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*Research Article*

# Time-Frequency Connectedness between Shariah Indices in a Systemic Crisis Era

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We examine the time- and frequency-domain spillover connectedness between regional and world Shariah indices. The spillover index approach is employed with data over the period from April 30, 2012, to May 9, 2022, for African, American, Asian, European, and world emerging and developed markets' Shariah-based equity indices. The results indicate significant time- and frequency-dependent spillovers between Shariah indices. The world and developed markets' Shariah indices transmit the greatest return spillover to their African and Asian counterparts, which act as net recipients of system spillovers. Our findings show that Asian Shariah assets are a perfect hedge against all relevant market shocks over the last decade. Our findings have implications for Shariah market regulators, investors, practitioners, and policymakers.

## 1. Introduction

Complexities in financial markets result in heterogeneous market connectedness not only in conventional markets but also in faith-based investments. One of the notable faith-based investment vehicles is Shariah assets. Shariah indices contain equities that adhere to the Islamic Shariah rules established by Shariah scholars. As a corollary to the rigorous procedures followed in classifying equities as Shariah compliant, numerous stocks are screened out, resulting in a smaller Shariah index portfolio than the traditional benchmark [1, 2]. As a result, the issue of Shariah indices being underperformed by their conventional equivalents has been a concern for market participants [3]. This influences empirics, practitioners, and academics to validate this by analysing the performance of Shariah and conventional indexes over numerous years [1–16]. Given the credence that Shariah index portfolios may be outperformed by conventional portfolios, numerous prior scholarly assessments will be incomplete if the properties of Shariah markets (i.e., contributors to the Shariah index) towards risk reduction are unknown empirically.

Faith-based investments are gaining increasing interest among all classes of investors owing to the recent growth of the Islamic financial market and the ability of Shariah-compliant assets to meet investor needs [8, 14]. Central to portfolio management is the connectedness between assets [17–21], and the need to manage portfolios is highlighted by the devastating impacts of financial meltdowns over the last decade, notable amongst them being Brexit, the trade tension between China and the US, the COVID-19 pandemic, and the Russia-Ukraine conflict. Of the numerous empirical works on Shariah markets, little is known about the risk management characteristics of major Shariah indices across regions and the globe. The recent study by Balli et al. [7] has focused on firm-level data, which have little to offer in terms of Shariah index portfolios relative to regional Shariah indices.

Moreover, investors most likely adapt to changing market dynamics during crisis periods to reallocate assets and rebalance their portfolios based on their risk appetite [17, 22–26]. Theoretically, the fractal market hypothesis suggests that market response to shocks differs across time and trading horizons [27]. The implication is that the connectedness between markets would differ across short-, medium-, and long-term trading periods, yet existing works on Shariah markets fail to cater to this complexity in investor behaviour and market response.

Market participants mostly trade along investment horizons, and hence, such an analysis is key to determining how they allocate assets across both time and trading (frequency) horizons. Market participants and regulators alike need empirical evidence to influence their decisions on Shariah investments and market regulation, respectively. As a result, several questioning themes may be of concern to investors and policymakers. For instance, inter alia, to what extent are Shariah markets connected? Are there significant return spillovers between Shariah markets? Which markets are the largest transmitters or recipients? How are spillovers between Shariah markets distributed across trading horizons? Are Shariah markets susceptible to financial contagion? Are there diversification and safe-haven benefits between Shariah markets in the context of spillovers?

Answers to these questions warrant empirical assessments of the connectedness between Shariah markets. We contribute to the literature in this direction by investigating the return spillover connectedness between Shariah indices across the world. The studys' main contributions are as follows: First, novel to the literature, we provide rigorous assessments of the static (overall) and time- and frequency-varying connectedness of major Shariah indices. Such an analysis is instrumental to risk management and effective portfolio construction but is nonexistent in the empirical literature concerning Shariah portfolio indices. Second, through spillover analysis, we provide empirical evidence for risk management concerning investment in Shariah-based assets, and this is particularly beneficial to the growing investor base for Shariah-compliant assets in periods of heightened systemic crises such as the ongoing era of the coronavirus pandemic and the Russia-Ukrain geopolitical conflict. Spillover analysis is essential to reveal the directional linkages between diverse Shariah markets in a system and helps identify, on a pairwise basis, the contribution of each Shariah market to system spillovers and how they evolve across both time and frequency domains. These dynamics are important because the sample period captures the aforementioned key events, and as a result, knowing the evolution of connectedness between Shariah investments would influence the timely rebalancing of Shariah asset-dominated portfolios.

Third, the study period covers significant events, both past and present (such as Brexit, the financial meltdowns of Chinese and Russian markets, the US-China trade conflict, the COVID-19 pandemic, and the Russia-Ukraine war), in the history of financial markets over the last decade. These events provide a means of analysing the cross-market connectedness between Shariah assets over a wide range of financial crises, either of systemic or idiosyncratic character. This makes the use of time-frequency approaches relevant. Fourth, in addition to the world Shariah index, we cover Shariah portfolio indices from six major regions, viz., Africa, America, Asia, developed markets, emerging markets, and Europe. The use of these variables in a single study is new to the empirical literature.

Methodologically, to cater to heterogeneous market linkages and investor responses, we primarily employ the spillover index approach of Baruník and Křehlík [28]. This approach is based on heterogeneous shock frequency responses within a rolling window paradigm. It is effective in detailing the transmission sources of system spillovers, recipients of shocks, and the size of contagion (if any). More importantly, BK-18 isolates frequency-domain spillovers from aggregate spillovers through decomposition, which is necessary for detailing spillover dynamics across trading horizons for market participants. Given that market participants (policymakers) trade (plan) along heterogeneous investment horizons (short term, medium term, and long term), this approach is particularly important to this study, unlike the earlier approach of Diebold and Yilmaz [19], which assumes a static measure for spillovers.

The approach of Diebold and Yilmaz [19] has recently been modified by the authors of [29] in their time-varying parameter vector autoregression (TVP-VAR)-based spillover technique, but it does not segregate aggregate spillovers into their frequency components, as performed by the BK-18 approach. Therefore, to overcome the issue of arbitrary rolling window size and loss of observations through the rolling window process, as Antonakakis et al. [29] advocated, we supplement all our BK-18 estimates with the TVP-VAR-based spillover technique. No existing study employs these techniques while utilising return series from regional Shariah markets.

We find significant and more stable return spillovers between Shariah markets over the last decade. Our findings show that these spillovers are transitory as they dominate the short-term trading horizon. Shariah indices' connectedness is resistant to Brexit, the Chinese and Russian financial markets' meltdowns, and the US-China trade conflict but not to the systemic shocks of the COVID-19 pandemic. We found that Shariah portfolio indices from Asia, Africa, and emerging markets are diversifiers for Shariah indices from America, Europe, and developed markets during normal market conditions and safe havens during crisis periods.

In Section 2, we describe the methodology and provide a preliminary assessment of the data in Section 3. The main results are discussed in Section 4, and the conclusion is given in Section 5.

## 2. Methods

The [28] spillover index is employed to examine the dynamic connectedness and spillovers between Shariah-compliant regional indices. This approach helps show the time and frequency dynamics of regional Shariah indices. The BK-18 spillover index approach (See [29] for detailed steps on the TVP-VAR connectedness measure) is detailed as follows.

Generalised forecast error variance decompositions (GFEVDs) were utilised by Baruník and Křehlík [28] to measure connectedness, as championed by Diebold and Yilmaz [19]. Data are decomposed using the matrix of a vector autoregressive (VAR) model whose local covariance is stationary. From a $K$-variate procedure, $Y_t = (y_{1,t}, \ldots, y_{K,t})'$ such that $t = 1, \ldots, T$ and $VAR(p)$ are given as

$$Y_t = \sum_{i=1}^{p} \phi_i Y_{t-i} + \epsilon_t, \quad (1)$$

where coefficient matrices and white noise with (prospective nondiagonal) the covariance matrix $\Pi$ are denoted as $\phi_i$ and $\epsilon_i$, respectively. Each variable in system (1) and its $p$ lags are regressed, as well as the $p$ lags of all other variables. Consequently, $\phi$ holds inclusive information on the connections between all variables. Note that it is suitable to work with a $(K \times K)$ matrix $(\mathbf{I}_K - \varnothing_1 L - \ldots - \varnothing_p L^p)$ whose identity should be $\mathbf{I}_K$. A moving average $MA(\infty)$ bounds the VAR system when the representative equation $|\theta(z)|$ has its roots lying outside of the unit circle as

$$Y_t = \psi(L)\epsilon_t, \quad (2)$$

where $\psi(L)$ depicts an infinitive-lagged polynomial. The contribution of the $kth$ variable (i.e., GFEVD) towards the element $j$'s forecast error variance can be expressed as

$$(\Theta_H)_{j,k} = \frac{\sigma_{kk}^{-1} \sum_{h=0}^{H} \left( (\psi_h \Pi)_{j,k} \right)^2}{\sum_{h=0}^{H} (\psi_h \Pi \psi_{h}')_{j,j}}, \quad (3)$$

where $h = 1, \ldots, H$ and $\sigma_{kk} = (\Pi_{kk})$. Contributions by rows do not aggregate to 1, so owing to completeness, a standardised matrix $\Theta_H$ is generated as

$$\left(\widetilde{\Theta}_H\right)_{j,k} = \frac{(\Theta_H)_{j,k}}{\sum_{k=1}^{N} (\Theta_H)_{j,k}}. \quad (4)$$

Paired connectedness equation (4) may be summed for the system's overall connectedness. According to Diebold and Yilmaz [19], it is the share of variation in predictions brought about by errors other than own error such that

$$C_H = 100 * \frac{\sum_{j \neq k} \left(\widetilde{\Theta}_H\right)_{j,k}}{\sum \widetilde{\Theta}_H} = 100 * \left( 1 - \frac{Tr\left\{\widetilde{\Theta}_H\right\}}{\sum \widetilde{\Theta}_H} \right), \quad (5)$$

where $Tr\{.\}$ signifies the tracing operator and the denominator is the summation of the matrix's entire elements. Accordingly, relative to the other variables in the system, connectedness symbolises the contribution of the forecast variance. Then, bidirectional comovement may be assessed ("TO" and "FROM" variable $i$ from all other variables $k$). NET connectedness is then measured as the difference between spillovers "TO" and "FROM."" Hence, a variable with a positive NET is a net propagator, whereas one with a negative NET acts as a net recipient of shocks.

Given a frequency response function $\psi(e)^{-i\omega} = \sum_h e^{-i\omega h} \psi_h$ whose coefficients are transformable by Fourier transformations $\psi_h$ with $i = \sqrt{-1}$, $Y_t$, which is a spectral density, at frequency $\omega$, $MA(\infty)$ can be defined as a filtered series.

$$S_{y(\omega)} = \sum_{h=-\infty}^{\infty} E\left(Y_t Y_{t-h}'\right) e^{-i\omega h} = \psi\left(e^{-i\omega}\right) \Pi \psi'\left(e^{+i\omega}\right), \quad (6)$$

where $S_{y(\omega)}$ represents the power spectrum detailing the variance's $(Y_t)$ distribution for frequency constituents $\omega$. A causal spectrum for $\omega \in (-\pi, \pi)$ is explained by equation (7) which reflects $ith$ variable' s proportion resulting from the $kth$ variable's shocks at a named frequency $\omega$. Therefore, *within-frequency* causation based on the denominator is defined as

$$(\mathscr{F}(\omega))_{j,k} = \frac{\sigma_{kk}^{-1} \left| \psi\left(e^{-i\omega}\right) \Pi_{j,k} \right|^2}{\left( \psi\left(e^{-i\omega}\right) \Pi \psi'\left(e^{+i\omega}\right) \right)_{j,j}}. \quad (7)$$

We weigh $(\mathscr{F}(\omega))_{j,k}$ by the frequency share of the variance of the $jth$ variable to naturally decompose GFEVD into frequencies defined by the weighting function as

$$\Gamma_j = \frac{\left( \psi\left(e^{-i\omega}\right) \Pi \psi'\left(e^{+i\omega}\right) \right)_{j,j}}{(1/2\pi) \int_{-\pi}^{\pi} \left( \psi\left(e^{-i\lambda}\right) \Pi \psi'\left(e^{+i\lambda}\right) \right)_{j,j} d\lambda}, \quad (8)$$

aggregating to real-valued (Baruník and Křehlík [28] indicated that a squared modulus of the weighted complex numbers, which result in a real-valued quantity, is the generalised causation spectrum) figures up to $2\pi$ and is representative of the $jth$ variable's index at a named frequency. Measuring connectedness across periods is practical for financial applications by market participants. Therefore, instead of quantifying the single-frequency connectedness, it is practical to perform quantification across frequency bands. Taking a formal depiction of the frequency band, $d$ is defined as $d = (a, b)$: $a, b \in (-\pi, \pi), a < b$, where GFEVDs are defined as

$$(\Theta_d)_{j,k} = \frac{1}{2\pi} \int_a^b \Gamma_j(\omega) (\mathscr{F}(\omega))_{j,k} d\omega. \quad (9)$$

We can construct scaled (the scaling factor is 100, and from a practical application of the BK-18 connectedness approach, H serves as the least forecast horizon) generalised variance decomposition at the same frequency band $d$ in the expression as

$$\left(\widetilde{\Theta}_d\right)_{j,k} = \frac{(\Theta_d)_{j,k}}{\sum_k (\Theta_d)_{j,k}}, \quad (10)$$

Hence, *within frequency* and frequency connectedness across $d$ are, respectively, expressed as

$$C_d^W = 100.\left(1 - \frac{Tr\{\widetilde{\Theta}_d\}}{\sum \widetilde{\Theta}_d}\right), \quad (11)$$

$$C_d^F = 100.\left(\frac{\sum \widetilde{\Theta}_d}{\sum \widetilde{\Theta}_\infty} - \frac{Tr\{\widetilde{\Theta}_d\}}{\sum \widetilde{\Theta}_\infty}\right) = C_d^W.\left(\frac{\sum \widetilde{\Theta}_d}{\sum \widetilde{\Theta}_\infty}\right). \quad (12)$$

Note that $C_d^W$ denotes the connectedness within a frequency band, and at a given frequency band, its weighting factor is derived from the power of the series. Conversely, $C_d^F$ segregates the overall connectedness into discrete proportions that aggregate the overall connectedness index [28].

The frequency bands we utilised can be denoted as "$(\pi + 0.00001, \pi/4, \pi/8, \pi/32, \pi/64, 0)$" and follow the specifications in the extant literature [18, 30, 31]. Frequency bands $d_1\,(3.14 \sim 0.79)$, $d_2\,(0.79 \sim 0.39)$, $d_3\,(0.39 \sim 0.10)$, $d_4\,(0.10 \sim 0.05)$, and $d_5\,(0.05 \sim 0.00)$ correspond to daily bands of "1~4 (intraweek), 4~8 (intraweek-to-week), 8~32 (fortnight-to-month), 32~64 (month-to-quarter), and 64~∞ (quarter-and-beyond)."

A 100-day forecast horizon ($H$) and rolling window periods are specified. The set window sums up to a little beyond a quarter of annum, which is ample to deal with time variations. Under a timely risk management plan, within 100 trading days, investors have ample time to reassess the contribution of assets in their portfolios. Hence, a rolling window of 100 days, which sums up to a quarter, is specified in line with prior works [18, 32]. It must be noted that, although one's risk management preferences may influence the use of alternative forecast and rolling window size, the time-varying setting of the connectedness index yields qualitatively similar results, as shown by existing studies [33–35]. Under a rolling window system, the problem of exogenously specifying the beginning and ending dates of crises is eliminated [29]. Additionally, the application of spillover bands allows us to identify which spillover band dominates the overall spillovers between the variables of interest [36, 37].

## 3. Data and Preliminary Analysis

We employ the daily Shariah-compliant indices from Dow Jones (the DJIM Asia Pacific Developed TopCap Index, DJIM Developed Markets Index, DJIM Europe Index, DJIM World Emerging Markets Index, and DJIM World Index) and Standard & Poor's (S&P Africa Frontier Shariah and S&P Global 1200 Shariah) listings. The dataset spanned between April 30, 2012, and May 9, 2022, and all data were gleaned from https://www.spglobal.com/.

A trajectory of the raw and return series is presented in Figure 1. The raw series largely depicts similar trends, with S&P Africa Frontier Shariah being exceptional, owing to the relatively low market capitalisation. All other series depict a falling trend during the early days (to months) of 2020 and 2022, which respectively reflect the impact of COVID-19 and the Russia-Ukraine disturbances of the sampled regional Shariah markets. The volatility clusters spotted in the return series plots confirm the stylised facts vis-à-vis asset returns.

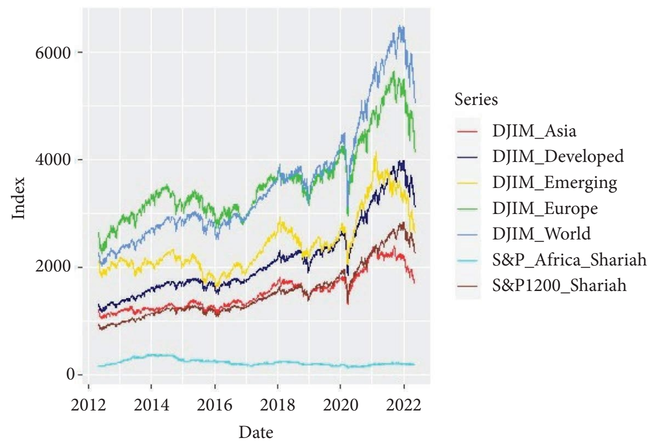
We report the descriptive summary of the returns on the studied stock markets in Table 1. The results confirm skewed and kurtosis distributions. Thus, the resultant skewness and kurtosis statistics depict a nonnormal distribution of all series and a leptokurtic distribution of Shariah markets.

These observations offer a strong motivation to employ the BK-18 technique, relative to the DY-12 static approach or just the TVP-VAR-based method, both of which do not express the overall connectedness across the frequency domain, to examine the dynamic connection between emerging and developed market stocks. Over the studied period, all regional Shariah indices indicate positive mean returns, but negative skewness suggests that negative returns were mostly recorded. This is unsurprising because the last decade has been full of uncertainties and unprecedented market downturns, causing irregularities in financial markets [9, 23].

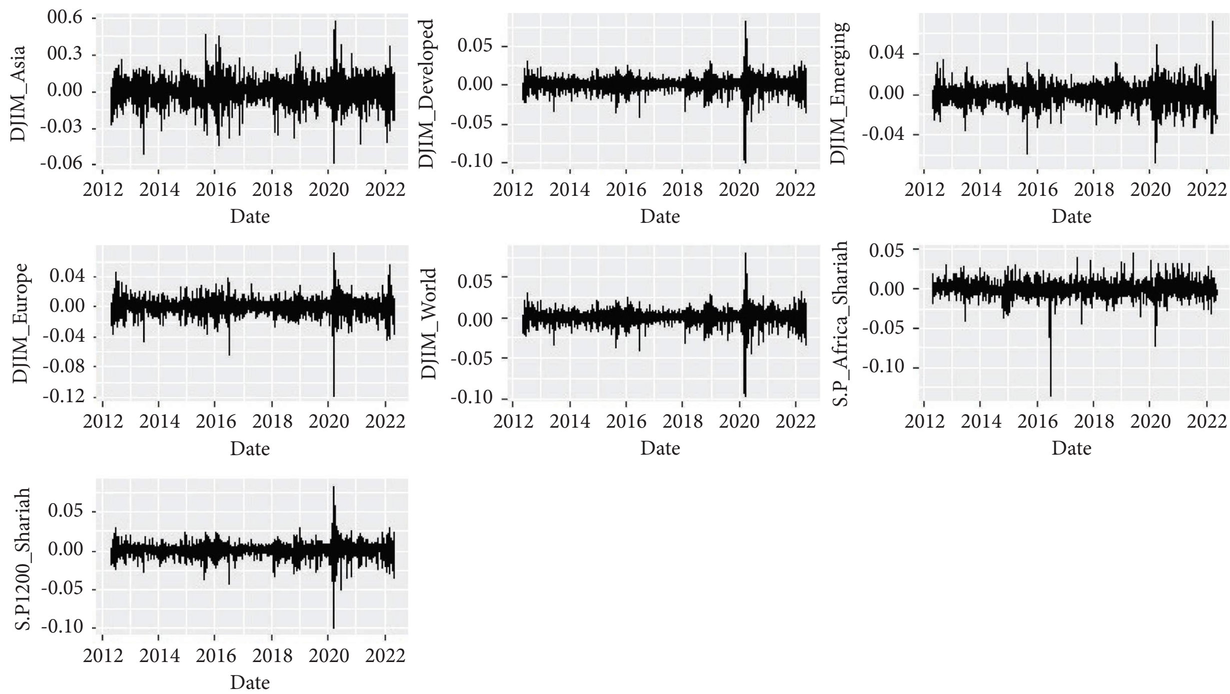
## 4. Empirical Results

We report and discuss the main findings of the study in this section. Within the time-frequency space, we present intriguing findings on the overall spillover connectedness of regional Shariah markets. To ensure robust findings from onset, we report on the static connectedness between the studied markets to show the veracity of the findings from the primary approach used, the BK-18 spillover index. Since the DY-12 approach was improved by the authors of [29] in their time-varying parameter vector autoregression (TVP-VAR) connectedness measure, the static connectedness between markets is rather reported preliminarily to the time-frequency analysis from the BK-18 approach. The relevance of the static analysis is to show the supposed spillovers between Shariah indices altogether, but the approach only deals with the time space, implying that limited (or no) information will be available to investors that trade along trading horizons of short-, medium-, and long-term periods, which are only reflective in the frequency space, and hence, the BK-18 time-frequency approach is of significance.

*4.1. Static Analysis.* The overall connectedness measure of spillovers between regional Shariah markets is reported in Table 2. The overall degree of interconnectedness in the system is expressed by the total connectedness index (TCI), which is 66.79%, in the right bottom corner of Table 2. This means that the combined dynamics of the system variables may explain roughly 67% of the variations in system variables. We turn to the last but the third row "TO" to learn more about each variable's contribution to the system's interconnectivity. DJIM_World (102.01%), DJIM_Developed (98.2%), and S&P1200_Shariah (98.04%%) are the largest providers of spillover TO in the system. DJIM_Asia and S&P_Africa_Shariah transmit the least return spillovers. The last column "FROM" depicts the spillover received by each variable from the system. Again, we can see that DJIM_World, DJIM_Developed, and S&P1200_Shariah receive the largest system spillovers, while DJIM_Emerging and S&P_Africa_Shariah receive the least spillovers.




(a)




(b)

Figure 1: Time series plots of Shariah indices. (a) Raw series and (b) return series for seven regional Shariah indices.

Interestingly, findings from the static connectedness between regional Shariah markets reveal less idiosyncratic spillovers. Relative to conventional assets and other popularly known assets, which possess high idiosyncratic spillovers [18, 38], Shariah markets exhibit low self-induced spillovers. Except for S&P_Africa_Shariah, all other markets' idiosyncratic spillovers are generally below a third of the overall system spillovers they receive. This indeed distinguishes Shariah assets as a separate asset class whose return may be hardly replicated using simple combinations of traditional nonfaith-based assets.

Whereas the directional ("TO" and "FROM") analysis emphasises each variable's contribution to the system, net spillover transmitters and receivers must also be distinguished. The net spillover for each variable is shown in the penultimate row ("NET") of Table 2. A positive (negative) value indicates a net transmitter (receiver) of spillovers. Note that DJIM_Asia (−30.22%), S&P_Africa_Shariah (19.52%), DJIM_Emerging (17.06%), and DJIM_Europe (−1.04%) are net spillover recipients, whereas DJIM_World (24.80%), DJIM_Developed (21.66%), and S&P1200_Shariah (21.38%) are net spillover transmitters.

We turn to the pairwise spillover connectedness between regional Shariah markets. We use network analysis to properly evaluate the static pairwise connectedness of net transmitters and receivers of spillovers in the system. It is worth noting that this network plot shows the pairwise transmission of shocks between the system variables under the spillover connectedness model. This version of network connectivity has been employed in related works due to its

Table 1: Descriptive statistics.

| | DJIM_Asia | DJIM_Developed | DJIM_Emerging | DJIM_Europe | DJIM_World | S&P_Africa_Shariah | S&P1200_Shariah |
|---|---|---|---|---|---|---|---|
| *Panel A: sample statistics* | | | | | | | |
| Observations | 2599 | 2599 | 2599 | 2599 | 2599 | 2599 | 2599 |
| Min | −0.0583 | −0.0997 | −0.0673 | −0.1178 | −0.0964 | −0.1349 | −0.0999 |
| Max | 0.0579 | 0.0825 | 0.0725 | 0.0705 | 0.0792 | 0.0443 | 0.0830 |
| Average | 0.0001 | 0.0003 | 0.0001 | 0.0002 | 0.0003 | 0.0000 | 0.0003 |
| Std. dev | 0.0096 | 0.0092 | 0.0095 | 0.0102 | 0.0089 | 0.0093 | 0.0092 |
| Skewness | −0.2595 | −0.9560 | −0.4401 | −0.7833 | −0.9935 | −1.4009 | −0.9208 |
| Kurtosis | 3.1801 | 16.3810 | 5.3872 | 10.1810 | 16.1881 | 19.7960 | 16.3581 |
| Normtest.W | 0.9650*** | 0.8759*** | 0.9504*** | 0.9312*** | 0.8796*** | 0.9181*** | 0.8764*** |
| *Panel B: correlation matrix* | | | | | | | |
| DJIM_Asia | 1.0000 | | | | | | |
| DJIM_Developed | 0.3629*** | 1.0000 | | | | | |
| DJIM_Emerging | 0.5682*** | 0.5836*** | 1.0000 | | | | |
| DJIM_Europe | 0.3953*** | 0.7118*** | 0.6002*** | 1.0000 | | | |
| DJIM_World | 0.3980*** | 0.9964*** | 0.6497*** | 0.7283*** | 1.0000 | | |
| S&P_Africa_Shariah | 0.3435*** | 0.9933*** | 0.5913*** | 0.6999*** | 0.9910*** | 1.0000 | |
| S&P1200_Shariah | 0.0971*** | 0.0921*** | 0.0988*** | 0.1191*** | 0.0958*** | 0.0873*** | 1.0000 |

Notes: this table presents the summary (panel A) and correlation (panel B) statistics for the studied Shariah indices. *** signifies a 1% significance level.

Table 2: Static connectedness of regional Shariah markets.

| | DJIM_Asia | DJIM_Developed | DJIM_Emerging | DJIM_Europe | DJIM_World | S&P_Africa_Shariah | S&P1200_Shariah | FROM |
|---|---|---|---|---|---|---|---|---|
| DJIM_Asia | 27.73 | 15.66 | 10.29 | 13.65 | 16.01 | 1.22 | 15.44 | 72.27 |
| DJIM_Developed | 6.85 | 23.46 | 8.20 | 13.74 | 23.22 | 1.37 | 23.16 | 76.54 |
| DJIM_Emerging | 11.13 | 12.81 | 34.50 | 11.25 | 15.71 | 1.01 | 13.59 | 65.50 |
| DJIM_Europe | 7.34 | 18.20 | 8.90 | 27.86 | 18.39 | 1.43 | 17.89 | 72.14 |
| DJIM_World | 7.28 | 22.60 | 9.87 | 13.67 | 22.79 | 1.32 | 22.47 | 77.21 |
| S&P_Africa_Shariah | 2.65 | 5.81 | 2.36 | 5.27 | 5.60 | 72.82 | 5.48 | 27.18 |
| S&P1200_Shariah | 6.81 | 23.13 | 8.81 | 13.52 | 23.07 | 1.31 | 23.35 | 76.65 |
| TO | 42.06 | 98.20 | 48.44 | 71.10 | 102.01 | 7.66 | 98.04 | 467.50 |
| Inc. own | 69.78 | 121.66 | 82.94 | 98.96 | 124.80 | 80.48 | 121.38 | **TCI** |
| NET | −30.22 | 21.66 | −17.06 | −1.04 | 24.80 | −19.52 | 21.38 | **66.79** |
| NPDC | 4.00 | 2.00 | 5.00 | 3.00 | 0.00 | 6.00 | 1.00 | |

Notes: "FROM" (last column) represents the system's return spillovers contributed by all other variables to a stated variable. "TO"" (fourth to the last row) displays return spillovers from a named variable to the system of all other variables. "NET" (penultimate row) shows the net directional return spillovers of each variable, while the net pairwise position is depicted by NPDC (last row). TCI (bold at the bottom of the last column) is the total connectedness index of the system of all variables. The TCI is an index measured in percentage. There is no significance level associated with the estimate.

ability to give a comprehensive view of static spillovers between the examined system of variables (see, e.g., [33, 34, 39, 40]). To ascertain the robustness of the findings from the BK-18 approach, we employ a 200-day rolling window analysis under the TVP-VAR connectedness model. This is in line with several studies that employ a 200-day window to analyse the time-varying connectedness between the variables [25, 34, 35, 41]. Our network analysis aids in identifying the net transmitters and net receivers of spillovers on a pairwise basis. Figure 2 shows the net pairwise connectivity patterns and linkages between the studied Shariah markets. The arrow's source denotes the spillover transmitter, while the arrow's edge denotes the spillover receiver for that particular pair.

On a pairwise level, we find that DJIM_World and DJIM_Developed emerge as the most influential Shariah markets, as they transmit the greatest spillovers in the system. The net positions of DJIM_Asia and S&P_Africa_Shariah are also shown by the network analysis.

Note that, in the static system, time-conditional effects that are buried in the aggregate show a noteworthy transient transmission of shocks [33, 42], and hence, relying on the complete period may obscure some patterns because of probable structural changes or varying trends in their linkages [9, 33]. Therefore, the connectivity component of a dynamic estimation utilising a rolling window technique may change. This leads us to our analysis of the system's dynamic connectedness under the BK-18 framework.

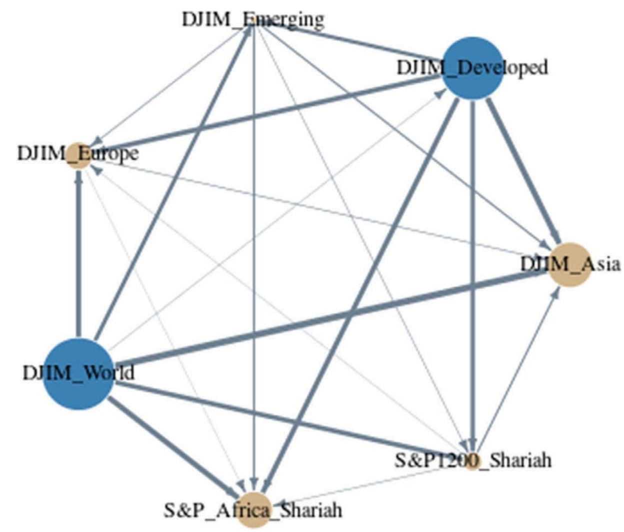



Figure 2: Static pairwise connectedness between regional Shariah markets. Notes: with a one-way direction arrow, arrows represent the net directional connectivity between two variables in the system. Blue (brown) nodes illustrate the net transmitter (receiver) of shocks. Vertices are weighted by averaged net pairwise directional connectedness measures. The size of nodes represents the weighted average net total directional connectedness.

*4.2. Time- and Frequency-Domain Analysis.* By accounting for the evolution of total connection through time, the time-frequency spectrum analysis aids in determining the existence or absence of contagion. We proceed with our analysis by looking at the cross-frequency spillover effects across regional Shariah markets. This breakdown takes into consideration market players' changing expectations and requirements throughout time. There are five frequency bands ("intraweek, week-fortnight, fortnight-month, month-quarter, and quarter and beyond") for short- (Band 1), medium- (Bands 2 and 3), and long-term (Bands 4 and 5) spillovers, respectively, as shown in Table 3.

*4.2.1. Overall Spillover Connectedness.* From the overall spillover indices for all the studied Shariah markets (see Table 3), we find that the magnitude of spillovers reduces with increasing frequencies. Thus, in the short-term horizon (intraweek scale), spillovers are higher than in the medium- (monthly scale) and long-term (quarterly scale) horizons. For instance, the return spillover within the first band, 3.14~0.79, which approximates 1~4 days, is 44.17%, which reduces to 9.05%, 7.65%, 1.53%, and 0.77%, respectively through the second to fifth (0.79~0.00) spillover/frequency bands. Our findings are consistent with those of [18, 38], who used a similar methodology and found that short-term spillovers are more significant than intermediate-term spillovers for individual Islamic and conventional markets and between Islamic and BRICS markets, respectively.

It is worth noting that individual Shariah markets are less influenced by their own shocks. This means that internal shocks are less significant to take much into consideration in asset allocation decisions between Shariah assets. Unlike the individual Islamic or conventional stock indices which may exhibit high idiosyncratic risks [9, 39, 43], assets that strictly comply with the Shariah standards, as monitored by S&P and Dow Jones, produce less idiosyncratic risks. A significant proportion of spillovers they endure emanate from external markets.

In Table 3, we reveal the net transmitters and recipients of spillovers among Shariah markets. The results suggest that, in the short term (3.14~0.79), the net transmitters (recipients) of spillovers among the regional Shariah markets are DJIM_World, DJIM_Developed, and S&P_Shariah (DJIM_Asia, DJIM_Emerging, S&P_Africa_Shariah, and DJIM_Europe). In the mid-to-long-term periods, similar observations are found in terms of the recipient/transmitter position of each Shariah market but in diminishing magnitudes.

To substantiate our findings, we present the time-frequency subtleties of the return spillovers among the regional Shariah markets in Figure 3.

Assessments of the dynamic connectedness help ascertain the extent to which the connectedness between Shariah markets evolves across different market periods and calendar years. When the analysis is conducted in the frequency domain, we can ascertain the extent to which the connectedness between Shariah markets differs in the short-, medium-, and long-term trading horizons. Impliedly, the frequency-domain spillover connectedness accumulates to the overall (static) spillover index. These features are combined with the BK-18 approach.

Table 3: Frequency-domain connectedness.

| | DJIM_Asia | DJIM_Developed | DJIM_Emerging | DJIM_Europe | DJIM_World | S.P_Africa_Shariah | S.P1200_Shariah | FROM_ABS | FROM_WTH |
|---|---|---|---|---|---|---|---|---|---|
| *The spillover table for the band: 3.14 to 0.79 (roughly corresponds to 1 to 4 days)* | | | | | | | | | |
| DJIM_Asia | 23.39 | 9.29 | 7.08 | 7.10 | 9.53 | 0.24 | 9.29 | 6.08 | 8.56 |
| DJIM_Developed | 3.48 | 18.42 | 7.04 | 10.21 | 18.31 | 0.40 | 18.20 | **8.24** | **11.60** |
| DJIM_Emerging | 5.99 | 8.78 | 22.13 | 7.74 | 10.36 | 0.26 | 9.05 | 6.03 | 8.49 |
| DJIM_Europe | 3.16 | 12.14 | 7.70 | 22.45 | 12.46 | 0.39 | 11.86 | 6.81 | 9.60 |
| DJIM_World | 3.73 | 17.53 | 8.12 | 10.06 | 17.65 | 0.39 | 17.38 | 8.17 | 11.51 |
| S.P_Africa_Shariah | 0.40 | 0.88 | 0.46 | 0.75 | 0.88 | 65.08 | 0.86 | 0.61 | 0.85 |
| S.P1200_Shariah | 3.27 | 18.34 | 7.32 | 10.05 | 18.29 | 0.40 | 18.61 | **8.24** | **11.60** |
| TO_ABS | 2.86 | 9.57 | 5.39 | 6.56 | 9.98 | 0.30 | 9.52 | **44.17** | |
| TO_WTH | 4.03 | 13.48 | 7.59 | 9.24 | 14.05 | 0.42 | 13.41 | | 62.22 |
| NET | −3.21 | 1.33 | −0.64 | −0.26 | 1.80 | −0.31 | 1.28 | | |
| *The spillover table for the band: 0.79 to 0.39 (roughly corresponds to 4 to 8 days)* | | | | | | | | | |
| DJIM_Asia | 4.04 | 2.71 | 2.01 | 1.94 | 2.82 | 0.02 | 2.65 | **1.74** | **12.55** |
| DJIM_Developed | 0.60 | 2.80 | 1.04 | 1.55 | 2.78 | 0.01 | 2.76 | 1.25 | 9.02 |
| DJIM_Emerging | 1.35 | 2.71 | 4.73 | 2.15 | 3.09 | 0.02 | 2.77 | 1.73 | 12.48 |
| DJIM_Europe | 0.73 | 2.83 | 1.38 | 3.72 | 2.85 | 0.02 | 2.78 | 1.51 | 10.94 |
| DJIM_World | 0.66 | 2.84 | 1.28 | 1.62 | 2.85 | 0.01 | 2.81 | 1.32 | 9.52 |
| S.P_Africa_Shariah | 0.18 | 0.41 | 0.19 | 0.32 | 0.41 | 12.55 | 0.40 | 0.27 | 1.98 |
| S.P1200_Shariah | 0.57 | 2.75 | 1.08 | 1.50 | 2.74 | 0.01 | 2.77 | 1.24 | 8.94 |
| TO_ABS | 0.58 | 2.04 | 1.00 | 1.30 | 2.10 | 0.01 | 2.02 | **9.05** | |
| TO_WTH | 4.22 | 14.73 | 7.22 | 9.38 | 15.18 | 0.09 | 14.64 | | 65.44 |
| NET | −1.15 | 0.79 | −0.73 | −0.22 | 0.78 | −0.26 | 0.79 | | |
| *The spillover table for the band: 0.39 to 0.10 (roughly corresponds to 8 to 32 days)* | | | | | | | | | |
| DJIM_Asia | 3.40 | 2.32 | 1.71 | 1.64 | 2.41 | 0.00 | 2.26 | 1.48 | 12.66 |
| DJIM_Developed | 0.50 | 2.32 | 0.86 | 1.28 | 2.30 | 0.00 | 2.29 | 1.03 | 8.85 |
| DJIM_Emerging | 1.16 | 2.36 | 4.03 | 1.86 | 2.68 | 0.00 | 2.40 | **1.49** | **12.81** |
| DJIM_Europe | 0.61 | 2.38 | 1.15 | 3.08 | 2.40 | 0.01 | 2.33 | 1.27 | 10.86 |
| DJIM_World | 0.55 | 2.37 | 1.06 | 1.35 | 2.38 | 0.00 | 2.34 | 1.10 | 9.40 |
| S.P_Africa_Shariah | 0.16 | 0.38 | 0.18 | 0.30 | 0.38 | 10.68 | 0.37 | 0.25 | 2.16 |
| S.P1200_Shariah | 0.47 | 2.28 | 0.89 | 1.25 | 2.27 | 0.00 | 2.30 | 1.02 | 8.77 |
| TO_ABS | 0.49 | 1.73 | 0.83 | 1.10 | 1.78 | 0.00 | 1.71 | **7.65** | |
| TO_WTH | 4.23 | 14.79 | 7.15 | 9.40 | 15.22 | 0.03 | 14.69 | | 65.51 |
| NET | −0.98 | 0.69 | −0.66 | −0.17 | 0.68 | −0.25 | 0.69 | | |
| *The spillover table for the band: 0.10 to 0.05 (Roughly corresponds to 32 days to 64 days)* | | | | | | | | | |
| DJIM_Asia | 0.68 | 0.47 | 0.34 | 0.33 | 0.48 | 0.00 | 0.45 | 0.30 | 12.68 |
| DJIM_Developed | 0.10 | 0.46 | 0.17 | 0.26 | 0.46 | 0.00 | 0.46 | 0.21 | 8.81 |
| DJIM_Emerging | 0.23 | 0.48 | 0.81 | 0.37 | 0.54 | 0.00 | 0.49 | 0.30 | 12.88 |
| DJIM_Europe | 0.12 | 0.48 | 0.23 | 0.62 | 0.48 | 0.00 | 0.47 | **0.25** | **10.84** |
| DJIM_World | 0.11 | 0.47 | 0.21 | 0.27 | 0.48 | 0.00 | 0.47 | 0.22 | 9.37 |
| S.P_Africa_Shariah | 0.03 | 0.08 | 0.04 | 0.06 | 0.08 | 2.15 | 0.08 | 0.05 | 2.20 |
| S.P1200_Shariah | 0.09 | 0.46 | 0.18 | 0.25 | 0.45 | 0.00 | 0.46 | 0.20 | 8.74 |
| TO_ABS | 0.10 | 0.35 | 0.17 | 0.22 | 0.36 | 0.00 | 0.34 | **1.53** | |
| TO_WTH | 4.24 | 14.80 | 7.14 | 9.41 | 15.23 | 0.01 | 14.70 | | 65.52 |

Table 3: Continued.

| | DJIM_Asia | DJIM_Developed | DJIM_Emerging | DJIM_Europe | DJIM_World | S.P_Africa_Shariah | S.P1200_Shariah | FROM_ABS | FROM_WTH |
|---|---|---|---|---|---|---|---|---|---|
| NET | −0.20 | 0.14 | −0.13 | −0.03 | 0.14 | −0.05 | 0.14 | | |
| *The spillover table for the band: 0.05 to 0.00 (roughly corresponds to 64 to inf days)* | | | | | | | | | |
| DJIM_Asia | 0.34 | 0.23 | 0.17 | 0.17 | 0.24 | 0.00 | 0.23 | **0.15** | **12.68** |
| DJIM_Developed | 0.05 | 0.23 | 0.09 | 0.13 | 0.23 | 0.00 | 0.23 | 0.10 | 8.81 |
| DJIM_Emerging | 0.12 | 0.24 | 0.40 | 0.19 | 0.27 | 0.00 | 0.24 | **0.15** | **12.88** |
| DJIM_Europe | 0.06 | 0.24 | 0.11 | 0.31 | 0.24 | 0.00 | 0.23 | 0.13 | 10.84 |
| DJIM_World | 0.06 | 0.24 | 0.11 | 0.14 | 0.24 | 0.00 | 0.23 | 0.11 | 9.37 |
| S.P_Africa_Shariah | 0.02 | 0.04 | 0.02 | 0.03 | 0.04 | 1.07 | 0.04 | 0.03 | 2.21 |
| S.P1200_Shariah | 0.05 | 0.23 | 0.09 | 0.12 | 0.23 | 0.00 | 0.23 | 0.10 | 8.74 |
| TO_ABS | 0.05 | 0.17 | 0.08 | 0.11 | 0.18 | 0.00 | 0.17 | **0.77** | |
| TO_WTH | 4.24 | 14.80 | 7.14 | 9.41 | 15.23 | 0.01 | 14.70 | | 65.52 |
| NET | −0.10 | 0.07 | −0.07 | −0.02 | 0.07 | −0.03 | 0.07 | | |

Notes: this table presents the total connectedness index of the system of all variables across five frequency bands ("intraweek, week-fortnight, fortnight-month, month-quarter, and quarter and beyond") for short- (Band 1), medium- (Bands 2 and 3), and long-term (Bands 4 and 5) spillovers, respectively.

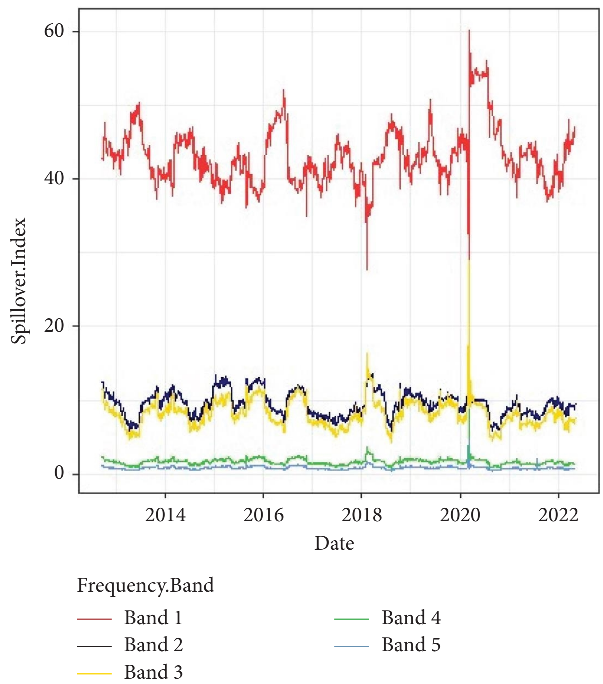



Figure 3: Dynamic return spillovers between regional Shariah markets. Notes: time- and frequency-domain return connectedness between Shariah regional markets is presented. Band 1 (red colour) represents short-term dynamics, Bands 2 (navy colour) and 3 (gold colour) depict the medium term, while the long-term dynamics are shown by Bands 4 (lime green) and 5 (cornflower blue). The horizontal axis displays the time domain, while the spillover indices (in %) are plotted against the vertical axis for the respective frequency bands.

The spillover connectedness between the sampled Shariah markets (see Figure 3) (note that our estimations provide qualitatively similar results under window sizes of 100, 200, and 400; for brevity, they are available upon request) ranges between 28% and 61% in the short term (Band 1), 5% and 28% in the intermediate term (Bands 2 and 3), and between 1% and 10% in the long term (Bands 4 and 5). The differences in spillover connectedness across time and frequency domains suggest that cross-market linkages for Shariah assets respond to changing market dynamics. It is not surprising that there were some moderate peaks in 2016, 2019, and 2020, particularly in the short term. These dates match significant events like the Brexit dialogues and vote in 2016, the trade tension between China and the US in 2019, and the emergence of the COVID-19 pandemic in 2020. This observation is expected since in stressed conditions, market participants usually rush into asset allocation and portfolio decisions in an attempt to secure the safety of portfolio returns amid worst-performing assets [17, 24, 26]. By doing so, safe assets like faith-based investments and non-traditional assets like bonds and commodities appeal to investors. Hence, the rush for these assets is most likely a cause for their high return linkages in the short term during tumultuous trading periods [44].

It must be noted that the most significant hikes among the identified periods were the ones in 2020 across all frequency bands (i.e., the short term, medium term, and long term). This period corroborates the coronavirus pandemic era. At the apogee of the pandemic, cross-asset and cross-market connectedness saw significant hikes [14, 45]. The intuition is that, amid the systemic risk accompanying the COVID-19 pandemic, the rush for safe assets augmented and caused market participants to move from one asset to another, causing high market connectivity among Shariah markets. It is expected that once Shariah assets are highly regulated as per the principles of Shariah, their returns are less likely to be affected by similar factors that affect the returns of conventional assets. Therefore, investors are most likely to be comfortable including such assets in their portfolios during crisis periods. The struggle for these faith-based assets in the early periods of the COVID-19 pandemic will cause their high connectedness in such a period as the competitive market hypothesis underscores [46]. The differences in the high connectivity across frequency bands during the same crises are attributable to the heterogeneity in market responses in such tumultuous periods, as the fractal market hypothesis explicates [27]. Thus, market participants adapt to market trends based on investment horizons, as represented by frequencies [8, 47, 48].

In the time-domain analysis, these findings are consistent with the dynamic spillovers under the TVP-VAR paradigm. This is shown by the TVP-VAR spillover connectedness in Figure 4.

In Figure 4, the dynamic spillovers, which are in the time domain only, under the TVP-VAR connectedness approach, depict comparable patterns with their time- and frequency-domain counterparts as shown by the BK-18 spillover connectedness approach. As indicated earlier, the significant hike in the system's connectivity relates to the COVID-19 era.

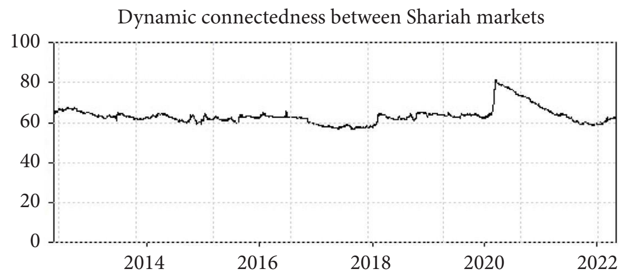



Figure 4: Dynamic spillovers between regional Shariah markets. Notes: time-varying spillover connectedness between regional Shariah markets is presented.

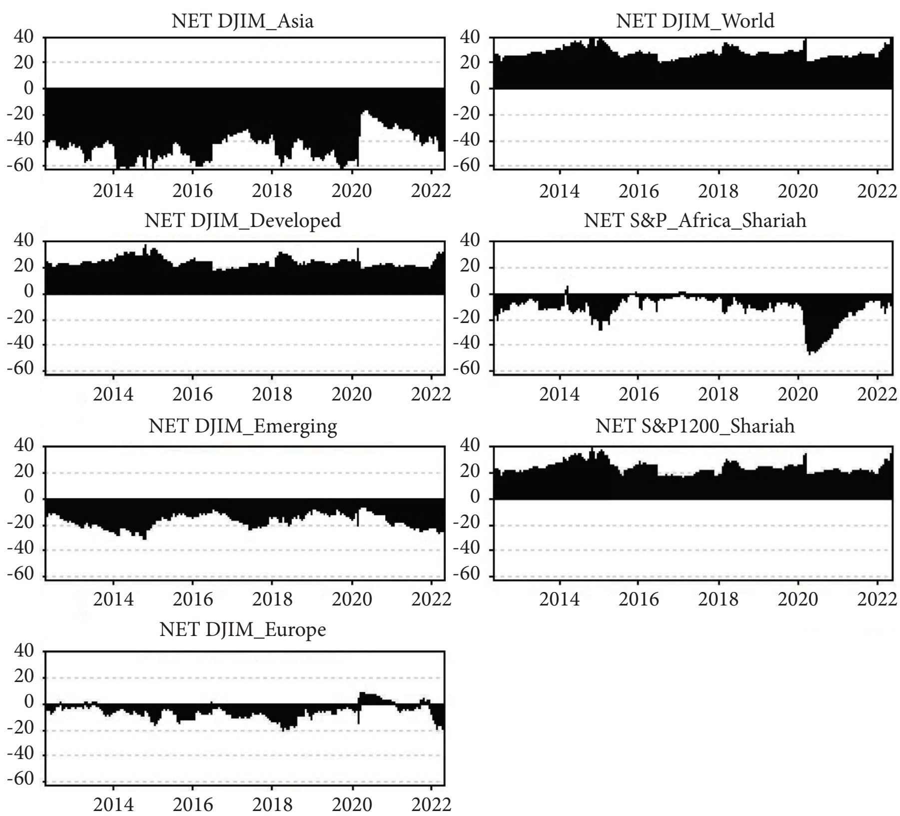



Figure 5: Directional and net spillovers between regional Shariah markets. Notes: the dynamic directional ("TO" and "FROM") and net pairwise spillover dynamics between regional Shariah markets is presented.

*4.2.2. Directional Spillover Connectedness.* So far, our general dynamic analysis has revealed that the interconnectedness of the variables in the system fluctuates throughout time. Analysing the contribution of each variable to the system's overall interconnectivity, on the other hand, is just as significant. This will aid in our understanding of each Shariah market's potential role in risk reduction. As a result, we explore each variable's dynamic return connectivity with the whole system. Figure 5 shows a pictorial elaboration on how each variable interacts with the system.

The net contribution of each variable to all other variables in the system of commodity classes is depicted in Figure 5. Positive (negative) values indicate that the variable is a net transmitter (recipient) in the system. The results are consistent with the main findings of the static and frequency-domain analysis. DJIM_Asia, DJIM_Emerging, and S&P_Africa_Shariah are all consistent net recipients across the study period. The net position of DJIM_Europe proved inconsistent, particularly in the systemic risk era of the COVID-19 pandemic. DJIM_World, DJIM_Developed, and S&P1200_Shariah are all transmitters of system spillovers. We infer, based on these results, that the risk-reduction role of Shariah indices is mostly preserved for DJIM_Asia, DJIM_Emerging, and S&P_Africa_Shariah but is dynamic for DJIM_Europe, which switches between a net transmitter and a net recipient across systemic crisis periods.

Significant observations from the dynamic analysis suggest that DJIM_Asia, DJIM_Emerging, and

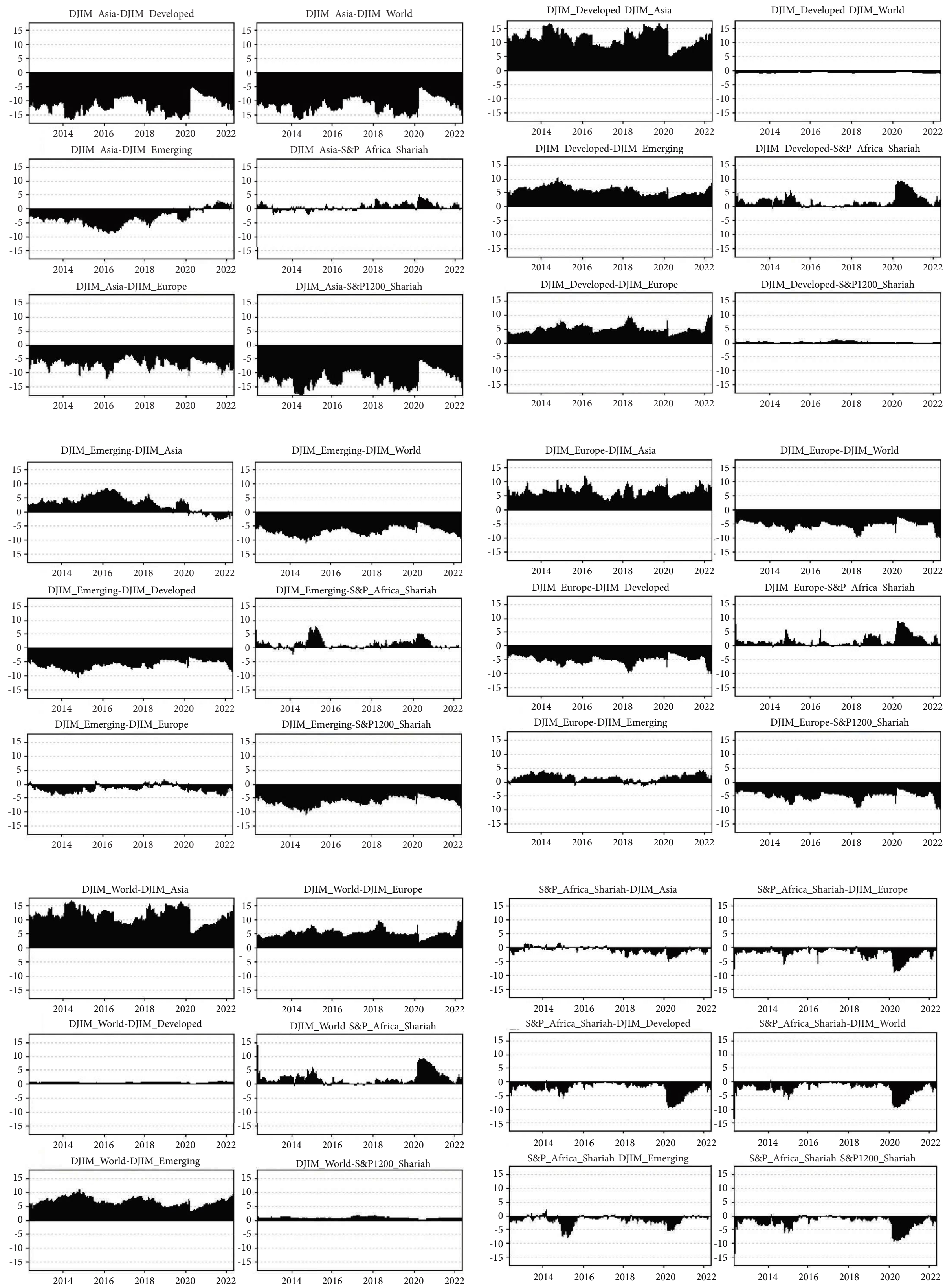



Figure 6: Continued.

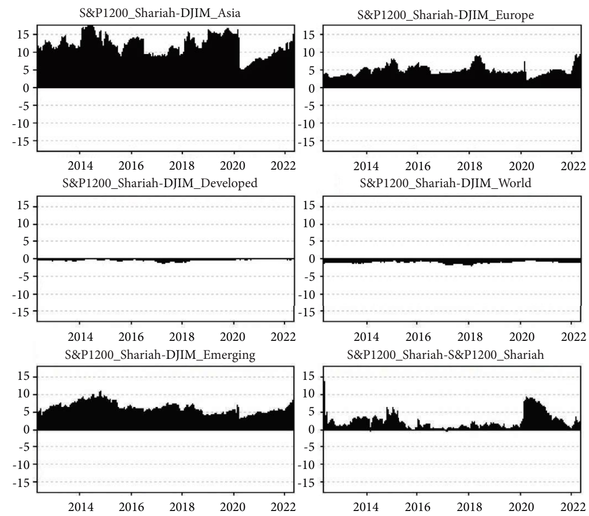



Figure 6: Dynamic pairwise spillovers between regional Shariah markets. Notes: dynamic net pairwise spillovers between regional Shariah markets are presented.

S&P_Africa_Shariah could retain their diversification benefits across time and stand the chance of being consistent safe havens for the other Shariah markets whose returns are detrimentally affected in turbulent trading periods. Notable strategic combinations between pairs (the pairwise spillover dynamics between Shariah markets are reported in Figure 6) of Shariah markets could be achieved by investors who seek to combine faith-based assets.

Furthermore, the hikes in the system's connectedness during the COVID-19 systemic crisis signify that the fundamental linkages between Shariah markets could be affected in turbulent trading periods despite the credence that they may withstand shocks. This observation is consistent with existing studies that find increased connectedness between financial assets during crisis periods [25, 34, 35, 41]. This observation corroborates the contagion literature by Forbes and Rigobon [49, 50], which suggested that there is contagion when the connectedness between markets undergoes a significant change after one market or country has experienced a shock. Given the significant increases in the connectedness between the studied Shariah markets, we document that regional Shariah markets are susceptible to contagious spillovers during systemic risk periods. Our findings are backed by recent works that underscore contagion [18, 51–54], arousing market susceptibilities to implied volatilities (Alsubaie et al., 2022) [55]. The sources of these contagious spillovers are the Shariah markets of developed markets and the world market.

Having found dynamic connectedness between regional Shariah markets, we advocate that investors adapt to evolving market dynamics, in line with the adaptive market hypothesis, by rebalancing their portfolios when new markets emerge as a result of structural breaks [22], as expounded by the fractal market hypothesis [27]. However, in adapting to new markets created from structural changes, investors should consider the dynamic behaviour of individual Shariah markets after incorporating their appetite for risks and rewards [8, 47, 48].

## 5. Conclusions and Recommendations

We examined the dynamic spillover connectedness between seven regional Shariah-based equity markets (i.e., DJIM Asia Pacific Developed TopCap Index, DJIM Developed Markets Index, DJIM Europe Index, DJIM World Emerging Markets Index, DJIM World Index, S&P Africa Frontier Shariah, and S&P Global 1200 Shariah). The dataset covered the period from April 30, 2012, to May 9, 2022. Spillover index techniques were employed to ascertain the extent to which Shariah markets move across time and frequency domains, which markets are the largest transmitters or recipients, whether Shariah markets are susceptible to financial contagion, and whether there are diversification and safe-haven benefits between Shariah markets.

Our findings suggest significant time- and frequency-varying spillovers between regional Shariah markets. Across the time domain, we underscore a significant hike in connectivity in the systemic crisis occasioned by the COVID-19 pandemic. Consistent with the existing literature, we conclude that connectedness between assets was driven by the systemic risk associated with the COVID-19 pandemic. At the apogee of the pandemic, cross-asset and cross-market connectedness saw a significant rise [14, 45, 55]. Across the frequency domain, we report that spillovers are largely short-lived and that Shariah markets are less susceptible to idiosyncratic shocks. These observations are consistent with the work by Bossman and Owusu Junior et al. [9], who found that spillovers between Islamic markets are dominant in the short term. Shariah markets are susceptible to financial contagion emanating from systemic crises, and the propagators of contagion are the Shariah indices of American, European, developed, and world markets. Given their net recipient positions, African, Asian, and emerging market Shariah indices are more susceptible to contagious spillovers during systemic crises. Furthermore, our findings suggest significant diversification potential between regional Shariah investments. Indicatively, Shariah equity returns from Asian, African, and emerging markets are consistent diversifiers for their counterpart from European, developed, and world Shariah markets.

Findings from the time-varying analysis indicate that the hikes in connectedness between regional Shariah indices over the last decade are negligible, except for the COVID-19 pandemic era. This could be attributed to the novelty of the systemic crisis occasioned by the COVID-19 pandemic relative to those propagated by Brexit or the US-China trade conflict. Impliedly, market regulation should incorporate systemic risk factors that drive the connectedness between Shariah markets to peaked levels. Strategic asset allocation between Shariah assets should take into consideration the time- and frequency-domain dynamics and take advantage of the diversification potential between regional Shariah markets. We note that, from the position of net spillovers, some regional markets are net transmitters, while others are net recipients of spillovers. Hence, for investors and portfolio managers, the relevance of cross-regional and cross-asset investments is highlighted. Investors and portfolio managers can focus on the net position of various regional Shariah markets to ascertain a well-diversified portfolio and hedge downside risks during contagious periods like pandemics and geopolitical conflicts.

Future studies could consider the extent to which specific international shocks affect the returns on Shariah markets. To cater to asymmetries and nonlinearities, future studies could employ quantile-based methods to examine the conditional dependencies between global shocks and Shariah-based asset returns from individual countries rather than regional markets. This could ascertain the plausible differences between constituent Shariah markets from various regions. The overall market integration between Shariah assets could also be examined using wavelet techniques. It would also be fascinating to see future studies analysing the sensitivity of markets towards extreme spillovers during crisis periods. Ascertaining the system connectedness in network analysis for various frequencies could also be undertaken in future studies.

## Data Availability

All data are available at https://www.spglobal.com/.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

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