on raw and denoised volatility spillover both in the time and frequency domains.

Table 2. The BK spillover matrix at frequency 1 for bands 3.14 to 1.57 which roughly corresponds to 1 days to 2 days.

Panel A	MSCI	BRENT	SPX	JALSH	SENSEX	KOSPI	TWSE	SHCOMP	BBD	FROM_ABS	FROM_WTH
MSCI	23	5	5	11	7	8	7	1	5	5	13.28
BRENT	2	22	1	2	0	0	0	0	2	1	1.81
SPX	8	5	37	9	2	1	1	0	6	3	8.29
JALSH	10	5	5	25	3	3	2	0	4	3	8.29
SENSEX	5	1	1	3	25	2	2	0	1	2	4.04
KOSPI	3	1	0	1	1	12	3	0	0	1	2.86
TWSE	7	1	0	2	3	9	26	1	0	3	6.49
SHCOMP	2	2	0	1	1	1	1	11	0	1	2.67
BBD	1	1	0	1	0	0	0	0	11	0	0.69
TO_ABS	4	2	1	3	2	3	2	0	2	20	
TO_WTH	10.28	5.38	3.61	8.21	4.66	6.71	4.25	0.72	4.6		48.42
NET	-1.24	1.47	-1.93	-0.03	0.26	1.58	-0.92	-0.80	1.61		
Panel B	MSCI	BRENT	SPX	JALSH	SENSEX	KOSPI	TWSE	SHCOMP	BBD	FROM_ABS	FROM_WTH
MSCI	11	3	4	7	3	3	2	0	4	3	17.35
BRENT	1	11	0	2	0	0	0	0	1	0	2.77
SPX	3	2	15	5	1	0	0	0	3	2	10.05
JALSH	4	3	4	9	1	1	0	0	3	2	10.17
SENSEX	2	1	1	1	10	0	0	0	0	1	3.67
KOSPI	1	1	0	0	1	3	1	0	0	0	1.94
TWSE	2	1	0	1	1	2	8	0	0	1	4.08
SHCOMP	1	1	0	0	0	0	0	2	0	0	2.04
BBD	0	0	0	0	0	0	0	1	3	0	1.46
TO_ABS	2	1	1	2	1	1	0	0	1	9	
TO_WTH	8.91	7.95	6.18	10.51	4.28	4.36	2.71	1.01	7.63		53.54
NET	-1.46	0.90	-0.67	0.06	0.11	0.42	-0.24	-0.18	1.07		

The forecast error variance of i^{th} market contributed by j^{th} market is presented through off-diagonal elements. TO_ABS (column sum) measure the amount of variance going from j^{th} market to remaining i^{th} markets in the system and FROM_ABS (row sum) measure the amount of variance contributed by i^{th} to remaining j^{th} markets. TO_WTH and FROM_WTH are the corresponding values which includes own variance. Panel A and Panel B present raw and denoised volatility spillover respectively. The high frequency (short run) Total Spillover Index is marked in bold in the bottom right corner cell.

As far as bilateral connectedness is concerned, while volatility spillover from all three global markets to MSCI as an emerging market asset class is overstated due to noise in the short run (1–2 days),

it is overstated in the long run (more than 15 days) from SPX only. As far as individual emerging markets are concerned, although the mixed impact of noise on the volatility spillover from global markets

Table 3. The BK spillover matrix at frequency 4 for band 0.21 to 0.00 which corresponds to more than 15 days.

Panel A	MSCI	BRENT	SPX	JALSH	SENSEX	KOSPI	TWSE	SHCOMP	BBD	FROM_ABS	FROM_WTH
MSCI	23.09	2.8	14.83	14.19	5.2	9.61	11.78	7.38	4.86	7.85	8.14
BRENT	11.83	30.38	18.19	13.57	3.23	6.46	3.71	7.4	2.75	7.46	7.74
SPX	16.56	4.36	30.64	13.08	3.2	8.21	7.78	6.26	4.2	7.07	7.33
JALSH	17.67	4.08	18.48	21.71	6.53	8.04	8.26	7.11	3.32	8.17	8.47
SENSEX	16.15	1.54	15.31	12.56	21.62	7.66	10.15	9.11	2.44	8.32	8.63
KOSPI	20	1.74	19.8	13.15	5.62	17.69	10.85	5.93	3.11	8.91	9.24
TWSE	16.23	0.71	16.06	11.36	6.36	10.85	22.78	9.16	2.16	8.1	8.4
SHCOMP	6.08	0.69	0.82	1.29	4.44	3.9	5.81	74.91	0.26	2.59	2.68
BBD	15.73	4.52	17.13	13.68	1.95	4.99	6.11	4.27	30.42	7.6	7.88
TO_ABS	13.36	2.27	13.4	10.32	4.06	6.64	7.16	6.29	2.57		
TO_WTH	13.86	2.35	13.9	10.7	4.21	6.88	7.43	6.53	2.66	66.07	68.52
NET	5.51	-5.19	6.33	2.16	-4.27	-2.28	-0.94	3.70	-5.03		
Panel B	MSCI	BRENT	SPX	JALSH	SENSEX	KOSPI	TWSE	SHCOMP	BBD	FROM_ABS	FROM_WTH
MSCI	21.54	3.93	12.45	16.84	4.4	11.08	13	6.82	5.91	8.27	8.46
BRENT	12.43	27.22	19.55	17.05	2.21	6.41	3.31	7.54	2.75	7.92	8.1
SPX	16.46	5.22	27.12	15.27	2.68	9.55	8.56	5.77	5.36	7.65	7.83
JALSH	16.83	5.35	16.19	23.44	5.54	9.52	8.7	6.67	4.72	8.17	8.36
SENSEX	15.38	2.74	12.47	14.27	20.82	9.15	11.26	8.58	3.29	8.57	8.77
KOSPI	19.25	2.6	16.1	15.19	4.58	19.28	12.24	5.66	4.03	8.85	9.05
TWSE	14.98	1.38	11.75	12.35	6.14	14.71	24.7	8.44	2.66	8.05	8.23
SHCOMP	5.9	0.67	0.51	1.5	5.29	6.52	6.54	72.02	0.04	3	3.07
BBD	16.12	4.23	17.18	18.58	0.98	5.35	6.65	3.25	27.05	8.04	8.22
TO_ABS	13.04	2.9	11.8	12.34	3.54	8.03	7.81	5.86	3.2		
TO_WTH	13.34	2.97	12.07	12.62	3.62	8.22	7.98	5.99	3.27	68.51	70.08
NET	4.77	-5.01	4.15	4.17	-5.03	-0.82	-0.24	2.86	-4.84		

The forecast error variance of i^{th} market contributed by j^{th} market is presented through off-diagonal elements. TO_ABS (column sum) measure the amount of variance going from j^{th} market to remaining i^{th} markets in the system, and FROM_ABS (row sum) measure the amount of variance contributed by i^{th} to remaining j^{th} markets. TO_WTH and FROM_WTH are the corresponding values which includes own variance. Panel A and Panel B present raw and denoised volatility spillover respectively. The low frequency (long run) Total Spillover Index is marked in bold in the bottom right corner cell.



Figure 2. DY and BK total volatility spillover (TVS). Orange and blue colour represent denoised and raw total volatility spillover, respectively. BK1 and BK4 are freq1 and freq4 indicating 1–2 days and more than 15 days, respectively. Extension DN indicates denoised.

is observed in the short run, the impact in the long term corresponds to the average impact observed in the time domain as per the DY results.

One of the important findings in the bilateral connectedness is that, in the short run, five emerging markets are more integrated to MSCI as an emerging market asset class than the three global factors of SPX, BRENT, and BBD. However, in the long run, except for China, the other four individual emerging markets – India, Taiwan, South Korea, and South Africa – are equally integrated to both global financial markets and MSCI as an asset class. But it is more integrated to MSCI than the global markets.

The net positions of the financial markets as either a net receiver or transmitter of volatility in the system are reported through the last rows of Tables 2 and 3. The net positions of the markets are reversed while moving from short to long run. As far as the impact of noise on net position of the financial market is concerned, no impact is observed. However, the magnitude of net volatility spillover is under and overstated across the all the financial markets both in short and long run.

Dynamic analysis volatility spillover

In this section, we investigate how the cointegration and the impact of noise on cointegration

between emerging and global markets will behave in a dynamic macroeconomic and financial environment using a rolling window approach with a window size of 250 days and fixed lag determined by the Akaike information criterion (AIC). The time varying evolution of the total and pairwise volatility spillover based cointegration are graphically presented through Figures 2–5a, respectively, for DY and BK analyses. For brevity, although BK analysis is done at four different frequencies, a graphical presentation is done for Freq1 and Freq 4 representing short- and long-run respectively. However, Freq2 and Freq3 graphical analysis along with net volatility spillover graph are available upon request.

As evident from Figure 2, the DY raw and denoised volatility spillover are time varying. Like volatility, spillover of volatility also clusters reflecting the high, low, and average volatility spillover regime. Chevallier et al. (2018) mentioned the geographical clustering of volatility spillover in the cases of Pacific Basin stock markets.

Specifically, clustering of volatility spillover is pronounced during a crisis period across time as is evident during the 2007–2008 global financial crisis, 2011 European crisis, and 2015–2016 global stock market turmoil due to turbulence in Chinese stock market. The higher level of dependency

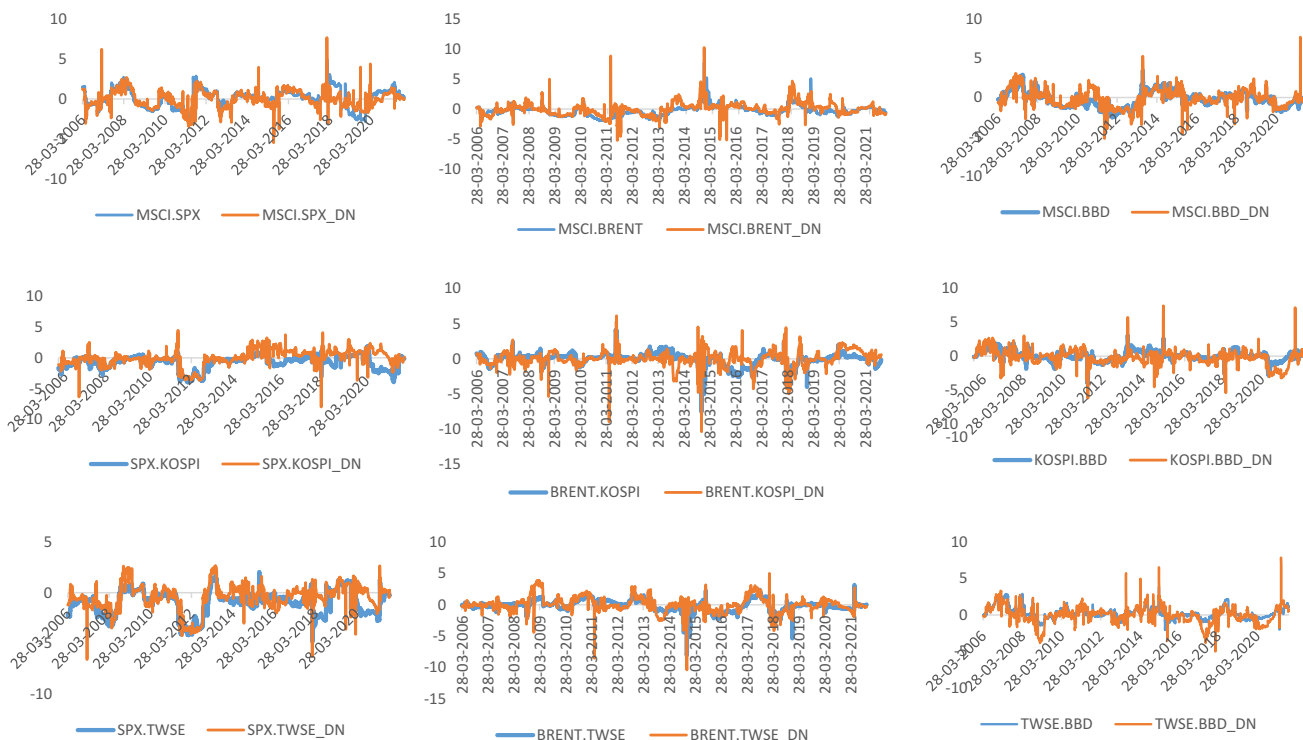


Figure 3a. DY net pairwise volatility spillover. Orange and blue colour represent denoised and raw net pairwise spillover, respectively. Net pairwise spillover= to the market j from market i – from the market j to the market i . So positive and negative value mean net transmitter to and receiver from the market i . Extension DN indicates denoised.

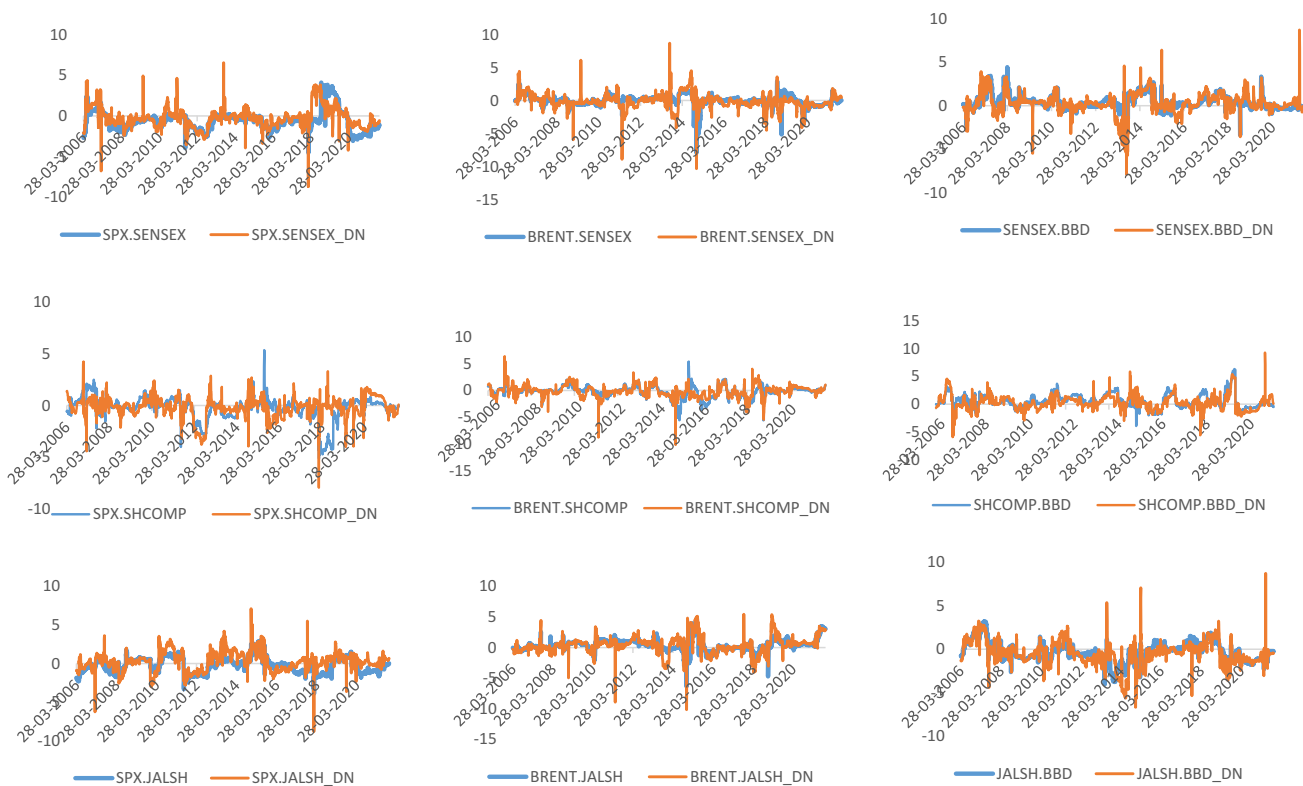


Figure 3b. DY net pairwise volatility spillover. Orange and blue colour represent denoised and raw net pairwise volatility spillover, respectively. Net pairwise spillover= to the market j from market i – from the market j to the market i . So positive and negative value mean net transmitter to and receiver from the market i .

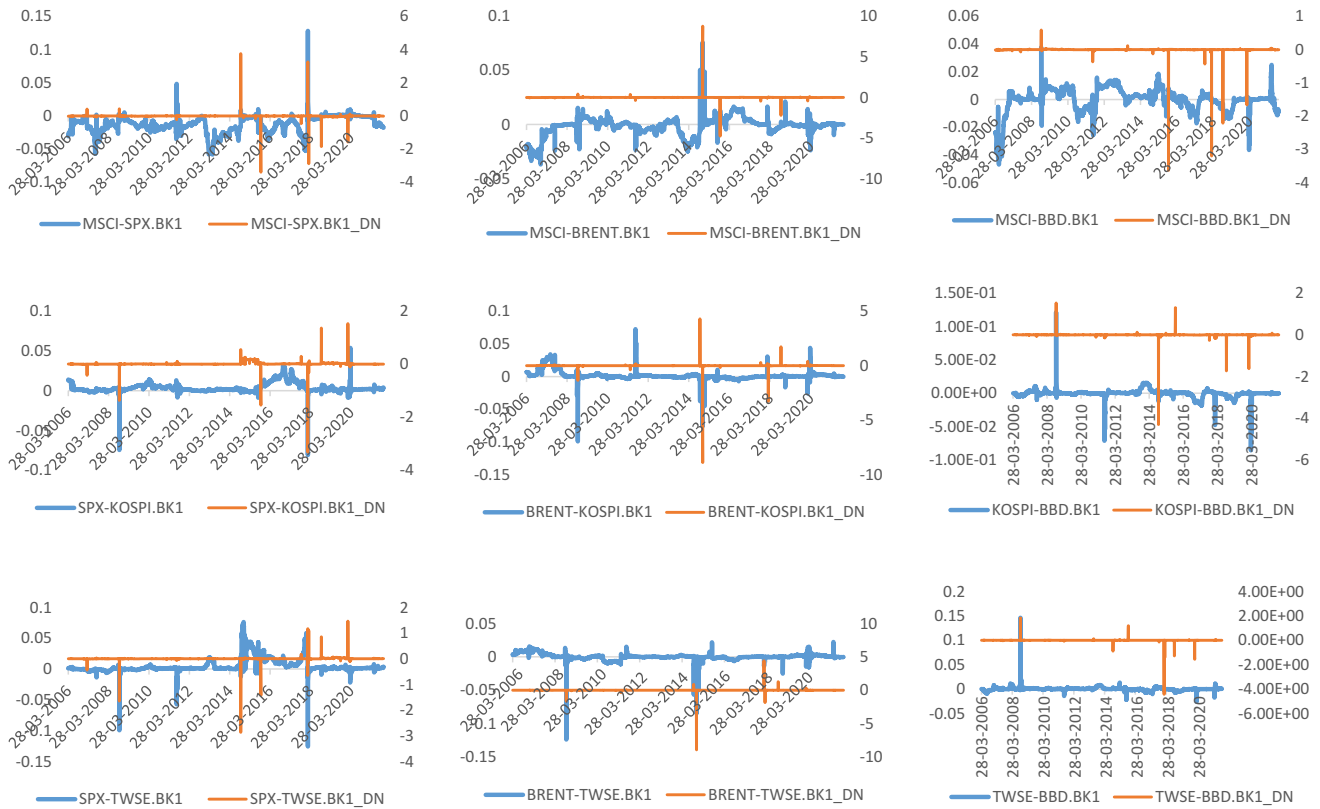


Figure 4a. BK net pairwise volatility spillover at frequency1 (BK1) corresponding to band: 3.14 to 1.57 which is 1 days to 2 days. Orange (right axis) and blue (left axis) colour represent denoised and raw net pairwise spillover, respectively. Extension DN indicates denoised.

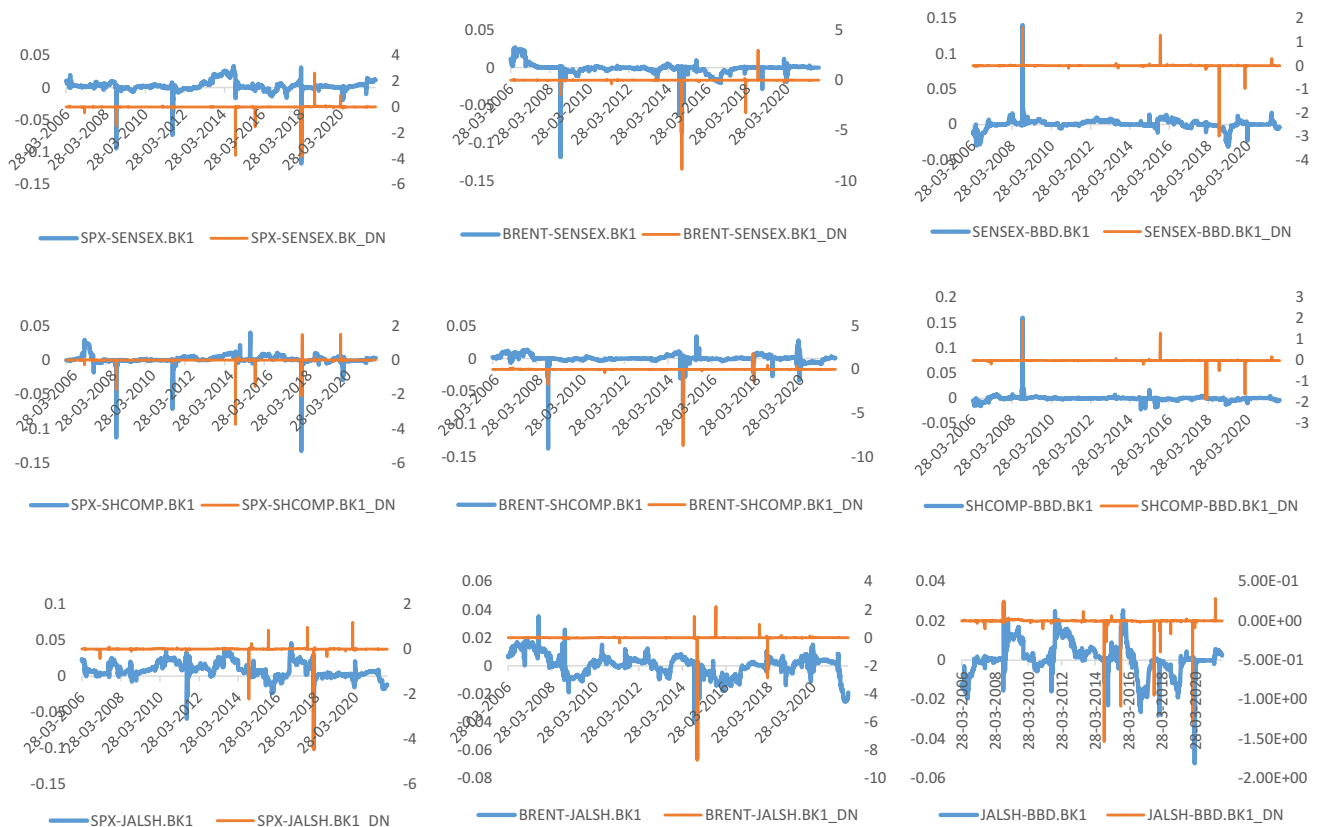


Figure 4b. BK net pairwise volatility spillover at frequency1 (BK1) corresponding to band: 3.14 to 1.57 which is 1 days to 2 days. Orange (right axis) and blue (left axis) colour represent denoised and raw net pairwise spillover, respectively.

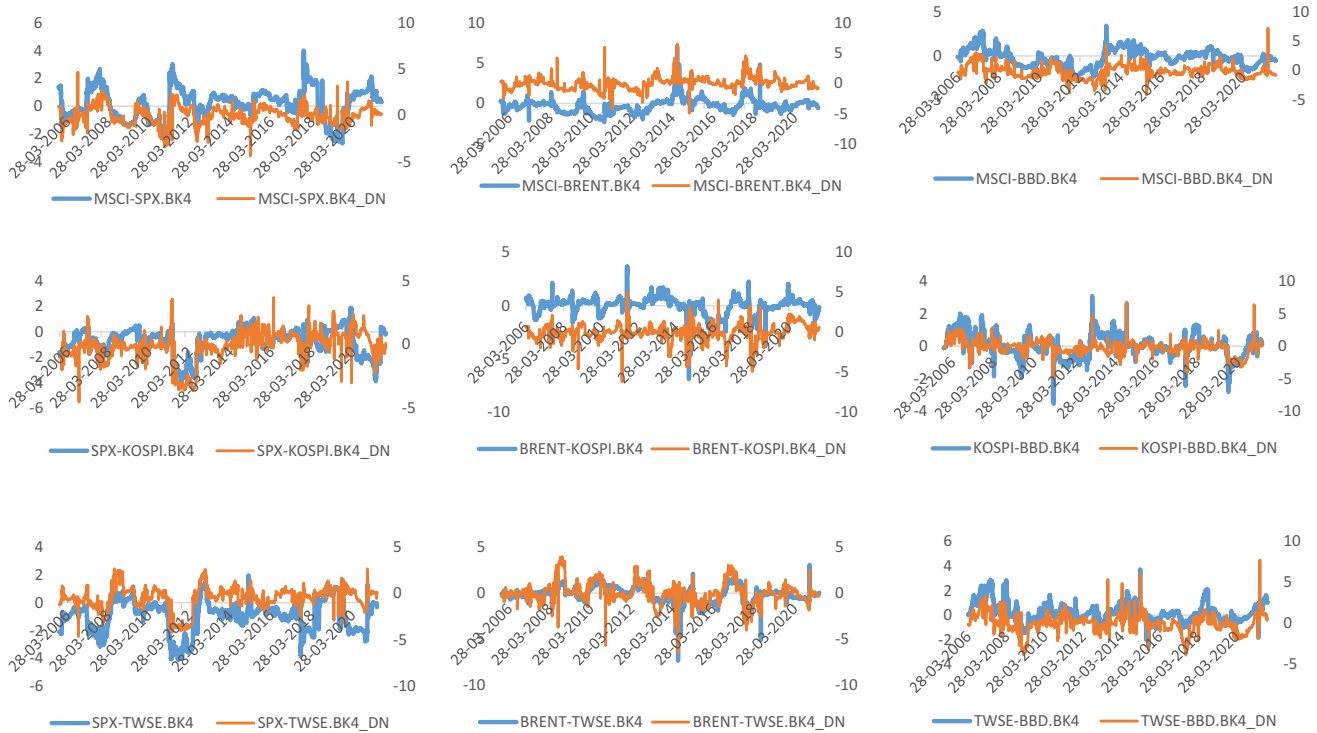


Figure 5a. BK net pairwise volatility spillover at frequency4 (BK4) corresponding band: 0.21 to 0.00 which is more than 15 days. Orange (right axis) and blue (left axis) colour represent denoised and raw net pairwise spillover, respectively extension DN indicates denoised.

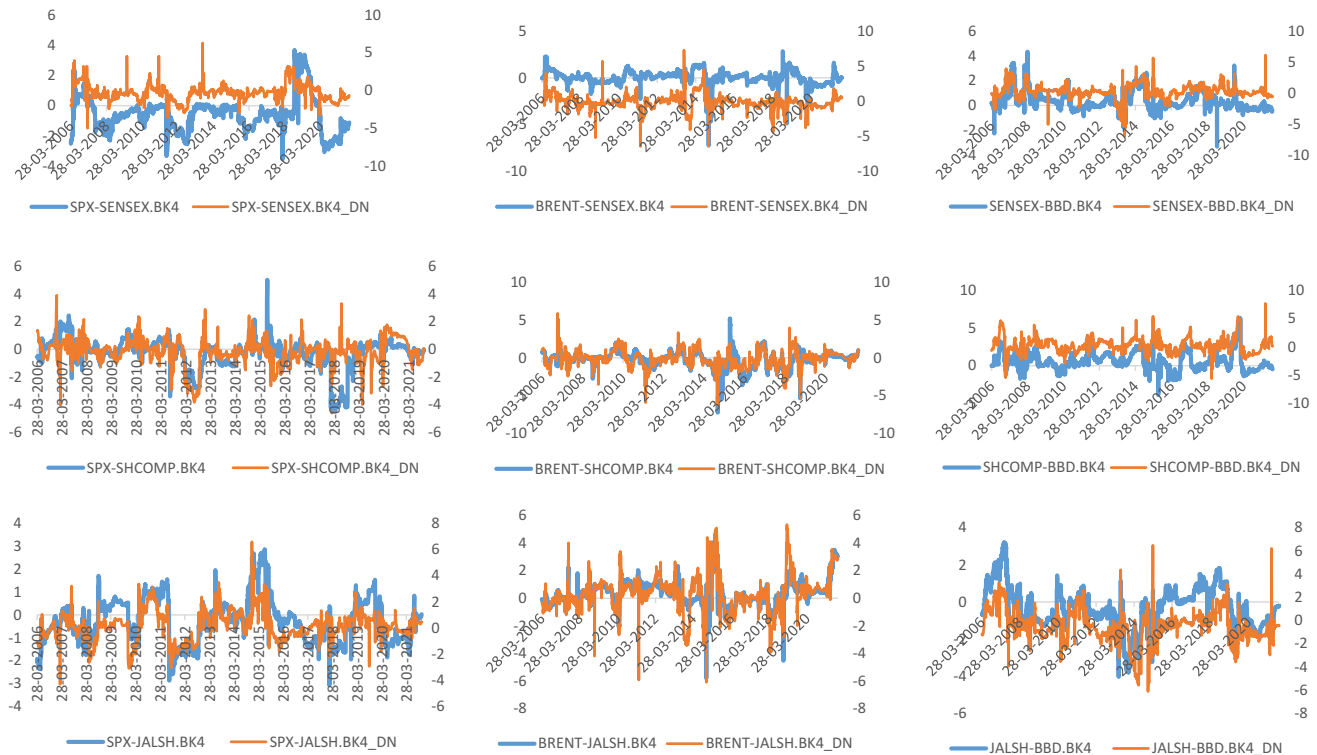


Figure 5b. BK net pairwise volatility spillover at frequency4 (BK4) corresponding band: 0.21 to 0.00 which is more than 15 days. Orange (right axis) and blue (left axis) colour represent denoised and raw net pairwise spillover, respectively.

through volatility spillover across markets during a crisis is also supported by the study of Gong, Tang, and Wang (2019).

One interesting thing observed is that, during the financial market crisis, both raw and denoised volatility spillovers are of similar magnitude. But during the other periods, the significant impact of noise is observed in the volatility spillover and resulting integration between the emerging and global markets. Moreover, the presence of noise leads to overstatement and understatement of spillover in the time domain.

BK raw and denoised volatility spillover presented in Figure 2 show that, in the short run, integration/connectedness between financial market is noisier than in the long run, which is more fundamental. Another interesting aspect of volatility spillover observed during financial market crises is that the short-term denoised volatility spillover is significantly greater than its long-term counterparts. This implies that the integration between emerging and global financial markets during a financial market crisis is due to short-term factors. On the other hand, in the remaining periods under study, the long-term aspect of spillover is greater than its short-term counterparts, showing the existence of fundamental connectedness between emerging and global financial markets. This justifies our first-ever study on denoised volatility spillover in the frequency domain.

Now we will discuss the net pairwise volatility spillover to understand how bilaterally financial markets connectedness is based on volatility spillover in the system. DY and BK pairwise net spillover are presented through Figures 3a–5a respectively.

The time varying volatility spillover indicates that although MSCI is connected to global factors such as SPX, BBD and BRENT, its position as net receiver and transmitter of volatility from and to those factors are changing in time and frequency domain. Like in case of static analysis, over and understatement of connectedness are observed throughout in both time and frequency domain and it more prominent in short term. Further, the average time domain connectedness reflects long term aspect of connectedness as in case of static analysis.

The raw DY net pairwise spillover in Figure 3 shows that MSCI is the net transmitter (receiver) of volatility to (from) Brent and BBD (SPX). However, denoised spillover shows that it is occasional and mutual and not continuous. Similarly, the net pairwise spillover trend is observed between individual emerging markets and SPX, Brent, and BBD. Further, understatement and overstatement of net pairwise spillover is observed.

In the case of individual emerging markets, the time varying DY spillover upholds the connectedness with SPX as a global factor and MSCI, except China for which MSCI is a major factor. However, in the short run (1–2 days) as evidenced from Figure 4, they are more connected with MSCI than the global factors. In the long run (more than 15 days), as evidenced from Figure 5a, in case of static analysis both global and MSCI are important factors in terms of connectedness based on volatility spillover. Like in the time domain, overstatement, and understatement of connectedness between emerging and global markets due to noise are observed in both the short and long term. The impact is more prominent in the short run relative to the long run. This confirms the results of static analysis that the emerging and global market connectedness is fundamental (noisy) in the long (short) run.

VI. Concluding comments

Given the significance of emerging equity markets for global investors from portfolio diversification perspective, the study investigates the integration between five largest emerging stock markets and MSCI as an emerging market asset class and global markets such as US S&P500, Brent crude oil and Dollar index. As noise misleads the results, we have used the wavelet denoised volatility spillover framework of Diebold and Yilmaz (2014) and Baruník and Křehlík (2018) to estimate the linkages in time and frequency domain, respectively. We find high degree of systemic connectedness between these set of markets in the long run. The impact of noise on connectedness is observed more in short than long run. Thus, our study confirms the existence of fundamental (noisy) connectedness in the long (short) run. Noise impacts connectedness throughout in both time and frequency domain with varied magnitude. While

emerging markets are more connected to MSCI in the short term, in the long term, they are more connected to both MSCI and global financial markets. Future research related to impact of noise may be conducted across different set of assets and markets considering the market conditions such as bull, bear, and normal markets.

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