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Downside risk connectedness between Islamic sectors and green bond markets: implications for hedging and investment strategies

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ABSTRACT

This study explores the relationship between the green bond and Islamic sectoral markets in terms of downside risk. A new framework was developed using CAViaR and QVAR techniques to construct hedging and portfolio strategies. Results show higher levels of downside risk connectedness and spillover across different risk environments, with short-run connectedness outperforming long-run. The downside risk connectedness and spillover are time-varying, influenced by major events like the Shale Oil Revolution, US–China trade war, COVID-19 pandemic, and Russo-Ukrainian conflict. Green bond market indices of China, the European Union, the US, and the global market receive net shocks in moderate and higher downside risk environments across various frequencies. US and global green bonds exhibit net transmitter roles in a downside-risk environment. Islamic Sectors BM, OG, FIN, CG, and HC are shock transmitters, while TELE and UTL are shock receivers across different downside risk environments and frequencies. Net roles are CS, INDUS, and TECH, subject to the downside risk environment and frequencies.

KEYWORDS

Green bond market; Islamic markets; dynamic connectedness; hedging effectiveness

JEL CLASSIFICATION

G20; G11; G15

I. Introduction

In recent years, there has been a growing global concern about climate change and environmental sustainability. This has led governments worldwide to decarbonize their economies and mitigate rising temperatures, especially after the Paris Agreement on Climate Change, 2015 (Savaresi 2016). Even corporations are increasingly embracing environmentally conscious growth strategies such as the adoption of renewable energy sources, promotion of green products, investment in green securities and integration of green financing initiatives. Green bonds have emerged as a popular financing tool and investment avenue in global financial markets (Dutordoir, Li, and Quariguasi Frota Neto 2022), due to their allocation towards financing sustainable and eco-friendly projects (Sustainable Banking Network 2018). The green bond market has witnessed explosive growth since the issue of the first green bond in 2007 by 'The European Investment Bank'. In 2021, green bond issuance reached half a trillion, reflecting a 75% growth from the previous year (Climate Bonds Initiative 2022). Today, investors prefer green assets over conventional financial market instruments due to their earmarked sustainable growth (Broadstock et al. 2021; Nguyen et al. 2021).

The green bond market is a relatively new investment avenue for investors, and it has emerged as an intriguing subject for empirical investigation. Prior research has examined the performance and efficacy of the green bond market (Flammer 2020). In recent years, the growing integration of financial markets has underscored the importance of assessing asset price movements to optimize asset allocation and elevate portfolio management. In this context, there has been an increasing number of studies evaluating the connectedness of the green market with other markets like conventional stock and bond markets (Pham 2016), commodities market (Kanamura 2020) and several non-green markets (Saeed, Bouri, and

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Alsulami 2021). The empirical exploration of the interconnections between the green bond market and other financial markets is yet to be fully ascertained (Billah et al. 2023a; 2023b). One area that lacks sufficient investigation pertains to the interconnectedness between the green market and specialized financial instruments like Islamic stocks, which have also gained attention globally. Islamic stocks are expected to provide diversification opportunities in times of economic uncertainties owing to their features and past performance.

The correlation between the price movements of two assets is supported by the market integration theory, which suggests that financial markets are interlinked, and changes in one market may impact other markets (Kearney and Lucey 2004; Billah et al. 2022). The information flow theory also states that the dissemination of information has a significant impact on the decision-making of investors, which ultimately affects the efficiency of financial markets.

The Islamic stock market is expected to have a strong connection with sustainable investment instruments such as green bonds due to its adherence to Islamic principles that promote ethical practices like environmental and social responsibility (Rabbani et al. 2023). As a result, these two markets experience spillovers and can be used for hedging purposes. Investors are particularly interested in tail risk connectivity, especially downside risk, which cannot be hedged if markets are highly interrelated or depend on the transmission role of each market in spillover effects. Tail risk connectivity is a vital measure of how uncertainty spreads among variables in a network, providing essential information about how increased vulnerability to loss is transmitted.

Thus, the present study analyzes the dynamic downside connectedness between the green bond market and Islamic sectoral stocks using extreme value theory (Zhao 2021). We combine the Conditional Autoregressive Value-at-Risk (CAViaR) with quantile and frequency connectedness to better capture downside risk (Baruník and Křehlík 2018; Chatziantoniou et al. 2022). Based on the relationship between the two markets, we provide hedging and investment strategies.

Our research offers significant contributions to the literature in several ways. Firstly, we explore the inter-connectedness between Islamic stock markets and green bonds and the associated hedging and diversification benefits. While previous studies have investigated green bonds' hedging potential against traditional securities (Billah, Amar, and Balli 2023; Billah, Elsayed, and Hadhri 2023a; Nguyen et al. 2021), our study examines the dynamic spillovers, hedging, and portfolio development concerning green and Islamic markets. Secondly, we provide empirical evidence on the relationship between green bonds and Islamic sectoral stocks, which has not been explored in other studies. It is crucial to consider Islamic sectoral stocks since ignoring them could lead to overlooked portfolio diversification benefits. Additionally, unlike Tiwari et al. (2023) and we focused on downside risk connectedness, and our study extends the literature related to extreme value theory and the connectedness of green and Islamic assets. Thirdly, we employ a revised version of the quantile connectedness framework (Chatziantoniou, Gabauer, and Stenfors 2021) and the frequency connectedness framework (Baruník and Křehlík 2018) to assess the relationship between green bonds and Islamic sectoral markets during extreme and normal market conditions over short-term and long-term investment horizons. Our methodology enables us to determine the degree of interdependence and directional influence among the examined series across different time periods. We also reveal the tail dependency structure of tail risk spillovers between the markets we examine, which explains tail propagation in green bond and Islamic sectoral markets. Our findings can benefit investors and policymakers alike by improving their decisions and risk management during extreme market conditions. Overall, our study provides a comprehensive analysis of the correlation between green bond and Islamic sectoral markets under different market conditions and investment horizons.

The study highlights significant findings on the shock transmission roles of green bond market indices in different downside risk scenarios and time periods. China, EU, U.S.A. and the global market tend to receive shocks in moderate and higher downside risk environments. In a downside-risk environment, US and global green bonds transmit shocks to other sectors. Certain Islamic sectors consistently act as either shock transmitters or receivers depending on the downside risk scenario and time frequency. Some of the Islamic sectors transmit shocks, whereas the telecom and utility sectors receive shocks. The net shock transmission roles of the technology and industry Islamic sectors can vary depending on the precise downside risk environment and time frequency. The study also found that the portfolio weights of MCP and MCoP differ marginally, with some exceptions, while MVP suggests selecting three green bond assets. The volatility in the dynamic portfolio weights is minimum when using the MCoP approach compared to MVP or MCP.

II. Review of literature

Theoretical underpinning

There has been a growing interest in environmentally sustainable investment strategies and instruments due to the increased awareness about the risks of climate change. In recent years, green bonds and renewable energy have gained momentum in the finance literature, particularly among environmentally conscious investors. According to a bibliographic analysis conducted by Broadstock et al. (2022), the literature on green bonds is still thin but rapidly increasing, with an average of 27 papers published post-2018, compared to only 9.3 papers published prior to 2018. The study also found loosely connected themes and non-overlapping keywords, indicating a need for more academic attention to this field of knowledge.

Research on green bonds has shown that they help in funding climate change costs, lead to positive stock price movement (Tang and Zhang 2020), and result in better financial performance with sustainable green innovation in the long run (Flammer 2020). In addition, there is a potential correlation between green bonds and Sharia-compliant investments, as both have a shared focus on environmental and social objectives. This correlation may arise from a shared response to news or occurrences pertaining to ESG considerations (CFI Institute, 2019). The increasing inclination towards ESG considerations may also stimulate the desire for green bonds and Islamic financial assets, as investors seek to allocate their funds towards more morally upright and sustainable alternatives (Tiwari et al. 2023).

Furthermore, the Islamic market and assets offer novel prospects for investors in the green bond market to enhance portfolio diversification and access sustainable investment options (Asl et al. 2023). These two unconventional markets experience spillovers from each other and can be used for hedging purposes against other risks. Finally, extreme value theory supports the downside risk connectedness of the green bond and Islamic markets (Ahmed et al. 2022; Ren et al. 2023; Zhao 2021).

Related empirical studies

Research has explored the relationship between green bonds and financial markets, with varying degrees of dependence found in different market conditions (Caramazza, Ricci, and Salgado 2004). Zhou et al. (2021) used Gumbel Rotated Gumbel (GRG) copula with Markov-switching to examine the relationship and dependence between the Chinese green bonds market and the conventional bond market, finding positive dependence between the green bond market and all conventional bond markets. Pham (2016) analysed the volatility behaviour of the green bond market and found spillover effects from the conventional bond market to the green bond market. Furthermore, Kanamura (2020) explored the relationship, volatility connectedness and risk transmission between green bonds and commodity markets, finding significant volatility transmissions from crude oil, gold and silver markets to the green stock market. Asymmetric return spillovers between energy markets and green markets were also reported (Saeed, Bouri, and Alsulami 2021). Pham and Nguyen (2021) analysed the connectedness between the green bond market and uncertainty indices, finding that green bonds and uncertainty indices are connected, but the relationship is time-varying and state-dependent. Abdullah et al. (2023) identified asymmetric connectedness among green stocks, halal tourism stocks, cryptocurrency, gold and oil, with green stocks found to be net transmitters of return shocks.

Scholars have investigated the potential of green bonds to act as a hedge against traditional securities. Jin et al. (2020) examined the effectiveness of the green bond index in hedging carbon market risk and found it to be the best hedge for carbon futures, even during crisis periods. Nguyen et al. (2021) used a rolling window wavelet correlation approach to test the hedging potential of green bonds and found that they provide diversification benefits for conventional stock and commodity markets. Saeed et al. (2020) found that clean energy stocks can effectively hedge against dirty energy assets such as crude oil and energy ETFs. Studies have also assessed the hedging and safe-haven potential of green bonds during the COVID-19 pandemic. Arif et al. (2021) reported short- and medium-term lead-lag association between green bonds and conventional markets during the pandemic and concluded that green bonds can be used as a hedging and safe-haven instrument for medium and long-term equity, forex, and commodity investors. Abakah et al. (2023) discovered that green bonds are a perfect hedge for fintech stocks, while clean energy stocks are a good hedge for AI stocks and Islamic stocks for Bitcoin. However, Tiwari et al. (2023) found that green bonds cannot be hedged and are not much useful for hedging other assets under study but can be used to reduce the investment risk of other assets, while Huynh et al. (2020) found that green bonds and top-rated government bonds have contagion risk between them.

The current literature on the relationship between green bonds and other financial markets has primarily focused on conventional market instruments and developed nations such as the US and Europe, with limited scope (Table 1). However, there is a lack of evidence regarding the interconnectedness between green bonds and specific markets. One such market is the Islamic stock market, which has unique features and has reported increased spillovers with other markets (Balli et al. 2022; Mensi et al. 2022). Previous studies have investigated the interconnectedness of Islamic equities and their return spillovers, whether Islamic stocks have the potential to be a safe haven for G7 stock indices, and patterns of spillovers between Islamic stock and bond markets and conventional stock and bond markets during the COVID-19 pandemic (Arif et al. 2021; Billah, Nguyen, and Chowdhury 2023; Chowdhury, Balli, and de Bruin 2023).

Mensi et al. (2022) found strong short-term spillovers between crude oil and US Islamic sector stocks, intensifying during extreme events like the global financial crisis and the COVID-19 pandemic. Tiwari et al. (2023) investigated price spillovers between green bonds, Islamic stocks, and stock market indices using quantile cross-spectral (coherency) and found that green bonds are a good hedge against Islamic stocks as the quantile coherency between the two assets shows weak dependency.

Previous studies have mostly focused on studying the green market's efficacy, its interconnectedness with other markets, and the hedging potential of green assets (Tiwari et al. 2023). However, the present study differs from previous research by offering empirical evidence on the connectedness between Islamic sectoral stocks and green bonds using tail risk methodology and extreme value theory. We use Conditional Autoregressive Value-at-Risk (CAViaR) as a proxy for downside risk or negative shocks, which allows us to explore implied hedging and investment strategies.

III. Methodology

Conditional autoregressive value-at-risk (CAViaR)

We use a method for measuring Value-at-Risk (VaR) that is different from most approaches. Instead of estimating the distribution of returns and then recovering its quantiles indirectly, we use the asymmetric slope CAViaR approach proposed by Engle and Manganelli (2004) to estimate VaR directly. In our opinion, this method is the most flexible of the three relevant options because it allows for asymmetric effects, unlike the symmetric absolute value or the indirect GARCH (1,1) approach. The asymmetric slope CAViaR model assumes that the VaR of a certain quantile follows an autoregressive process. This process is mathematically formulated as follows:

$$f_{a,t}(\beta) = \beta_0 + \beta_1 f_{a,t-1}(\beta) + \beta_2 x^+_{t-1} + \beta_3 x^-_{t-1} \quad (1)$$

Here, $f_{a,t}$ represents the VaR at a level (we use 5% in our case) in period t,β_0 is the model constant, β_1 and $f_{a,t-1}(\beta)$ are the weights of the lagged VaRs,

Table 1. Summaries of prior studies.

S.No.	Article	Countries	Assets	Methodology	Findings (Diversification/hedging possible)
1	Jin et al. (2020)	EU	Carbon futures	Dynamic hedge ratio model (DCC-APGARCH, DCC-T-GARCH, and DCC-GJR-GARCH models) and the constant hedge ratio model (OLS model)	Yes (Green bonds are best hedge for carbon futures)
2	Roberedo (2018)	US	Treasury bonds, corporate bonds, stock market and energy commodity market	Copula	Yes (stock and energy market)
3	Reboredo et al. (2020)	US, EU	Treasury bonds, corporate bonds, stocks and energy assets	Wavelet-based models and VAR models	Yes (corporate bond, stock and energy assets)
4	Tiwari et al. (2022)	Australia	Renewable energy stocks and carbon pries	TVP – VAR	No. Helps to reduce investment risk of the renewable energy stocks
5	Pham and Do (2022)	US, Europe, China, Emerging markets	Implied volatilities of energy, oil and commodity markets	Time varying granger causality and TVP-VAR	Return spill over and connectedness vary across time and type of implied volatility
6	Arif et al. (2022)	US	Equity market, fixed income, commodity and forex investment	Cross quantilogram approach	Yes (commodity and forex investments)
7	Guo and Zhou (2021)	US, China	Conventional bond market, stock market, commodity and forex market	Copula-based approach	Yes (for forex market)
8	Pham and Nguyen (2021)	US	Stock volatility, oil volatility and Economic policy uncertainty	Markov switching dynamic regression (MSDR) and TVP-VAR	Yes (in periods of low uncertainty)
9	Nguyen et al. (2021)	Global	Conventional bonds, equities, commodities and clean energy	Rolling window wavelet correlation	Yes (equities and commodities)
10	Huynh 2020	Global	Government bonds	Student's t-copulas	No

Table 2. Descriptive statistics of Islamic sectors and green bonds.

	Mean	Max	Min	SD	Skew	Kurt	JB	ADF	PP
Islamic Sectoral Markets									
BASIC MATERIALS (BM)	0.024	0.584	−0.148	0.111	1.344	5.460	1349.690***	−15.36***	−15.39***
CONSUMER GOODS (CG)	0.001	0.615	−0.146	0.106	1.228	5.082	1053.685***	−22.28***	−22.07***
CONSUMER SERVICES (CS)	0.006	0.608	−0.147	0.108	1.167	4.654	832.061***	−8.49***	−16.85***
FINANCIALS (FIN)	0.008	0.680	−0.149	0.113	1.342	5.466	1349.986***	−23.23***	−26.32***
HEALTH & CARE (HC)	−0.013	0.604	−0.145	0.108	1.205	4.836	933.066***	−10.51***	−16.71***
INDUSTRIALS (IND)	0.008	0.710	−0.144	0.110	1.272	5.220	1158.344***	−13.90***	−20.49***
OIL & GAS (OG)	0.037	0.638	−0.149	0.115	1.152	4.516	772.981***	−15.94***	−15.65***
TECHNOLOGY (TEC)	−0.013	0.604	−0.148	0.115	1.219	4.768	921.472***	−17.85***	−17.82***
TELECOMMUNICATION (TELE)	−0.040	0.692	−0.146	0.105	1.219	5.155	1075.581***	−12.32***	−13.97***
UTILITIES (UTL)	0.017	0.524	−0.143	0.106	1.152	4.561	787.437***	−19.72***	−19.73***
Green bonds									
FTSE Chinese (Onshore CNY) Green Bond Index (CH GB)	−0.072	0.607	−0.142	0.076	2.110	11.985	10013.000***	−18.639***	−38.461***
Bloomberg Barclays MSCI Euro Green Bond Index (EU GB)	0.049	0.863	−0.140	0.097	1.449	7.449	2864.845***	−18.730***	−19.23***
Bloomberg Barclays MSCI Green bond index (GL GB)	0.081	0.518	−0.137	0.097	1.262	5.089	1091.075***	−19.734***	−20.34***
Bloomberg Barclays MSCI US Green Bond Index (US GB)	−0.004	0.636	−0.131	0.081	1.409	7.048	2472.158***	−21.695***	−22.67***

This table provides the descriptive statistics for the Sukuk, Green bonds and Global factors of the sample under study. Max, Min, SD, Skew, Kurt and JB represents Maximum, Minimum, Standard Deviation, Skewness, Kurtosis, and Jarque-Bera, respectively. *** Indicates significance at 1%.

and β_2 and β_3 represent the effects of positive and negative returns on the VaR, respectively.

Frequency based quantile connectedness analysis

To establish the quantile connectivity between Islamic sectoral markets and green bonds within short and long spectral timeframes, we use the CAViaR changes and follow the methodology established by Chatziantoniou et al. (2022). The frequency quantile connectedness approach is utilized, and the connectivity component in the frequency domain is captured using the spectral response function given by the following equation:

$$B(\tau) = \sum_{h=0}^{H-1} e^{iwh} B_h B(\tau), i = \sqrt{-1} \tag{2}$$

we proceed by calculating the spectrum of generalized causation across all frequencies, $\omega \in (-\pi, pi)$

$$(f(\tau)(\omega))_{j,k} = \frac{\sum_{kk}^{-1} \left| (B(\tau)(e^{-iw}) \sum)_{jk} \right|^2}{(B(\tau)(e^{-iw}) \sum B'(\tau)(e^{+i\omega}))_{jj}} \tag{3}$$

here $(f(\tau)(\omega))_{j,k}$ represents the percentage of variable $j's$ spectrum at frequency ω that is caused by variable $k's$ shock at quantile τ. Then, we calculate GFEVD using a weighted technique:

$$\Theta_{jk}(\tau)(d) = \frac{1}{2\pi} {}_d W_j(\tau)(\omega)(f(\tau)(\omega)_{jk} dw \tag{4}$$

where $d = (s, m, l)$ representing frequency bands with $sml \in (\pi, \pi)$, the apparatus mechanism and equation description is as follows:

$$W_j(\tau)(\omega) = \frac{(B(\tau)(e^{-iw}) \sum^B{}'(\tau)(e^{+i\omega}))_{jj}}{\frac{1}{2\pi} \int_{-\pi}^{\pi} (B(\tau)(e^{-ir}) \sum^B{}'(\tau)(e^{+ir}))_{jj} dr} \tag{5}$$

First, we can standardize the $H - step - ahead$ forecast error $j$to determine the contribution of the kth idiosyncratic innovation, $\in_k(\tau)$, as follows:

$$\underset{jk}{\Theta}(\tau)(d) = \frac{\Theta_{jk}(\tau)(d)}{\sum_{j,k=1}^{n} \Theta_{jk}(\tau)(\infty)} \tag{6}$$

Following that, the connectivity measurements can be evaluated as follows:

$$TCI(\tau)(d) = \left(\frac{\sum_{j=1,k=1}^{n} \Theta_{jk}(\tau)(d)}{\sum_{j=1,k=1}^{n} \Theta_{jk}(\tau)(\infty)} - \frac{T_r[\Theta_{jk}(\tau)(d)]}{\sum_{j=1,k=1}^{n} \Theta_{jk}(\tau)(\infty)} \right) * 100 \tag{7}$$

$$TO_{j\to*,\tau(d)} = \left(\left(\sum_{k=1, j\neq k}^{n} \Theta_{kj}(\tau)(d) \right) \frac{\sum_{j=1,k=1}^{n} \Theta_{jk}(\tau)(d)}{\sum_{j=1,k=1}^{n} \Theta_{jk}(\tau)(\infty)} \right) * 100 \tag{8}$$

$$FROM_{j\leftarrow*,\tau(d)} = \left(\left(\sum_{k=1, j\neq k}^{n} \Theta_{jk}(\tau)(d) \right) \frac{\sum_{j=1,k=1}^{n} \Theta_{jk}(\tau)(d)}{\sum_{j=1,k=1}^{n} \Theta_{jk}(\tau)(\infty)} \right) * 100 \tag{9}$$

$$NET_{(\tau)(d)} = TO_{j\to*,\tau(d)} - FROM_{j\leftarrow*,\tau(d)} \tag{10}$$

where $T_{r(\blacksquare)}$ is the Trace operator.

Furthermore, we utilized several multivariate portfolio construction techniques to identify the hedging potential of green bonds against Islamic sectoral markets and cause of the spillovers. For a detailed explanation of the methodology used, please refer to the appendix (A.1.1–A.2.1).

Data

Our research study uses the Dow jones Islamic sectors and green bond markets using daily closing index and starts on 1 January 2014, and upright 30 June 2023. The Dow Jones Islamic sectoral stocks include the Basic Materials (BM), Consumer Goods (CG), Consumer Services (CS), Financial (FIN), Healthcare (HTH), Industrial (IND), Oil & Gas (OG), Technology (TEC), Telecommunication (TELE) and Utility sector (UTL). Generally, the Dow Jones Islamic sectoral markets, which ignore companies that handle endeavours that do not parallel the Shariah canons, for example, trading in alcohol, tobacco, pork and it is related materials, gambling, and so on, comprise about 2578 firms across 58 countries. Additionally, the sample used consists of the daily closing prices of the four green bond indices. The MSCI Green Bond Index (GB GL) is employed to represent the global green bond markets' financial performance. In November 2014, the GB GL index has been launched and it becomes the leading green bond index. In addition, the performance of green bonds in China, the US and the EU is monitored using the FTSE Green Bond Index (Onshore CNY) (CH GB), the MSCI Bloomberg Barclays Euro Green Bond Index (EU GB) and the MSCI Bloomberg Barclays US Green Bond Index (US GB). The statistical measures that summarize and describe the central tendency, dispersion, and shape of the data have been presented in Table 2.

We calculate the first logarithmic differences of the tail risk (CAViaR), which can be understood as the fluctuations in anticipated uncertainty. Furthermore, it is observed that all series exhibit a significant right skewness, leptokurtosis, and non-normal distribution at a significance level of 1%. It is noteworthy that all the series in the study are stationary at the 1% significance level, as determined by the unit-root test. This indicates that all necessary conditions for estimating a QVAR model are satisfied.

IV. Empirical findings and discussion

Downside risk connectedness discoveries across quantiles and frequencies

In study, we estimated QVAR with three distinct downside risk conditions: extreme downside risk (5% quantile), moderate downside risk (50% quantile), and low downside risk (95% quantile). Tables 3–11 provide insights into the static nature of downside risk spillovers within the specified contexts.

Extreme downside risk connectedness

The study conducted by Chatziantoniou et al. (2022) presents the spillover index between Islamic sectors and Green Bond markets during periods of extreme downside risk. Tables 3, 4 , and 5 show the spillover index at the 5th quantile for different time intervals. The total spillover across all variables was 88.97% on average, with short-term spillovers accounting for 71.54% and long-term spillovers representing 17.48%. Figures 1(a–c) & 2(a–c) indicates during COVID-19 and Russia–Ukraine war significant spillover between Islamic sector and green bonds markets, with short-term connectedness dominating the long term. Both asset classes offer sustainable returns, and investors prefer to address sustainability, leading to cross spillover (Rizvi et al. 2022). The empirical findings are supported by market integration theory (Kearney and Lucey 2004) and theory of information flow. The cross-market contagion theory (see, Hoque et al. 2023; Hoque, Soo-Wah, and Billah 2023; Leung, Schiereck, and Schroeder 2017) and extreme value theory (see, Yoon et al. 2022) underpin the findings of higher downside risk connectedness, suggesting high levels of contagion (see Ahmed et al. 2022; Ren et al. 2023).

GB US, GB EU, GB GL, and GB CH are net receivers across frequencies, indicating that green bonds are highly sensitive for lower tail movement. On the other hand, the Islamic Sector exhibits mixed roles in the shocks transmission. BM, CG, CS, FIN, HC and INDS are net shock transmitters, while OG, TECH, TELE, and UTL

Table 3. Averaged spillover index between Islamic sectors and green bond markets at the 5th quantile.

	GB US	GB EU	GB GL	GB CH	BM	CG	CS	FIN	HC	INDS	OG	TECH	TELE	UTL	FROM
GB US	19.54	6.00	5.73	5.12	6.35	6.36	6.46	6.59	6.24	6.82	6.18	6.58	6.17	5.86	80.46
GB EU	6.22	20.53	5.67	6.05	6.29	6.65	6.24	5.79	6.01	6.38	5.88	6.01	6.29	5.99	79.47
GB GL	5.78	5.53	19.97	6.92	6.80	6.33	6.02	6.11	6.01	6.46	5.83	5.83	6.18	6.24	80.03
GB CH	6.24	6.21	7.72	20.15	5.93	5.92	5.97	6.00	6.06	6.06	5.89	5.94	5.86	6.05	79.85
BM	5.19	5.07	5.59	4.39	15.67	7.84	7.10	6.60	6.64	9.31	6.79	6.86	6.51	6.42	84.33
CG	5.14	5.13	5.00	4.42	7.82	15.22	8.21	7.12	7.63	8.67	5.72	7.66	6.09	6.16	84.78
CS	5.20	4.83	4.67	4.39	6.92	8.31	15.33	8.13	7.59	9.04	6.34	8.84	5.08	5.31	84.67
FIN	5.36	4.62	5.00	4.31	6.62	7.36	8.42	15.86	7.86	8.59	6.25	9.27	5.10	5.37	84.14
HC	5.22	4.85	4.96	4.68	6.81	8.01	7.92	8.01	16.57	8.33	5.68	7.97	5.44	5.56	83.43
INDS	5.20	4.71	4.85	4.14	8.69	8.27	8.60	7.88	7.45	14.46	6.49	8.36	5.41	5.48	85.54
OG	5.72	5.32	5.28	4.77	7.64	6.58	7.27	6.97	6.25	7.81	18.15	6.98	5.62	5.64	81.85
TECH	5.20	4.71	4.59	4.27	6.73	7.83	8.97	9.16	7.69	8.93	6.09	15.69	5.09	5.05	84.31
TELE	5.71	5.72	5.76	5.06	7.49	7.14	6.05	5.73	6.11	6.74	5.88	6.00	18.30	8.30	81.70
UTL	5.54	5.42	5.87	5.11	7.44	7.23	6.17	6.16	6.21	6.83	5.85	5.99	8.20	17.99	82.01
TO	71.73	68.14	70.70	63.64	91.54	93.81	93.41	90.26	87.74	99.98	78.89	92.29	77.04	77.41	**88.97**
NET	−8.73	−11.33	−9.33	−16.21	7.21	9.03	8.74	6.12	4.31	14.44	−2.96	7.98	−4.66	−4.60	

The above table illustrates the QVAR spillovers for Total, net and pairwise and lag length of order 1 (BIC) and a 20-step-ahead forecast with 250 rolling windows.

Table 4. Averaged spillover index between Islamic sectors and green bond markets at the 5th quantile of short term (1–5 days).

	GB US	GB EU	GB GL	GB CH	BM	CG	CS	FIN	HC	INDS	OG	TECH	TELE	UTL	FROM
GB US	16.20	4.80	4.61	4.12	5.12	5.12	5.17	5.26	5.01	5.50	4.98	5.24	4.95	4.72	64.59
GB EU	4.56	14.53	4.00	4.36	4.61	4.83	4.51	4.16	4.30	4.67	4.26	4.30	4.55	4.35	57.48
GB GL	4.78	4.50	16.80	5.70	5.52	5.20	4.87	4.96	4.94	5.28	4.79	4.74	5.07	5.15	65.48
GB CH	4.81	4.87	6.12	16.49	4.65	4.66	4.71	4.66	4.74	4.71	4.63	4.59	4.57	4.76	62.49
BM	4.21	4.08	4.53	3.55	12.91	6.43	5.75	5.32	5.38	7.58	5.52	5.51	5.29	5.22	68.38
CG	4.16	4.11	4.04	3.52	6.36	12.49	6.67	5.77	6.17	7.06	4.60	6.22	4.96	5.05	68.69
CS	4.23	3.91	3.75	3.57	5.66	6.79	12.73	6.68	6.22	7.47	5.16	7.29	4.12	4.34	69.20
FIN	4.28	3.63	3.96	3.39	5.31	5.93	6.83	12.97	6.36	6.95	4.99	7.51	4.07	4.32	67.51
HC	4.26	3.98	4.07	3.83	5.59	6.61	6.59	6.64	13.88	6.87	4.65	6.63	4.46	4.60	68.76
INDS	4.18	3.79	3.92	3.33	7.14	6.76	7.08	6.42	6.07	11.90	5.28	6.80	4.41	4.45	69.65
OG	4.62	4.28	4.26	3.84	6.19	5.33	5.83	5.63	5.07	6.42	15.10	5.66	4.55	4.59	66.25
TECH	4.26	3.82	3.73	3.45	5.49	6.43	7.37	7.50	6.31	7.37	4.96	13.02	4.17	4.14	68.98
TELE	4.68	4.69	4.76	4.09	6.13	5.81	4.93	4.60	4.92	5.49	4.77	4.85	15.43	6.87	66.60
UTL	4.41	4.32	4.71	4.07	6.04	5.85	4.98	4.95	4.99	5.52	4.69	4.79	6.65	14.94	65.99
TO	57.43	54.79	56.47	50.81	73.81	75.75	75.28	72.56	70.48	80.90	63.29	74.12	61.80	62.56	**71.54**
NET	−7.16	−2.69	−9.01	−11.69	5.42	7.06	6.09	5.05	1.72	11.25	−2.97	5.15	−4.80	−3.43	

The above table illustrates the QVAR spillovers for Total, net and pairwise and lag length of order 1 (BIC) and a 20-step-ahead forecast with 250 rolling windows.

Table 5. Averaged spillover index between Islamic sectors and green bond markets at the 5th quantile of long term (5-INF days).

	GB US	GB EU	GB GL	GB CH	BM	CG	CS	FIN	HC	INDS	OG	TECH	TELE	UTL	FROM
GB US	3.34	1.20	1.12	1.00	1.23	1.23	1.29	1.33	1.24	1.31	1.20	1.34	1.23	1.14	15.87
GB EU	1.67	5.99	1.67	1.69	1.68	1.82	1.73	1.62	1.70	1.71	1.62	1.70	1.75	1.64	22.00
GB GL	1.01	1.03	3.17	1.22	1.28	1.13	1.15	1.16	1.07	1.18	1.05	1.09	1.11	1.08	14.56
GB CH	1.42	1.34	1.60	3.66	1.28	1.25	1.27	1.34	1.32	1.35	1.26	1.35	1.29	1.29	17.36
BM	0.98	0.99	1.06	0.85	2.76	1.42	1.35	1.28	1.25	1.73	1.27	1.35	1.22	1.20	15.94
CG	0.99	1.02	0.96	0.91	1.46	2.73	1.54	1.35	1.45	1.62	1.12	1.44	1.13	1.11	16.09
CS	0.97	0.93	0.91	0.83	1.26	1.51	2.60	1.45	1.36	1.58	1.18	1.56	0.96	0.96	15.47
FIN	1.08	0.99	1.04	0.92	1.31	1.43	1.59	2.89	1.51	1.64	1.26	1.77	1.03	1.05	16.63
HC	0.96	0.87	0.88	0.86	1.22	1.41	1.33	1.37	2.69	1.46	1.03	1.34	0.98	0.96	14.67
INDS	1.02	0.91	0.93	0.80	1.55	1.50	1.52	1.46	1.38	2.56	1.21	1.56	1.01	1.04	15.89
OG	1.10	1.04	1.03	0.93	1.45	1.25	1.44	1.34	1.17	1.40	3.05	1.32	1.07	1.05	15.60
TECH	0.95	0.89	0.87	0.82	1.24	1.40	1.60	1.66	1.39	1.56	1.14	2.67	0.92	0.91	15.34
TELE	1.03	1.03	1.00	0.98	1.36	1.33	1.12	1.13	1.19	1.25	1.11	1.15	2.88	1.42	15.10
UTL	1.13	1.10	1.15	1.04	1.40	1.37	1.19	1.21	1.22	1.32	1.16	1.20	1.54	3.05	16.02
TO	14.30	13.36	14.23	12.83	17.73	18.06	18.12	17.70	17.26	19.08	15.61	18.17	15.24	14.85	**17.43**
NET	−1.57	−8.64	−0.33	−4.53	1.78	1.97	2.65	1.07	2.59	3.19	0.01	2.83	0.14	−1.17	

The above table illustrates the QVAR spillovers for Total, net and pairwise and lag length of order 1 (BIC) and a 20-step-ahead forecast with 250 rolling windows.

are net receivers. Across different frequencies, Islamic sectoral market INDS is the largest average contributor of volatility spillover to all the other markets, followed by Islamic sectoral markets of CG, GS, and CG. Among green bond markets, China is the largest net receiver of volatility spillovers, closely followed by green EU and China.

Table 6. Averaged spillover index between Islamic sectors and green bond markets at the 50th quantile.

	GB US	GB EU	GB GL	GB CH	BM	CG	CS	FIN	HC	INDS	OG	TECH	TELE	UTL	FROM
GB US	56.06	3.33	2.96	2.52	3.45	3.63	3.43	3.35	3.43	4.30	3.36	3.68	3.25	3.26	**43.94**
GB EU	3.35	57.31	3.28	3.35	3.62	3.55	3.17	2.98	3.11	3.69	3.23	2.97	3.38	3.01	**42.69**
GB GL	3.17	2.72	52.97	4.54	5.27	4.04	3.25	3.95	3.39	3.87	3.18	3.05	3.22	3.37	**47.03**
GB CH	5.98	3.62	7.74	48.79	3.60	3.13	3.67	3.61	3.17	4.14	3.61	3.48	2.77	2.68	**51.21**
BM	2.44	2.48	3.69	1.77	35.88	7.37	5.46	4.97	4.90	11.71	5.29	4.87	4.26	4.90	**64.12**
CG	2.67	2.72	2.44	1.99	7.25	33.81	8.24	6.17	7.12	9.75	3.47	7.06	3.49	3.82	**66.19**
CS	2.65	2.16	2.34	2.26	5.19	8.22	32.89	8.24	6.89	10.88	3.91	9.90	2.14	2.34	**67.11**
FIN	2.49	1.96	2.35	1.96	4.83	6.22	8.42	35.53	7.05	9.43	4.01	11.21	1.86	2.68	**64.47**
HC	2.45	2.35	2.59	2.18	5.30	7.51	7.19	7.73	38.05	8.35	3.39	7.51	2.49	2.90	**61.95**
INDS	2.39	2.14	2.40	1.42	10.15	8.28	9.46	7.82	6.91	29.58	4.81	8.92	2.92	2.81	**70.42**
OG	2.93	3.22	2.95	2.36	6.51	3.92	4.90	4.96	3.79	6.88	46.67	4.93	2.91	3.08	**53.33**
TECH	2.57	2.13	2.17	1.81	4.87	6.92	9.73	10.81	6.83	10.10	3.73	33.61	2.11	2.62	**66.39**
TELE	3.17	3.14	3.11	2.50	5.92	5.36	3.45	3.41	4.13	4.74	3.90	3.58	46.62	6.96	**53.38**
UTL	3.22	2.59	3.35	2.08	6.49	5.36	3.65	3.83	3.69	4.76	3.41	3.73	6.78	47.05	**52.95**
TO	39.48	34.56	41.38	30.74	72.44	73.53	74.02	71.83	64.42	92.62	49.30	74.90	41.58	44.41	**61.94**
NET	−4.46	−8.14	−5.65	−20.47	8.32	7.34	6.91	7.36	2.48	22.19	−4.03	8.50	−11.80	−8.54	

The above table illustrates the QVAR spillovers for Total, net and pairwise and lag length of order 1 (BIC) and a 20-step-ahead forecast with 250 rolling windows.

Table 7. Averaged spillover index between Islamic sectors and green bond markets at the 50th quantile of short term (1–5 days).

	GB US	GB EU	GB GL	GB CH	BM	CG	CS	FIN	HC	INDS	OG	TECH	TELE	UTL	FROM
GB US	48.35	2.77	2.56	2.18	2.92	3.14	2.85	2.82	2.83	3.61	2.93	3.09	2.76	2.80	37.25
GB EU	2.66	41.65	2.48	2.57	2.83	2.76	2.53	2.45	2.49	2.93	2.55	2.30	2.67	2.36	33.58
GB GL	2.62	2.28	44.99	3.86	4.34	3.30	2.65	3.27	2.89	3.13	2.65	2.46	2.70	2.93	39.09
GB CH	4.95	2.88	6.30	41.53	2.91	2.55	3.03	3.05	2.64	3.40	2.97	2.87	2.37	2.28	42.20
BM	2.06	2.03	3.08	1.49	30.45	6.24	4.54	4.07	4.05	9.83	4.38	3.94	3.62	4.17	53.50
CG	2.26	2.21	2.00	1.67	6.08	28.71	6.92	5.20	6.01	8.14	2.84	6.06	2.97	3.33	55.69
CS	2.27	1.76	2.01	1.97	4.39	6.92	28.28	6.96	5.89	9.23	3.26	8.54	1.81	2.01	57.02
FIN	2.08	1.60	1.91	1.64	3.93	5.16	7.12	30.32	5.95	7.86	3.20	9.38	1.54	2.24	53.62
HC	2.10	1.97	2.23	1.92	4.36	6.25	6.20	6.53	32.74	6.92	2.76	6.43	2.07	2.49	52.23
INDS	1.98	1.72	1.93	1.20	8.42	7.07	8.00	6.48	5.88	25.11	3.94	7.40	2.46	2.38	58.85
OG	2.50	2.77	2.41	2.07	5.43	3.28	4.11	4.14	3.22	5.82	40.42	4.15	2.43	2.67	45.00
TECH	2.23	1.76	1.79	1.54	3.93	5.87	8.43	9.08	5.82	8.42	2.96	28.91	1.80	2.27	55.92
TELE	2.77	2.66	2.66	2.17	4.83	4.39	2.92	2.82	3.41	3.90	3.24	3.01	40.42	5.97	44.76
UTL	2.72	2.13	2.80	1.80	5.38	4.39	3.08	3.14	3.09	3.94	2.76	3.02	5.69	40.19	43.92
TO	33.20	28.54	34.15	26.09	59.75	61.31	62.38	60.02	54.17	77.13	40.45	62.65	34.88	37.88	**51.74**
NET	−4.04	−5.04	−4.93	−16.10	6.26	5.62	5.36	6.40	1.94	18.28	−4.55	6.73	−9.88	−6.04	

The above table illustrates the QVAR spillovers for Total, net and pairwise and lag length of order 1 (BIC) and a 20-step-ahead forecast with 250 rolling windows.

Table 8. Averaged spillover index between Islamic sectors and green bond markets at the 50th quantile of long term (5-INF days).

	GB US	GB EU	GB GL	GB CH	BM	CG	CS	FIN	HC	INDS	OG	TECH	TELE	UTL	FROM
GB US	7.71	0.56	0.40	0.34	0.53	0.49	0.58	0.53	0.60	0.69	0.43	0.59	0.49	0.46	6.69
GB EU	0.68	15.66	0.80	0.78	0.78	0.79	0.64	0.53	0.63	0.77	0.68	0.67	0.71	0.65	9.11
GB GL	0.56	0.45	7.98	0.67	0.93	0.74	0.60	0.68	0.50	0.75	0.53	0.59	0.52	0.44	7.94
GB CH	1.03	0.75	1.43	7.26	0.69	0.58	0.65	0.56	0.53	0.74	0.63	0.62	0.40	0.40	9.02
BM	0.39	0.45	0.62	0.28	5.43	1.13	0.91	0.90	0.86	1.89	0.91	0.93	0.64	0.73	10.62
CG	0.41	0.51	0.45	0.32	1.17	5.09	1.32	0.97	1.10	1.61	0.63	1.00	0.52	0.49	10.50
CS	0.39	0.39	0.33	0.28	0.80	1.30	4.60	1.28	1.00	1.65	0.65	1.36	0.33	0.33	10.09
FIN	0.41	0.36	0.44	0.32	0.90	1.06	1.30	5.20	1.11	1.56	0.81	1.83	0.32	0.44	10.85
HC	0.35	0.38	0.36	0.27	0.94	1.27	0.98	1.20	5.31	1.43	0.63	1.08	0.43	0.41	9.72
INDS	0.41	0.42	0.47	0.22	1.72	1.21	1.46	1.34	1.03	4.47	0.87	1.52	0.46	0.43	11.57
OG	0.43	0.46	0.53	0.29	1.08	0.64	0.79	0.82	0.57	1.05	6.25	0.79	0.48	0.41	8.33
TECH	0.33	0.36	0.38	0.27	0.94	1.05	1.30	1.73	1.01	1.68	0.77	4.70	0.31	0.35	10.47
TELE	0.40	0.47	0.45	0.33	1.09	0.97	0.53	0.58	0.73	0.84	0.66	0.57	6.20	0.99	8.62
UTL	0.51	0.45	0.55	0.28	1.12	0.97	0.57	0.69	0.60	0.83	0.64	0.71	1.09	6.87	9.02
TO	6.27	6.01	7.23	4.65	12.69	12.22	11.64	11.81	10.25	15.49	8.85	12.25	6.70	6.52	**10.20**
NET	−0.42	−3.10	−0.71	−4.37	2.07	1.71	1.55	0.96	0.53	3.92	0.52	1.78	−1.92	−2.50	

The above table illustrates the QVAR spillovers for Total, net and pairwise and lag length of order 1 (BIC) and a 20-step-ahead forecast with 250 rolling windows.

This study implies that Islamic sectoral markets of BM, CG, CS, FIN, HC and INDS could act as safe havens for green bond investors during periods of extreme risk or crashes in the green bond space, providing hedging qualities and safe haven attributes for more volatile green investments under stress. However, the findings differ from those of Abakah et al.

Table 9. Averaged spillover index between Islamic sectors and green bond markets at the 95th quantile.

	GB US	GB EU	GB GL	GB CH	BM	CG	CS	FIN	HC	INDS	OG	TECH	TELE	UTL	FROM
GB US	8.51	6.50	7.55	6.31	7.14	6.95	6.81	7.71	7.46	6.74	7.77	6.70	6.76	7.09	91.49
GB EU	7.54	9.46	7.37	6.22	6.90	6.82	6.66	7.42	7.21	6.71	7.47	6.66	6.55	7.01	90.54
GB GL	7.69	6.62	8.37	6.38	7.14	6.86	6.82	7.61	7.41	6.87	7.66	6.73	6.80	7.04	91.63
GB CH	7.90	6.66	7.80	6.99	7.03	6.79	6.74	7.57	7.36	6.81	7.72	6.71	6.82	7.10	93.01
BM	7.78	6.66	7.55	6.32	7.68	6.95	6.79	7.61	7.40	6.88	7.69	6.72	6.82	7.14	92.32
CG	7.68	6.53	7.51	6.36	7.11	7.51	6.96	7.58	7.43	6.95	7.64	6.75	6.82	7.18	92.49
CS	7.64	6.55	7.53	6.35	7.02	7.06	7.35	7.69	7.52	6.98	7.67	6.88	6.78	6.97	92.65
FIN	7.71	6.57	7.55	6.34	7.09	6.98	6.91	8.24	7.33	6.89	7.78	6.86	6.76	7.00	91.76
HC	7.71	6.58	7.63	6.35	7.12	6.94	6.89	7.64	8.04	6.93	7.60	6.77	6.73	7.08	91.96
INDS	7.68	6.52	7.63	6.35	7.21	6.97	6.93	7.66	7.37	7.37	7.70	6.80	6.76	7.06	92.63
OG	7.74	6.62	7.56	6.27	7.16	6.94	6.89	7.61	7.43	6.88	8.41	6.74	6.70	7.05	91.59
TECH	7.72	6.52	7.67	6.30	7.16	6.97	6.93	7.74	7.35	6.85	7.71	7.25	6.79	7.05	92.75
TELE	7.69	6.55	7.56	6.36	7.18	6.96	6.87	7.65	7.32	6.82	7.58	6.81	7.44	7.22	92.56
UTL	7.66	6.57	7.60	6.42	7.15	6.88	6.79	7.66	7.32	6.81	7.69	6.76	6.86	7.84	92.16
TO	100.13	85.44	98.52	82.33	92.40	90.07	88.98	99.16	95.91	89.11	99.67	87.89	87.95	91.98	**99.20**
NET	8.64	−5.10	6.89	−10.68	0.08	−2.42	−3.67	7.41	3.95	−3.53	8.08	−4.86	−4.62	−0.18	

The above table illustrates the QVAR spillovers for Total, net and pairwise and lag length of order 1 (BIC) and a 20-step-ahead forecast with 250 rolling windows.

Table 10. Averaged spillover index between Islamic sectors and green bond markets at the 95th quantile of short term (1–5 days).

	GB US	GB EU	GB GL	GB CH	BM	CG	CS	FIN	HC	INDS	OG	TECH	TELE	UTL	FROM
GB US	7.55	5.67	6.64	5.60	6.25	6.20	5.94	6.78	6.60	5.86	6.95	5.93	6.04	6.27	80.73
GB EU	6.43	6.49	6.23	5.29	5.79	5.78	5.50	6.25	6.12	5.56	6.40	5.60	5.62	5.93	76.49
GB GL	6.82	5.75	7.31	5.61	6.22	6.10	5.88	6.65	6.52	5.92	6.81	5.92	6.05	6.16	80.43
GB CH	6.94	5.78	6.78	6.09	6.12	6.02	5.79	6.58	6.48	5.83	6.80	5.85	6.03	6.21	81.21
BM	6.92	5.75	6.63	5.58	6.70	6.19	5.91	6.69	6.56	5.99	6.86	5.92	6.08	6.30	81.37
CG	6.80	5.65	6.59	5.62	6.19	6.64	6.02	6.66	6.57	6.01	6.78	5.93	6.06	6.32	81.19
CS	6.76	5.69	6.59	5.60	6.13	6.25	6.30	6.75	6.61	6.00	6.83	6.02	6.02	6.12	81.38
FIN	6.83	5.65	6.60	5.57	6.17	6.21	5.98	7.16	6.48	5.95	6.90	6.02	5.99	6.12	80.46
HC	6.77	5.67	6.62	5.58	6.15	6.13	5.91	6.67	7.04	5.95	6.71	5.92	5.95	6.21	80.24
INDS	6.73	5.60	6.63	5.57	6.25	6.18	5.93	6.65	6.46	6.31	6.78	5.93	5.96	6.13	80.79
OG	6.89	5.70	6.65	5.55	6.29	6.23	5.98	6.68	6.57	5.98	7.45	5.95	5.98	6.22	80.66
TECH	6.87	5.71	6.77	5.60	6.30	6.24	6.04	6.83	6.52	5.97	6.88	6.40	6.07	6.26	82.06
TELE	6.81	5.68	6.60	5.58	6.27	6.19	5.96	6.68	6.44	5.90	6.73	5.98	6.58	6.35	81.18
UTL	6.75	5.63	6.63	5.59	6.24	6.06	5.87	6.68	6.44	5.88	6.79	5.91	6.06	6.81	80.52
TO	88.32	73.93	85.96	72.35	80.36	79.78	76.70	86.55	84.37	76.80	88.23	76.88	77.90	80.59	**86.82**
NET	7.59	−2.55	5.53	−8.86	−1.01	−1.41	−4.67	6.09	4.12	−3.99	7.57	−5.18	−3.28	0.06	

The above table illustrates the QVAR spillovers for Total, net and pairwise and lag length of order 1 (BIC) and a 20-step-ahead forecast with 250 rolling windows.

Table 11. Averaged spillover index between Islamic sectors and green bond markets at the 95th quantile of long term (5-INF days).

	GB US	GB EU	GB GL	GB CH	BM	CG	CS	FIN	HC	INDS	OG	TECH	TELE	UTL	FROM
GB US	0.96	0.83	0.91	0.72	0.89	0.75	0.87	0.92	0.86	0.88	0.82	0.77	0.72	0.82	10.76
GB EU	1.11	2.96	1.14	0.93	1.11	1.04	1.16	1.18	1.09	1.15	1.07	1.06	0.94	1.08	14.06
GB GL	0.87	0.87	1.06	0.77	0.92	0.76	0.94	0.96	0.89	0.95	0.85	0.80	0.75	0.88	11.20
GB CH	0.95	0.89	1.03	0.91	0.91	0.77	0.95	0.99	0.88	0.97	0.91	0.86	0.80	0.89	11.80
BM	0.87	0.91	0.92	0.74	0.98	0.76	0.88	0.92	0.84	0.88	0.83	0.80	0.74	0.84	10.95
CG	0.87	0.88	0.93	0.74	0.92	0.87	0.94	0.92	0.86	0.94	0.85	0.82	0.76	0.86	11.29
CS	0.88	0.86	0.94	0.75	0.89	0.82	1.05	0.94	0.90	0.97	0.84	0.86	0.76	0.85	11.27
FIN	0.88	0.92	0.94	0.77	0.92	0.77	0.93	1.08	0.85	0.94	0.88	0.84	0.77	0.88	11.30
HC	0.94	0.91	1.01	0.78	0.96	0.81	0.98	0.97	1.00	0.98	0.88	0.85	0.78	0.87	11.72
INDS	0.95	0.92	0.99	0.77	0.96	0.79	1.01	1.01	0.92	1.06	0.92	0.88	0.80	0.92	11.84
OG	0.85	0.91	0.92	0.72	0.88	0.72	0.90	0.93	0.86	0.90	0.96	0.79	0.72	0.83	10.93
TECH	0.84	0.81	0.90	0.70	0.85	0.73	0.89	0.92	0.82	0.89	0.83	0.84	0.71	0.79	10.69
TELE	0.88	0.87	0.96	0.77	0.91	0.76	0.90	0.97	0.88	0.92	0.84	0.83	0.85	0.88	11.39
UTL	0.91	0.93	0.97	0.82	0.91	0.82	0.93	0.98	0.88	0.93	0.90	0.86	0.80	1.04	11.63
TO	11.81	11.51	12.56	9.98	12.04	10.28	12.28	12.61	11.55	12.31	11.44	11.01	10.05	11.39	**12.37**
NET	1.05	−2.55	1.36	−1.82	1.09	−1.01	1.01	1.32	−0.17	0.47	0.51	0.32	−1.33	−0.25	

The above table illustrates the QVAR spillovers for Total, net and pairwise and lag length of order 1 (BIC) and a 20-step-ahead forecast with 250 rolling windows.

(2023) and Tiwari et al. (2023), who reported alternative relationships between Islamic and green financial products under downturn conditions.

Moderate downside risk connectedness

Tables 6–8 provide valuable insights into the spillover index between Islamic sectors and Green Bond markets during periods characterized by

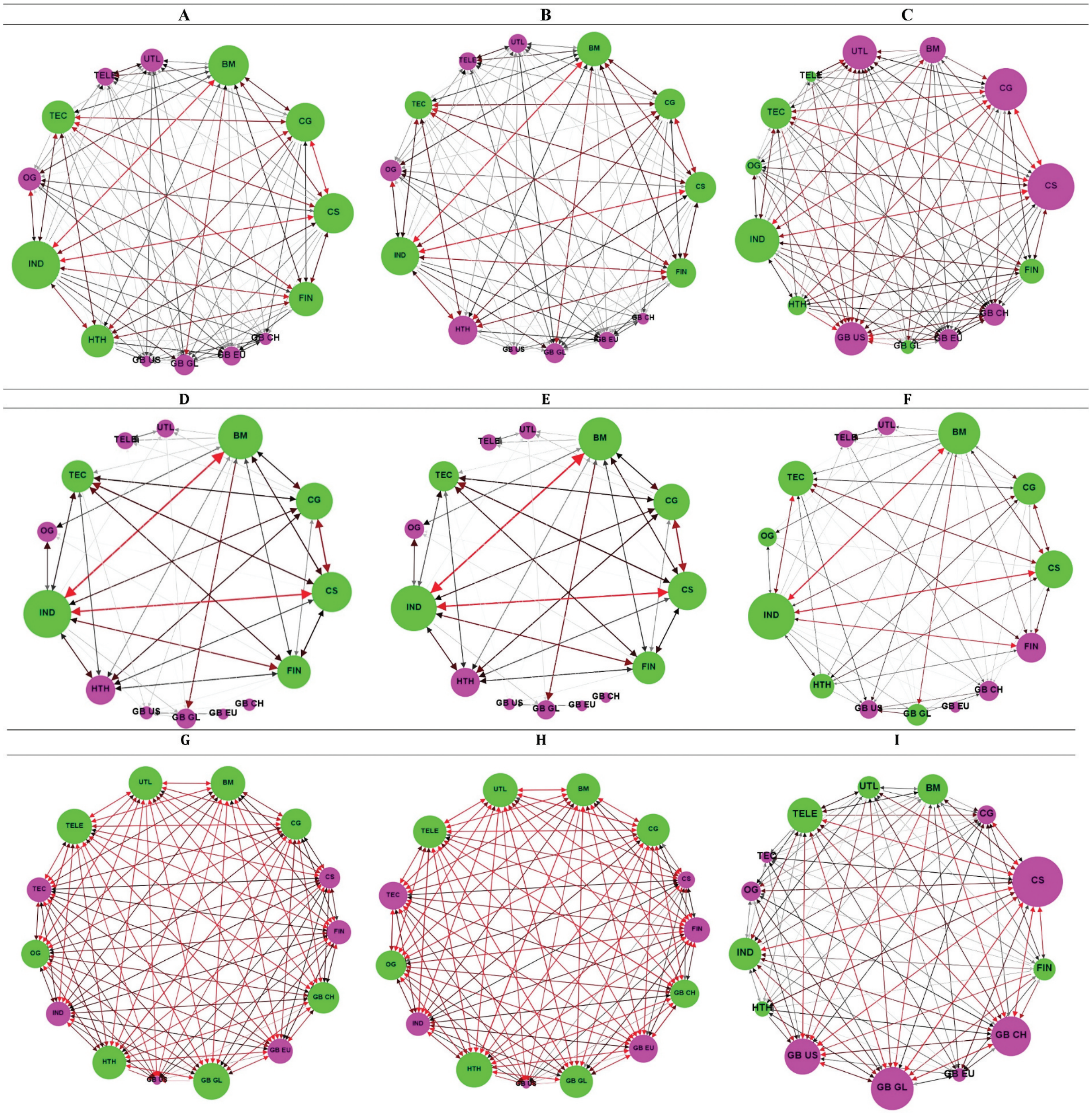

Figure 1. Network spillovers at the total, short and long terms of 5th, 50th, and 95th quantiles during COVID-19. The model has been based on QVAR and lag length of order 1 (BIC) and a 20-step-ahead forecast, rolling window 250. Node dimension indicates the degree of spillovers impact, and also colour defines whether a market is a net transmitter (green) or recipient (pink) of spillovers. Arrowhead size represents the toughness of the pair-wise spillovers and also colour defines greatest (red) to weakest (black) instructions of spillovers.

moderate downside risk across different timeframes. The results indicate that short-term connectedness holds greater significance than long-term connectedness in this context, highlighting the importance of considering the immediate interactions between Islamic sectors and Green Bond markets. Tables 6–8, along with Figures 1(d–f) & 2 (d–f), further show that there is a significant spillover effect between the Islamic sector and Green Bond markets, indicating a high level of integration at a moderate level of downside risk. Short-term spillovers dominated long-term effects, likely due to both asset classes offering sustainable returns that appeal to investors concerned with environmental, social, and governance (ESG) issues. The role of green bonds in transmitting

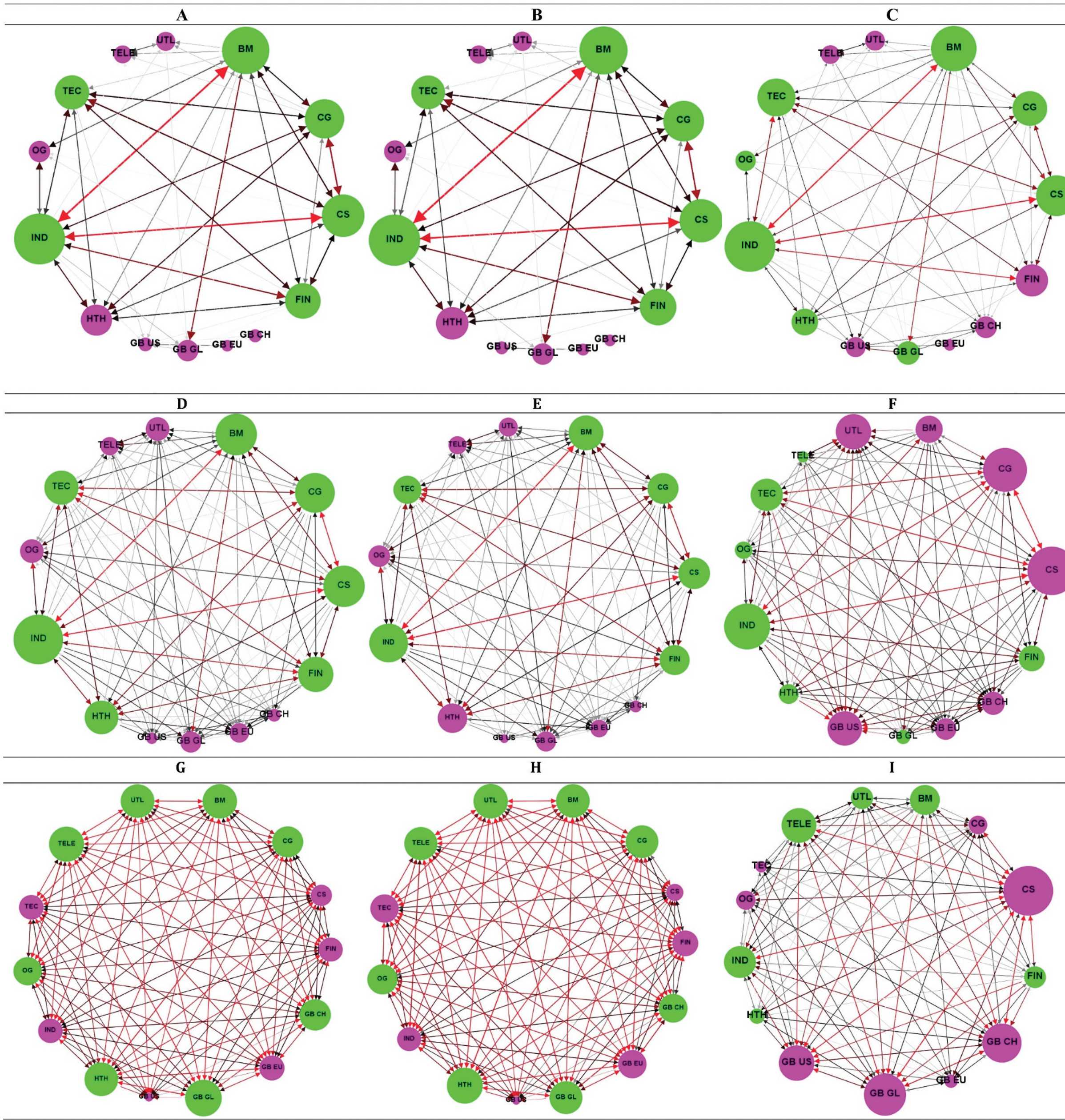

Figure 2. Network spillovers at the total, short and long terms of 5th, 50th, and 95th quantiles during Russia-Ukraine war.

shocks between Islamic sectors under moderate downside conditions is aligned with previous findings (Rizvi et al. 2022; Tiwari et al. 2023).

An analysis of the 10 Islamic sectors shows that seven sectors exhibited a net role in transmitting shocks across different frequencies, while two sectors received shocks. One sector exhibited mixed roles. The Islamic sector INDS consistently made the largest average contribution to downside risk spillovers impacting all other markets across different timeframes. The Islamic sectors TECH, BM, and FIN followed closely as outsized spillover transmitters. Concurrently, the green bond market of China consistently demonstrated the highest net receipt of downside risk spillovers among its peers, with the EU and global green bond markets also absorbing substantial spillover effects. These findings are consistent with previous research, indicating cross-market spillover occurring between these two responsible investment asset classes.

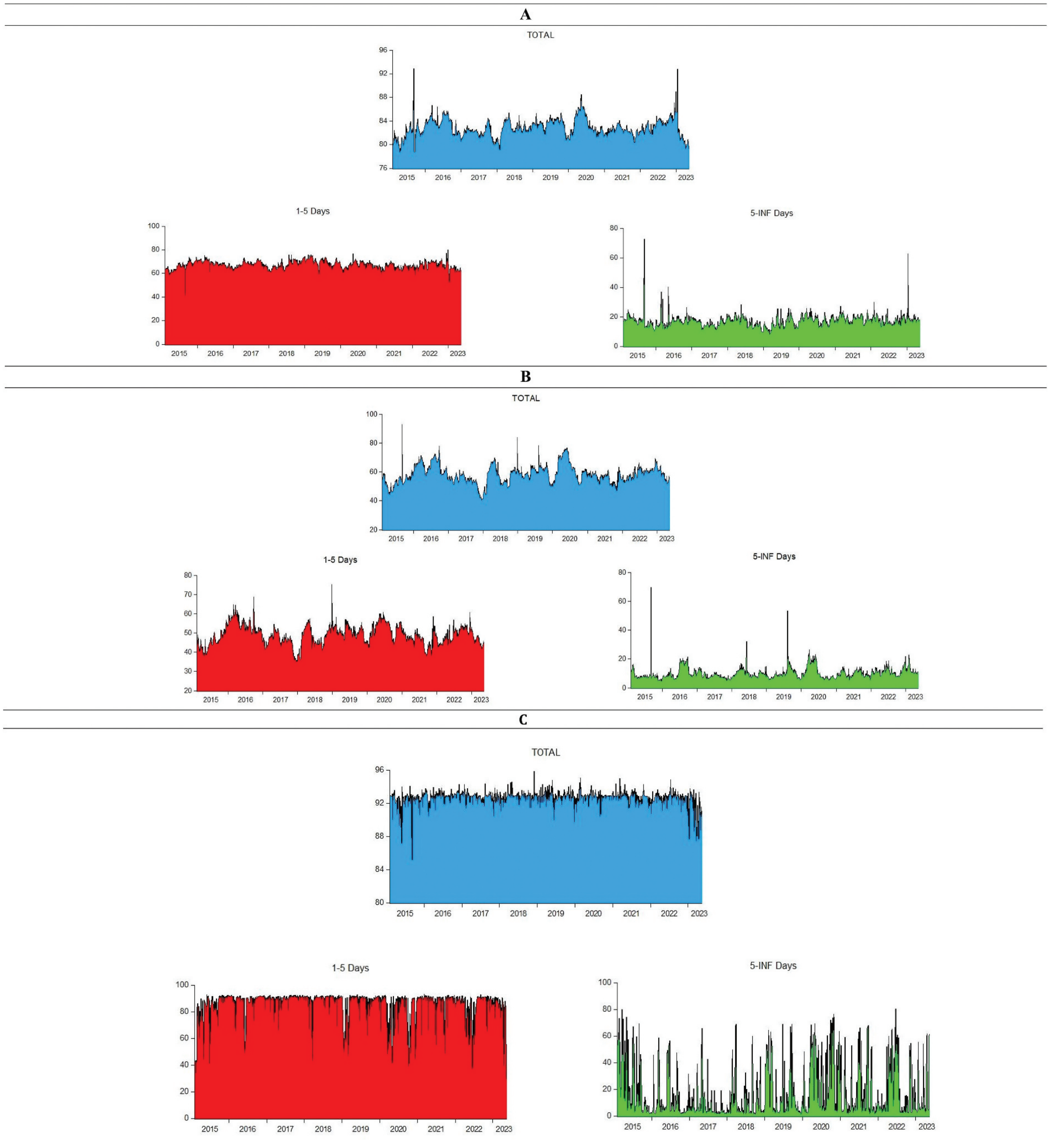

Figure 3. Time-varying spillovers at the total, short and long terms of 5th, 50th and 95th quantiles.

Specific green bond markets – GB US, GB EU, GB GL and GB CH – were net receivers of spillover effects across frequencies during periods of moderate downside risk. TELE and UTL SECTORS held a net receiving role across frequencies, indicating they absorbed spillover effects from other sectors and markets.

In conclusion, these results suggest that Islamic and green financial products allow for portfolio diversification while addressing sustainability preferences. It also highlights the importance of considering the immediate interactions between Islamic sectors and Green Bond markets to understand the spillover effects between them.

Low downside risk connectedness

Tables 9, 10 and 11 presented in this study demonstrate the relationship between Islamic sectors and Green Bond markets during periods of low downside risk. The total volatility spillover across all

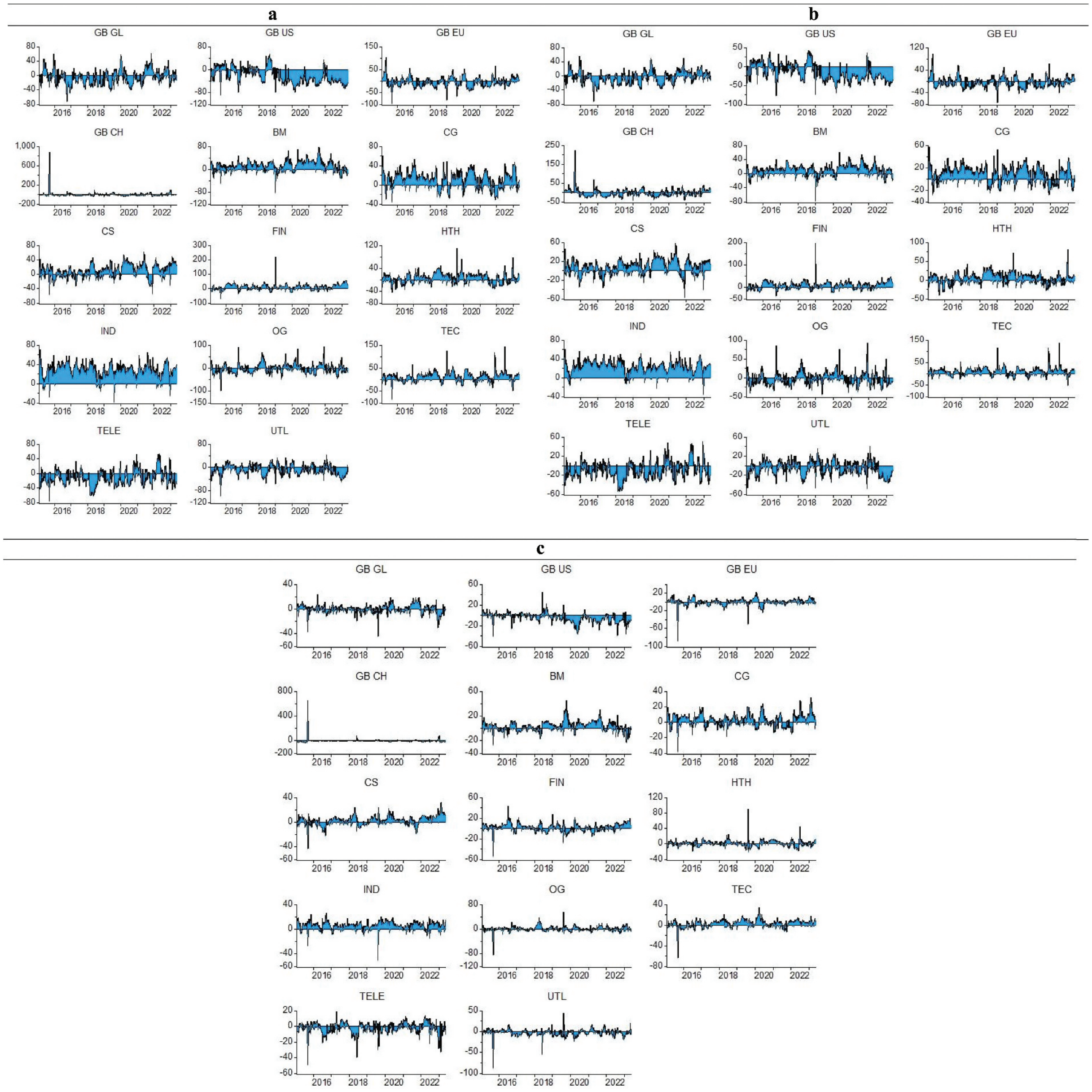

Figure 4. Net spillovers at the total, short and long terms of 5th quantile.

variables was found to be approximately 99.20%, with short-term shock transmission dominating the interconnectedness between these markets. Long-term linkages contributed a smaller portion of total spillover effects on average. These findings were consistent with previous empirical research (Chatziantoniou et al. 2022; Mensi et al. 2023). The results suggest that these markets are highly integrated and sensitive to uncertainty and shocks, regardless of the severity of downside fluctuations.

Furthermore, the study found that the green bond markets of the EU and China exhibited steady net receiving positions over multiple intervals, while the US and global green bond markets showed changed roles in absorbing versus propagating volatility spillovers between Islamic sectors. These results indicate differing dynamics between the markets during periods of minimal downside risk. Overall, this study reinforces the conclusion that Islamic sectors and green bond markets exhibit substantial

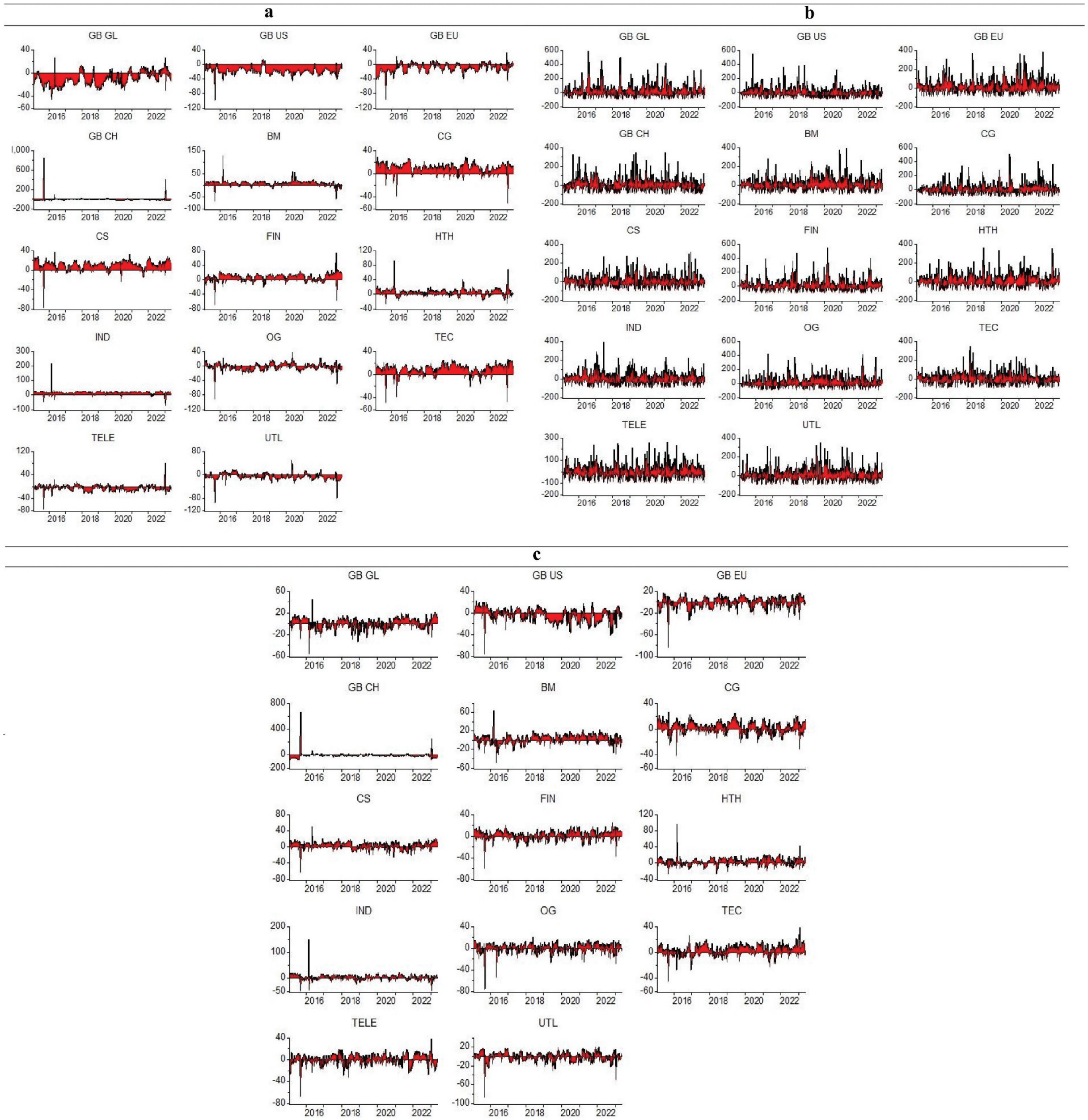

Figure 5. Net spillovers at the total, short and long terms of 50th quantile.

interdependence and an aptitude for contagion under varying degrees of downside market movement, see also Figures 1(g–i) & 2(g–i).

Moreover, it appears that there have been mixed roles exhibited by the Islamic Sector in the transmission of shocks. The sectors BM, FIN, OG, CG, and HC have shown positive effects, while CS, INDS, TECH, TELE, and UTL have shown negative effects. These results suggest that some Islamic sectoral markets and the green bond market may serve as safe havens during lower downside risk conditions.

Dynamic connectedness discoveries

In the analysis of the time-varying dynamic connectedness between the green bond markets and Islamic sectoral markets, the results show distinct phases over time at the 5th quantile, representing periods of higher downside risk. Figure 3a illustrates the Total Connectivity Index (TCI) recorded for the total, short, and long terms, with the highest TCI at 93% (80%) [75%] and the lowest at 78% (40%) [10%]. The connectivity index was low before 2015 and experienced a

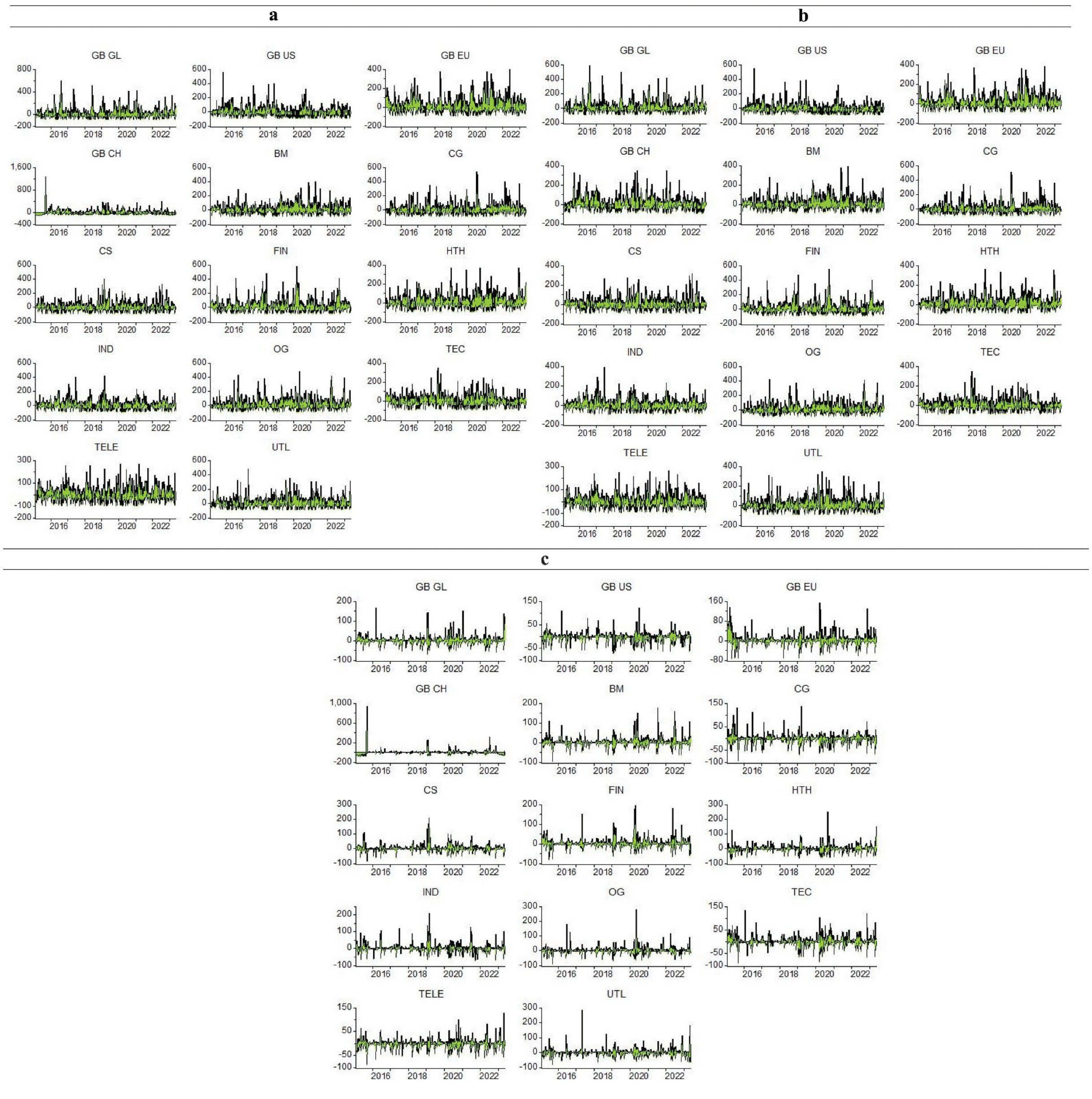

Figure 6. Net spillovers at the total, short and long terms of 95th quantile.

significant increase in that year, reaching 93% (75%) [76%] in total (short) [long] term. Even during the COVID-19 pandemic, the green bond markets maintained a high degree of volatility, resulting in a connection index of around 88% (77%) [25%] in total (short) [long] term. The results suggest that cross-market financial contagion effects may have been at work, pushing the interconnection between various industries. The military conflict between Russia and Ukraine in 2022 resulted in a total spillover effect of 65% (60%) [20%] between the Islamic sectors and green bond markets, indicating an uptick in downside risk spillovers. Major geopolitical events continue to amplify tail linkages between these systems during times of crisis and uncertainty (Rao et al. 2022).

Figure 3b provides important insights into how tail risk spillovers between the markets have varied over time at the median quantile (moderate level of downside risk), showing the highest levels of total, short, and long-run connections during periods of significant geopolitical and economic stress, including the COVID-19 pandemic and Russo-Ukrainian

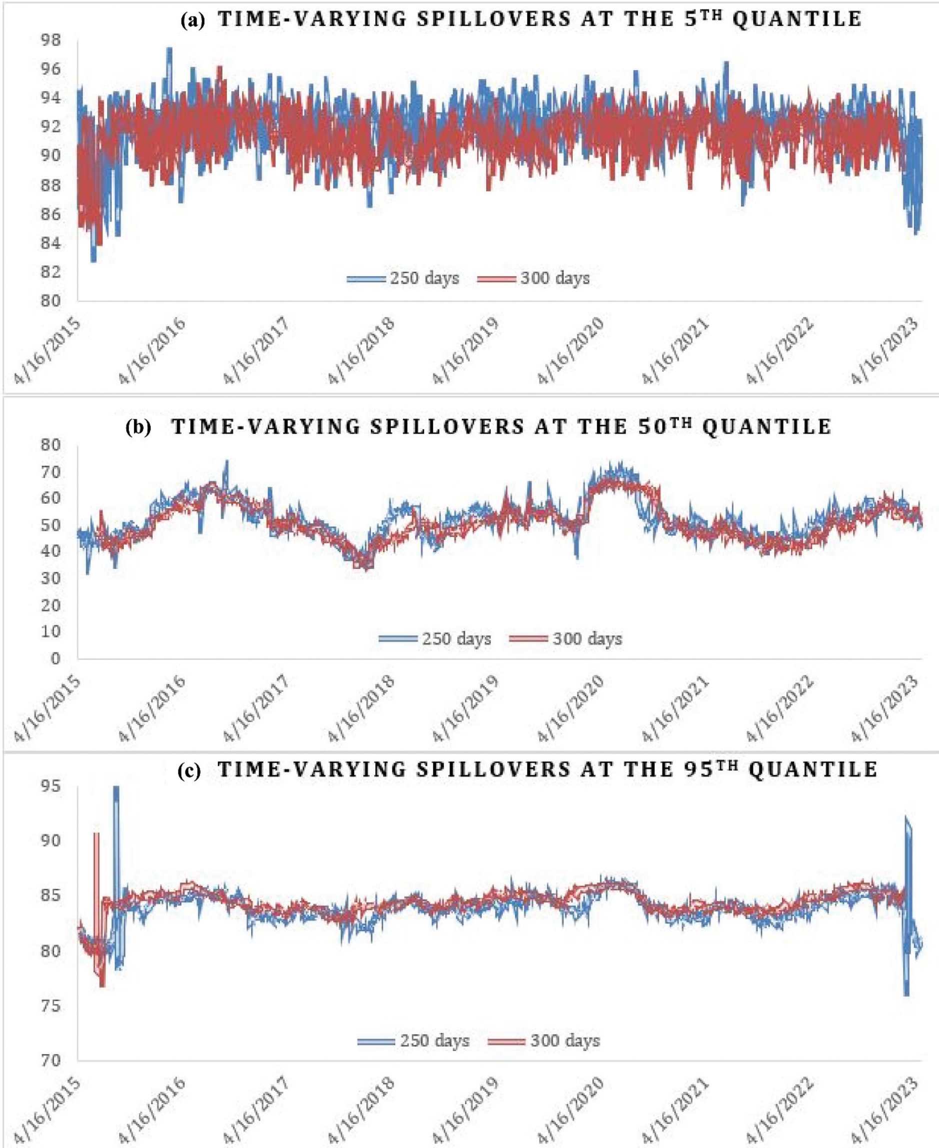

Figure 7. Time-varying spillovers at low, moderate and high-risk conditions with different rolling window sizes.

war. The figure also reveals three pronounced peaks in total spillovers in 2015, 2018 and 2019 that coincided with major global events, such as the Shale Oil Revolution, COP21 of Paris 2015, and the onset of the US–China trade war, confirming trade tensions can propagate shocks across markets. The markets appear highly interconnected, not just in the short run but also in integrating shocks over longer horizons, underscoring the lasting impact that global disturbances can have on linked financial systems even after initial volatility subsides.

Figure 3c provides a different perspective, illustrating the outcomes of dynamic total connectedness for the higher quantile (low downside risk) at various frequencies, with the Total Connectivity Index (TCI) consistently around 93% (90%) [7%] for the total (short) [long] term. Notably, spikes in downside movements are evident for normal and short-term frequencies, while the long-term frequency exhibits peaks on the upside. The effects of significant events such as the Shale Oil Revolution, US–China trade war, COVID-19 pandemic, and Russo-Ukrainian conflict are clearly visible in the plot for the years 2015, 2018, 2020, and 2022, respectively.

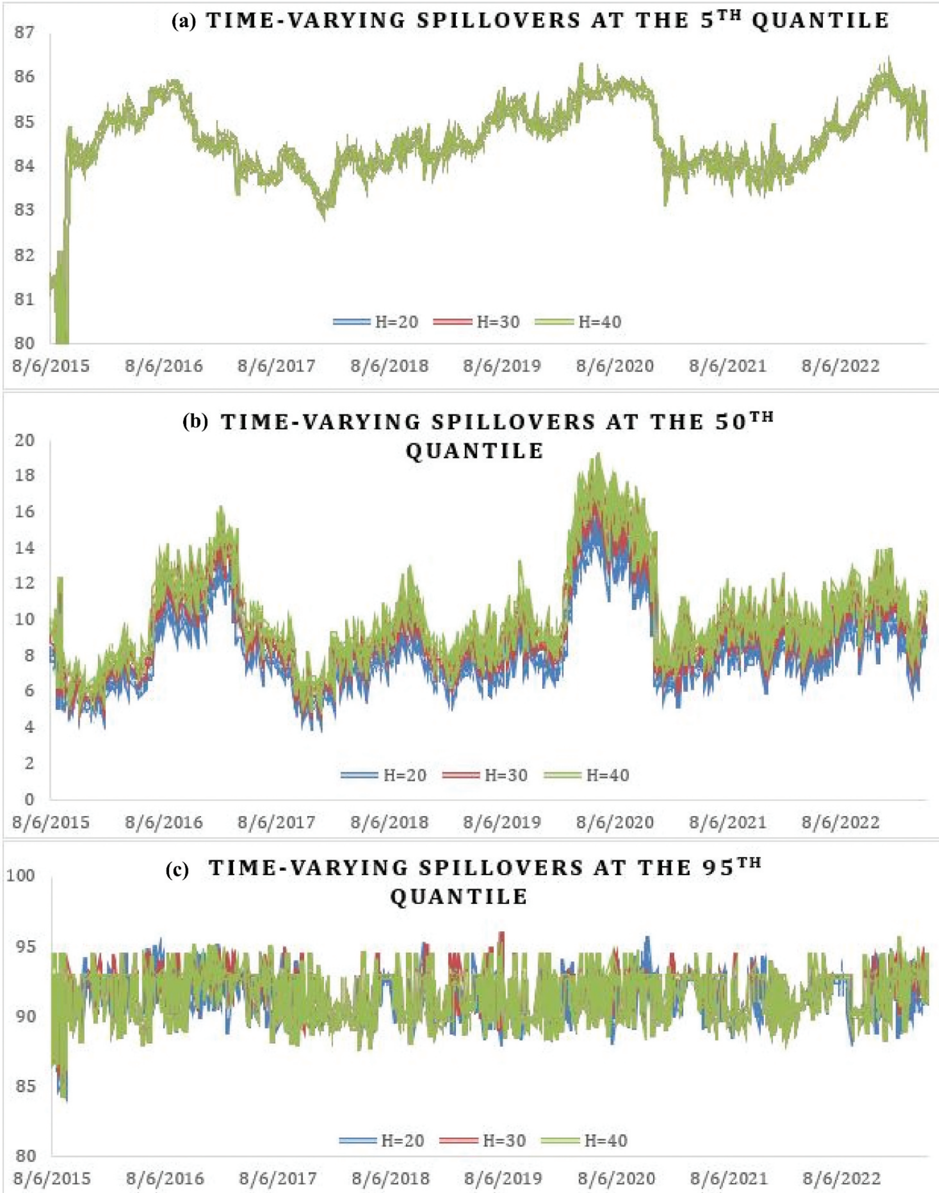

Figure 8. Time-varying spillovers at low, moderate and high-risk conditions with different forecast steps.

Figures 4–6 depict the fluctuation of spillovers between the green bond markets and Islamic sectors in relation to different levels of downside risk. During periods of increased tail risk, the green bond markets tend to absorb shocks from the Islamic sectors and play a net receiving role. The Islamic sectors, including basic materials, consumer goods, consumer services, and financials, consistently act as significant transmitters of volatility across different quantiles, while certain sectors, including oil and gas, technology, telecom, and utilities, act as net recipients, absorbing spillovers rather than exacerbating turmoil. The net direction of spillovers varied in response to significant events such as the shale oil disruption, US–China trade tensions, and the COVID-19 pandemic. Contemporary crises and past instances of stress have influenced the distribution of cross-market shocks between the green bond and Islamic sectors, confirming that the transmission of risk is procyclical, meaning it increases during periods when financial systems need to effectively reduce volatility.

Robustness check

To ensure the initial QVAR estimation was accurate, we conducted further investigations using multiple rolling windows and alternative forecast horizons. The model was re-estimated using a rolling 300-day window and a 20-day forecast horizon to calculate total connectedness (See Figures 7 and 8). The results showed that both models followed similar trends, with the time-varying connectedness index remaining at higher levels in lower and higher risk environments and at a moderate level in moderate risk environments. The results from these alternative models were consistent with those originally estimated from the QVAR model using a 200-day rolling window. We observed spikes in connectedness and spillover effects during significant events such as oil price shocks, the Brexit vote, the US–China trade war, the COVID-19 pandemic, and the Russia–Ukraine war. The findings from these QVAR models, which employed alternative rolling window specifications, demonstrated parallel and analogous trends in terms of the dynamic connectivity and spillover effects. Moreover, the consistency observed across models with different parameterizations provides support for the robustness of our main findings regarding the fluctuations in interconnectedness and spillovers between Islamic sectors and green bond markets. Therefore, the effects identified appear robust to alterations in modelling approach and time period examined.

Portfolio and hedging strategies analysis

In the next section, we evaluate different portfolio construction techniques for hedging effectiveness. These include bilateral hedge ratios and portfolio weights by Kroner and Sultan (1993), minimum variance technique by (Stuart and Markowitz (1959), Minimum Correlation Portfolio (MCP) by Christoffersen et al. (2014), and Minimum Connectedness Portfolio (MCoP) by Broadstock et al. (2021). We use a portfolio evaluation developed by Ederington (1979) and modified by Antonakakis et al. (2020b). Hedge ratios and effectiveness scores are also plotted for better insights into the relative performance of each portfolio.

Bilateral hedge ratios and portfolio weights

Table 12 shows metrics revealing the feasibility of hedging between green bonds and Islamic assets. Several GB.GL and GB.EU pairs exhibit negative ratios against Islamic sectors, signifying their potential as hedging instruments. GB.GL and GB.EU are suitable tools for mitigating risks associated with Islamic finance-focused holdings, providing valuable hedging opportunities within Sharia-compliant portfolios (Abbes and Trichilli 2015).

Table 13 provides insights into the optimal allocation of assets in relation to a $100 investment in assets. The optimal portfolio weight (OPW) of GB US/GB EU stands at 93%, indicating a potential opportunity for risk reduction. A similar reasoning is applicable for other pairs, and the discovery underscores the potential for substantial diversification benefits through the inclusion of Islamic sector investment alongside other green bonds in investment portfolios. The implementation of an optimal portfolio weighting strategy has proven to be highly effective in mitigating portfolio risk (Arif et al. 2021). Overall, the findings suggest that a strategic combination of green bonds and Islamic sectors could be an excellent portfolio diversification strategy that improves risk-adjusted returns.

Multivariate portfolio analysis

In the following section, we will discuss the multivariate investment portfolio of three approaches, namely MVP, MCP, and MCoP, along with the hedging effectiveness deliberated in section 3.2 of the methodology. With the help of dynamic portfolio weights reported in Figure A1, we will provide further insights about the individual's asset's portfolio weights to have a robust understanding with the aim of providing insight into the composition of an individual portfolio.

Table 14 in the minimum variance portfolio panel shows that by investing 17% in (GB.US and GB.GL), 59% in GB.CH, 2% in TELE, 1% in (GB.EU, CG, HC and UTL), and 0% in (BM, CS, FIN, INDS, OG and TECH), the volatility contribution by each asset in the portfolio would reduce. All the suggested assets can be invested in the same proportion without increasing volatility, suggesting that Islamic sectoral assets do not carry gainful hedging power in the portfolio.

Table 12. Bilateral hedge ratios.

	Mean	Std.Dev.	5%	95%	HE	p-value		Mean	Std.Dev.	5%	95%	HE	p-value
GB.EU/GB.US	0.26	0.31	−0.20	0.83	0.17	0.00	GB.US/FIN	0.00	0.01	−0.01	0.02	0.00	0.93
GB.GL/GB.US	0.25	0.18	0.11	0.66	0.37	0.00	GB.EU/FIN	−0.02	0.03	−0.07	0.03	−0.01	0.90
GB.CH/GB.US	0.03	0.06	−0.04	0.12	−0.02	0.69	GB.GL/FIN	0.00	0.01	−0.02	0.01	−0.01	0.89
BM/GB.US	0.21	0.31	−0.26	0.77	0.00	0.95	GB.CH/FIN	0.00	0.02	−0.01	0.02	0.01	0.91
CG/GB.US	0.09	0.23	−0.32	0.46	0.00	0.97	BM/FIN	0.52	0.14	0.31	0.76	0.43	0.00
CS/GB.US	0.13	0.30	−0.26	0.70	0.00	0.98	CG/FIN	0.48	0.11	0.31	0.70	0.56	0.00
FIN/GB.US	0.18	0.32	−0.28	0.70	0.00	0.96	CS/FIN	0.61	0.13	0.39	0.83	0.64	0.00
HC/GB.US	0.20	0.27	−0.19	0.66	0.00	0.92	HC/FIN	0.55	0.12	0.38	0.75	0.59	0.00
INDS/GB.US	0.22	0.29	−0.19	0.68	0.00	0.93	INDS/FIN	0.59	0.12	0.41	0.80	0.65	0.00
OG/GB.US	0.10	0.66	−0.94	1.07	0.00	1.00	OG/FIN	0.59	0.22	0.28	1.01	0.36	0.00
TECH/GB.US	0.12	0.36	−0.43	0.68	0.00	0.96	TECH/FIN	0.87	0.16	0.62	1.14	0.67	0.00
TELE/GB.US	−0.11	0.26	−0.56	0.23	0.00	0.91	TELE/FIN	0.24	0.11	0.11	0.46	0.15	0.00
UTL/GB.US	0.13	0.29	−0.25	0.60	0.00	0.94	UTL/FIN	0.30	0.13	0.14	0.55	0.19	0.00
GB.US/GB.EU	0.03	0.05	−0.01	0.13	0.06	0.16	GB.US/HC	0.01	0.01	−0.01	0.03	0.00	0.94
GB.GL/GB.EU	0.10	0.06	0.03	0.22	0.14	0.00	GB.EU/HC	0.00	0.03	−0.04	0.06	0.00	0.94
GB.CH/GB.EU	−0.01	0.03	−0.05	0.02	0.00	0.96	GB.GL/HC	0.00	0.01	−0.02	0.02	0.00	0.99
BM/GB.EU	0.02	0.09	−0.12	0.16	0.00	0.95	GB.CH/HC	0.00	0.02	−0.02	0.02	0.00	0.99
CG/GB.EU	0.02	0.07	−0.08	0.15	−0.01	0.91	BM/HC	0.66	0.15	0.45	0.95	0.43	0.00
CS/GB.EU	0.03	0.11	−0.11	0.22	0.00	0.92	CG/HC	0.60	0.15	0.40	0.89	0.57	0.00
FIN/GB.EU	−0.07	0.09	−0.25	0.05	0.00	0.92	CS/HC	0.69	0.17	0.46	0.99	0.55	0.00
HC/GB.EU	0.01	0.07	−0.14	0.12	0.00	0.92	FIN/HC	0.80	0.19	0.54	1.18	0.54	0.00
INDS/GB.EU	0.01	0.09	−0.14	0.18	0.00	0.94	INDS/HC	0.69	0.14	0.48	0.93	0.57	0.00
OG/GB.EU	0.02	0.14	−0.22	0.22	0.00	0.95	OG/HC	0.67	0.25	0.34	1.17	0.26	0.00
TECH/GB.EU	−0.05	0.10	−0.22	0.12	−0.01	0.86	TECH/HC	0.93	0.21	0.63	1.31	0.55	0.00
TELE/GB.EU	0.00	0.07	−0.08	0.12	−0.01	0.88	TELE/HC	0.30	0.10	0.17	0.49	0.17	0.00
UTL/GB.EU	−0.04	0.07	−0.16	0.06	−0.01	0.89	UTL/HC	0.37	0.12	0.22	0.61	0.21	0.00
GB.US/GB.GL	0.24	0.18	0.10	0.67	0.37	0.00	GB.US/INDS	0.01	0.01	−0.01	0.03	−0.01	0.87
GB.EU/GB.GL	0.99	0.39	0.47	1.70	0.28	0.00	GB.EU/INDS	0.01	0.04	−0.05	0.07	0.00	0.95
GB.CH/GB.GL	0.01	0.05	−0.05	0.07	−0.01	0.84	GB.GL/INDS	0.00	0.01	−0.02	0.02	0.00	0.93
BM/GB.GL	0.01	0.39	−0.67	0.57	0.00	0.94	GB.CH/INDS	0.00	0.02	−0.01	0.02	0.00	0.91
CG/GB.GL	−0.02	0.32	−0.55	0.37	0.01	0.89	BM/INDS	0.92	0.17	0.67	1.22	0.70	0.00
CS/GB.GL	0.08	0.32	−0.50	0.58	0.00	0.96	CG/INDS	0.68	0.14	0.48	0.94	0.71	0.00
FIN/GB.GL	−0.12	0.39	−0.77	0.39	0.00	0.92	CS/INDS	0.82	0.15	0.62	1.07	0.72	0.00
HC/GB.GL	0.01	0.32	−0.52	0.47	−0.01	0.87	FIN/INDS	0.85	0.15	0.63	1.13	0.63	0.00
INDS/GB.GL	0.05	0.32	−0.56	0.47	0.00	0.93	HC/INDS	0.68	0.13	0.49	0.90	0.61	0.00
OG/GB.GL	0.15	0.61	−0.91	0.92	0.00	0.93	OG/INDS	1.03	0.31	0.61	1.57	0.49	0.00
TECH/GB.GL	−0.14	0.36	−0.74	0.37	0.00	0.94	TECH/INDS	1.01	0.18	0.76	1.33	0.64	0.00
TELE/GB.GL	−0.14	0.19	−0.46	0.13	0.01	0.84	TELE/INDS	0.41	0.15	0.20	0.68	0.28	0.00
UTL/GB.GL	−0.09	0.28	−0.52	0.45	0.00	0.95	UTL/INDS	0.49	0.18	0.26	0.82	0.32	0.00
GB.US/GB.CH	0.24	0.43	−0.07	1.06	−0.01	0.79	GB.US/OG	0.00	0.01	−0.01	0.01	−0.01	0.84
GB.EU/GB.CH	−0.84	1.42	−3.99	0.27	0.00	1.00	GB.EU/OG	0.00	0.02	−0.02	0.04	0.00	0.93
GB.GL/GB.CH	0.11	0.24	−0.10	0.48	−0.01	0.83	GB.GL/OG	0.00	0.01	−0.01	0.01	−0.01	0.88
BM/GB.CH	0.27	1.27	−0.94	2.82	0.00	0.99	GB.CH/OG	0.00	0.01	−0.01	0.01	0.00	0.98
CG/GB.CH	0.40	1.18	−0.67	2.62	0.01	0.78	BM/OG	0.41	0.10	0.28	0.61	0.47	0.00
CS/GB.CH	0.46	1.39	−0.58	3.05	0.02	0.73	CG/OG	0.21	0.07	0.12	0.34	0.30	0.00
FIN/GB.CH	0.85	2.16	−0.89	5.17	0.00	0.92	CS/OG	0.29	0.08	0.18	0.43	0.37	0.00
HC/GB.CH	0.05	0.95	−1.09	1.25	0.00	0.95	FIN/OG	0.29	0.09	0.16	0.46	0.34	0.00
INDS/GB.CH	0.35	1.38	−0.76	2.92	0.00	0.97	HC/OG	0.23	0.08	0.11	0.38	0.28	0.00
OG/GB.CH	0.83	2.73	−1.71	6.75	0.00	0.96	INDS/OG	0.35	0.09	0.23	0.51	0.50	0.00
TECH/GB.CH	0.43	1.71	−1.49	3.46	0.01	0.76	TECH/OG	0.34	0.12	0.18	0.57	0.31	0.00
TELE/GB.CH	0.94	1.92	−0.43	5.02	0.00	0.99	TELE/OG	0.15	0.06	0.08	0.29	0.17	0.00
UTL/GB.CH	0.94	2.19	−0.67	5.77	0.00	0.98	UTL/OG	0.21	0.09	0.11	0.39	0.19	0.00
GB.US/BM	0.01	0.01	−0.01	0.03	0.00	0.98	GB.US/TECH	0.00	0.01	−0.01	0.02	0.00	0.96
GB.EU/BM	0.01	0.03	−0.03	0.06	0.00	0.93	GB.EU/TECH	−0.01	0.02	−0.05	0.03	−0.01	0.88
GB.GL/BM	0.00	0.01	−0.02	0.02	0.00	0.99	GB.GL/TECH	0.00	0.01	−0.02	0.01	0.00	0.97
GB.CH/BM	0.00	0.02	−0.01	0.01	0.00	0.92	GB.CH/TECH	0.00	0.01	−0.01	0.01	0.01	0.84
CG/BM	0.52	0.13	0.34	0.75	0.52	0.00	BM/TECH	0.47	0.14	0.26	0.73	0.36	0.00
CS/BM	0.55	0.13	0.36	0.79	0.46	0.00	CG/TECH	0.44	0.11	0.26	0.63	0.57	0.00
FIN/BM	0.57	0.15	0.35	0.85	0.38	0.00	CS/TECH	0.55	0.13	0.35	0.77	0.65	0.00
HC/BM	0.51	0.11	0.33	0.70	0.43	0.00	FIN/TECH	0.66	0.13	0.45	0.89	0.65	0.00
INDS/BM	0.71	0.13	0.52	0.95	0.70	0.00	HC/TECH	0.49	0.12	0.32	0.68	0.56	0.00
OG/BM	0.92	0.22	0.63	1.36	0.46	0.00	INDS/TECH	0.54	0.12	0.36	0.74	0.61	0.00
TECH/BM	0.67	0.18	0.42	0.98	0.38	0.00	OG/TECH	0.54	0.23	0.22	0.96	0.29	0.00
TELE/BM	0.42	0.12	0.26	0.64	0.37	0.00	TELE/TECH	0.21	0.10	0.08	0.40	0.10	0.02
UTL/BM	0.47	0.13	0.28	0.71	0.38	0.00	UTL/TECH	0.26	0.12	0.11	0.49	0.13	0.00
GB.US/CG	0.00	0.01	−0.02	0.02	0.00	0.97	GB.US/TELE	−0.01	0.02	−0.03	0.01	0.00	0.93
GB.EU/CG	0.00	0.04	−0.06	0.07	0.00	0.91	GB.EU/TELE	−0.01	0.05	−0.09	0.08	−0.01	0.90
GB.GL/CG	0.00	0.02	−0.02	0.02	0.00	0.99	GB.GL/TELE	−0.01	0.02	−0.04	0.01	0.00	0.99
GB.CH/CG	0.00	0.03	−0.02	0.02	0.00	0.94	GB.CH/TELE	0.00	0.02	−0.02	0.03	0.00	0.99
BM/CG	0.87	0.21	0.51	1.23	0.52	0.00	BM/TELE	0.80	0.20	0.53	1.18	0.37	0.00
CS/CG	0.89	0.17	0.62	1.18	0.65	0.00	CG/TELE	0.51	0.17	0.30	0.84	0.29	0.00

(*Continued*)

Table 12. (Continued).

	Mean	Std.Dev.	5%	95%	HE	p-value		Mean	Std.Dev.	5%	95%	HE	p-value
FIN/CG	0.91	0.22	0.57	1.29	0.53	0.00	CS/TELE	0.45	0.17	0.26	0.75	0.17	0.00
HC/CG	0.78	0.18	0.48	1.08	0.60	0.00	FIN/TELE	0.48	0.17	0.26	0.81	0.15	0.00
INDS/CG	0.89	0.19	0.59	1.22	0.69	0.00	HC/TELE	0.42	0.12	0.26	0.64	0.17	0.00
OG/CG	0.81	0.31	0.39	1.39	0.27	0.00	INDS/TELE	0.58	0.18	0.35	0.93	0.28	0.00
TECH/CG	1.06	0.23	0.75	1.46	0.59	0.00	OG/TELE	0.65	0.30	0.31	1.25	0.14	0.00
TELE/CG	0.47	0.18	0.18	0.77	0.25	0.00	TECH/TELE	0.52	0.17	0.31	0.83	0.14	0.00
UTL/CG	0.57	0.20	0.27	0.92	0.30	0.00	UTL/TELE	0.67	0.15	0.47	0.93	0.45	0.00
GB.US/CS	0.00	0.01	−0.01	0.02	0.00	0.95	GB.US/UTL	0.01	0.01	−0.01	0.03	0.00	0.99
GB.EU/CS	0.01	0.04	−0.05	0.07	0.00	0.93	GB.EU/UTL	−0.02	0.04	−0.10	0.03	−0.01	0.89
GB.GL/CS	0.00	0.01	−0.01	0.02	0.00	0.91	GB.GL/UTL	−0.01	0.02	−0.03	0.02	0.00	0.92
GB.CH/CS	0.00	0.01	−0.01	0.02	0.01	0.83	GB.CH/UTL	0.00	0.01	−0.01	0.02	0.00	0.92
BM/CS	0.67	0.17	0.38	0.97	0.46	0.00	BM/UTL	0.73	0.18	0.49	1.05	0.40	0.00
CG/CS	0.63	0.13	0.45	0.86	0.65	0.00	CG/UTL	0.52	0.15	0.34	0.79	0.33	0.00
FIN/CS	0.81	0.18	0.52	1.10	0.62	0.00	CS/UTL	0.46	0.15	0.27	0.73	0.19	0.00
HC/CS	0.64	0.16	0.37	0.89	0.56	0.00	FIN/UTL	0.51	0.18	0.28	0.89	0.18	0.00
INDS/CS	0.76	0.14	0.53	1.00	0.71	0.00	HC/UTL	0.45	0.13	0.27	0.70	0.19	0.00
OG/CS	0.79	0.28	0.38	1.34	0.34	0.00	INDS/UTL	0.58	0.17	0.37	0.91	0.33	0.00
TECH/CS	0.96	0.19	0.68	1.31	0.68	0.00	OG/UTL	0.69	0.22	0.40	1.12	0.21	0.00
TELE/CS	0.30	0.12	0.11	0.53	0.16	0.00	TECH/UTL	0.56	0.18	0.34	0.92	0.17	0.00
UTL/CS	0.36	0.14	0.17	0.63	0.17	0.00	TELE/UTL	0.57	0.16	0.27	0.83	0.44	0.00

Results are based on Kroner and Sultan (1993).

Table 13. Bilateral portfolio weights.

	Mean	Std.Dev.	5%	95%	HE	p-value		Mean	Std.Dev.	5%	95%	HE	p-value
GB.US/GB.EU	0.93	0.05	0.82	0.99	−0.10	0.02	FIN/GB.US	0.03	0.04	0.00	0.08	0.98	0.00
GB.US/GB.GL	0.52	0.04	0.48	0.60	0.18	0.00	FIN/GB.EU	0.28	0.14	0.06	0.53	0.85	0.00
GB.US/GB.CH	0.31	0.26	0.00	0.86	0.64	0.00	FIN/GB.GL	0.04	0.04	0.01	0.08	0.98	0.00
GB.US/BM	0.97	0.04	0.91	1.00	0.11	0.01	FIN/GB.CH	0.04	0.09	0.00	0.15	0.96	0.00
GB.US/CG	0.94	0.05	0.86	0.99	0.12	0.00	FIN/BM	0.46	0.22	0.08	0.81	0.33	0.00
GB.US/CS	0.96	0.04	0.90	0.99	0.09	0.03	FIN/CG	0.17	0.20	0.00	0.62	0.49	0.00
GB.US/FIN	0.97	0.04	0.92	1.00	0.10	0.02	FIN/CS	0.30	0.25	0.00	0.78	0.25	0.00
GB.US/HC	0.96	0.05	0.90	0.99	0.10	0.01	FIN/HC	0.29	0.22	0.00	0.68	0.46	0.00
GB.US/INDS	0.96	0.05	0.90	0.99	0.11	0.01	FIN/INDS	0.25	0.22	0.00	0.68	0.33	0.00
GB.US/OG	0.98	0.02	0.95	1.00	0.06	0.17	FIN/OG	0.75	0.16	0.45	1.00	−0.01	0.79
GB.US/TECH	0.98	0.03	0.94	1.00	0.05	0.20	FIN/TECH	0.71	0.26	0.19	1.00	0.06	0.14
GB.US/TELE	0.93	0.07	0.81	0.98	0.23	0.00	FIN/TELE	0.28	0.17	0.04	0.59	0.70	0.00
GB.US/UTL	0.95	0.05	0.87	0.99	0.13	0.00	FIN/UTL	0.33	0.20	0.03	0.67	0.62	0.00
GB.EU/GB.US	0.07	0.05	0.01	0.18	0.87	0.00	HC/GB.US	0.04	0.05	0.01	0.10	0.96	0.00
GB.EU/GB.GL	0.02	0.04	0.00	0.10	0.86	0.00	HC/GB.EU	0.33	0.14	0.11	0.57	0.75	0.00
GB.EU/GB.CH	0.09	0.17	0.00	0.51	0.92	0.00	HC/GB.GL	0.05	0.05	0.01	0.12	0.96	0.00
GB.EU/BM	0.72	0.14	0.48	0.92	0.28	0.00	HC/GB.CH	0.05	0.11	0.00	0.23	0.95	0.00
GB.EU/CG	0.61	0.17	0.35	0.90	0.38	0.00	HC/BM	0.64	0.19	0.33	0.96	0.04	0.40
GB.EU/CS	0.68	0.16	0.43	0.93	0.32	0.00	HC/CG	0.33	0.27	0.00	0.88	0.18	0.00
GB.EU/FIN	0.72	0.14	0.47	0.94	0.30	0.00	HC/CS	0.54	0.25	0.12	0.99	0.07	0.09
GB.EU/HC	0.67	0.14	0.43	0.89	0.34	0.00	HC/FIN	0.71	0.22	0.32	1.00	0.02	0.63
GB.EU/INDS	0.66	0.16	0.39	0.92	0.35	0.00	HC/INDS	0.51	0.23	0.11	0.93	0.05	0.20
GB.EU/OG	0.84	0.10	0.65	0.97	0.15	0.00	HC/OG	0.84	0.11	0.64	1.00	0.01	0.90
GB.EU/TECH	0.77	0.13	0.54	0.95	0.24	0.00	HC/TECH	0.85	0.18	0.48	1.00	0.00	0.95
GB.EU/TELE	0.60	0.15	0.36	0.84	0.43	0.00	HC/TELE	0.38	0.16	0.14	0.65	0.48	0.00
GB.EU/UTL	0.63	0.15	0.37	0.87	0.38	0.00	HC/UTL	0.43	0.19	0.12	0.76	0.38	0.00
GB.GL/GB.US	0.48	0.04	0.40	0.52	0.24	0.00	INDS/GB.US	0.04	0.05	0.01	0.10	0.97	0.00
GB.GL/GB.EU	0.98	0.04	0.90	1.00	−0.13	0.01	INDS/GB.EU	0.34	0.16	0.08	0.61	0.79	0.00
GB.GL/GB.CH	0.30	0.26	0.00	0.85	0.66	0.00	INDS/GB.GL	0.05	0.05	0.01	0.11	0.96	0.00
GB.GL/BM	0.96	0.05	0.90	0.99	0.13	0.00	INDS/GB.CH	0.05	0.11	0.00	0.21	0.96	0.00
GB.GL/CG	0.93	0.06	0.84	0.99	0.15	0.00	INDS/BM	0.73	0.29	0.10	1.00	0.03	0.46
GB.GL/CS	0.96	0.04	0.89	0.99	0.10	0.01	INDS/CG	0.29	0.29	0.00	0.90	0.26	0.00
GB.GL/FIN	0.96	0.04	0.92	0.99	0.11	0.01	INDS/CS	0.55	0.30	0.01	1.00	0.03	0.49
GB.GL/HC	0.95	0.05	0.88	0.99	0.12	0.00	INDS/FIN	0.75	0.22	0.32	1.00	−0.03	0.55
GB.GL/INDS	0.95	0.05	0.89	0.99	0.12	0.00	INDS/HC	0.49	0.23	0.07	0.89	0.20	0.00
GB.GL/OG	0.98	0.02	0.95	1.00	0.04	0.33	INDS/OG	0.93	0.12	0.68	1.00	0.00	0.94
GB.GL/TECH	0.97	0.03	0.93	0.99	0.07	0.11	INDS/TECH	0.90	0.17	0.57	1.00	−0.02	0.73
GB.GL/TELE	0.92	0.08	0.80	0.98	0.25	0.00	INDS/TELE	0.37	0.22	0.02	0.75	0.55	0.00
GB.GL/UTL	0.93	0.06	0.84	0.99	0.19	0.00	INDS/UTL	0.44	0.25	0.04	0.87	0.44	0.00
GB.CH/GB.US	0.69	0.26	0.14	1.00	0.79	0.00	OG/GB.US	0.02	0.02	0.00	0.05	0.99	0.00
GB.CH/GB.EU	0.91	0.17	0.49	1.00	0.60	0.00	OG/GB.EU	0.16	0.10	0.03	0.35	0.90	0.00
GB.CH/GB.GL	0.70	0.26	0.15	1.00	0.79	0.00	OG/GB.GL	0.02	0.02	0.00	0.05	0.99	0.00
GB.CH/BM	0.96	0.10	0.79	1.00	0.35	0.00	OG/GB.CH	0.02	0.07	0.00	0.11	0.98	0.00
GB.CH/CG	0.95	0.10	0.78	1.00	0.32	0.00	OG/BM	0.13	0.15	0.00	0.44	0.61	0.00

(Continued)

Table 13. (Continued).

	Mean	Std.Dev.	5%	95%	HE	p-value		Mean	Std.Dev.	5%	95%	HE	p-value
GB.CH/CS	0.96	0.09	0.83	1.00	0.19	0.00	OG/CG	0.10	0.12	0.00	0.37	0.74	0.00
GB.CH/FIN	0.96	0.09	0.85	1.00	0.14	0.00	OG/CS	0.15	0.15	0.00	0.45	0.59	0.00
GB.CH/HC	0.95	0.11	0.77	1.00	0.36	0.00	OG/FIN	0.25	0.16	0.00	0.55	0.45	0.00
GB.CH/INDS	0.95	0.11	0.79	1.00	0.34	0.00	OG/HC	0.16	0.11	0.00	0.36	0.70	0.00
GB.CH/OG	0.98	0.07	0.89	1.00	0.21	0.00	OG/INDS	0.07	0.12	0.00	0.32	0.65	0.00
GB.CH/TECH	0.97	0.08	0.89	1.00	0.19	0.00	OG/TECH	0.34	0.20	0.01	0.70	0.44	0.00
GB.CH/TELE	0.93	0.15	0.59	1.00	0.58	0.00	OG/TELE	0.13	0.10	0.00	0.33	0.82	0.00
GB.CH/UTL	0.95	0.12	0.74	1.00	0.40	0.00	OG/UTL	0.13	0.11	0.00	0.32	0.76	0.00
BM/GB.US	0.03	0.04	0.00	0.09	0.97	0.00	TECH/GB.US	0.02	0.03	0.00	0.06	0.98	0.00
BM/GB.EU	0.28	0.14	0.08	0.52	0.79	0.00	TECH/GB.EU	0.23	0.13	0.05	0.46	0.86	0.00
BM/GB.GL	0.04	0.05	0.01	0.10	0.97	0.00	TECH/GB.GL	0.03	0.03	0.01	0.07	0.98	0.00
BM/GB.CH	0.04	0.10	0.00	0.21	0.96	0.00	TECH/GB.CH	0.03	0.08	0.00	0.11	0.97	0.00
BM/CG	0.20	0.23	0.00	0.72	0.33	0.00	TECH/BM	0.33	0.22	0.01	0.75	0.40	0.00
BM/CS	0.39	0.24	0.02	0.84	0.16	0.00	TECH/CG	0.06	0.12	0.00	0.31	0.56	0.00
BM/FIN	0.54	0.22	0.19	0.92	0.09	0.03	TECH/CS	0.15	0.18	0.00	0.53	0.31	0.00
BM/HC	0.36	0.19	0.04	0.67	0.27	0.00	TECH/FIN	0.29	0.26	0.00	0.81	0.20	0.00
BM/INDS	0.27	0.29	0.00	0.90	0.14	0.00	TECH/HC	0.15	0.18	0.00	0.52	0.52	0.00
BM/OG	0.87	0.15	0.56	1.00	0.00	0.91	TECH/INDS	0.10	0.17	0.00	0.43	0.43	0.00
BM/TECH	0.67	0.22	0.25	0.99	0.04	0.31	TECH/OG	0.66	0.20	0.30	0.99	0.11	0.01
BM/TELE	0.21	0.18	0.00	0.57	0.56	0.00	TECH/TELE	0.22	0.15	0.02	0.50	0.73	0.00
BM/UTL	0.29	0.20	0.00	0.63	0.44	0.00	TECH/UTL	0.25	0.18	0.01	0.60	0.66	0.00
CG/GB.US	0.06	0.05	0.01	0.14	0.96	0.00	TELE/GB.US	0.07	0.07	0.02	0.19	0.94	0.00
CG/GB.EU	0.39	0.17	0.10	0.65	0.74	0.00	TELE/GB.EU	0.40	0.15	0.16	0.64	0.64	0.00
CG/GB.GL	0.07	0.06	0.01	0.16	0.96	0.00	TELE/GB.GL	0.08	0.08	0.02	0.20	0.94	0.00
CG/GB.CH	0.05	0.10	0.00	0.22	0.94	0.00	TELE/GB.CH	0.07	0.15	0.00	0.41	0.95	0.00
CG/BM	0.80	0.23	0.28	1.00	0.02	0.71	TELE/BM	0.79	0.18	0.43	1.00	0.03	0.42
CG/CS	0.75	0.25	0.24	1.00	−0.01	0.88	TELE/CG	0.52	0.25	0.16	0.95	0.19	0.00
CG/FIN	0.83	0.20	0.38	1.00	−0.01	0.81	TELE/CS	0.63	0.20	0.30	0.96	0.17	0.00
CG/HC	0.67	0.27	0.12	1.00	0.08	0.05	TELE/FIN	0.72	0.17	0.41	0.96	0.11	0.01
CG/INDS	0.71	0.29	0.10	1.00	0.02	0.57	TELE/HC	0.62	0.16	0.35	0.86	0.15	0.00
CG/OG	0.90	0.12	0.63	1.00	0.02	0.71	TELE/INDS	0.63	0.22	0.25	0.98	0.12	0.00
CG/TECH	0.94	0.12	0.69	1.00	−0.03	0.47	TELE/OG	0.87	0.10	0.67	1.00	0.03	0.52
CG/TELE	0.48	0.25	0.05	0.84	0.45	0.00	TELE/TECH	0.78	0.15	0.50	0.98	0.06	0.16
CG/UTL	0.55	0.26	0.12	0.95	0.33	0.00	TELE/UTL	0.59	0.24	0.18	0.94	0.08	0.05
CS/GB.US	0.04	0.04	0.01	0.10	0.97	0.00	UTL/GB.US	0.05	0.05	0.01	0.13	0.95	0.00
CS/GB.EU	0.32	0.16	0.07	0.57	0.82	0.00	UTL/GB.EU	0.37	0.15	0.13	0.63	0.70	0.00
CS/GB.GL	0.04	0.04	0.01	0.11	0.97	0.00	UTL/GB.GL	0.07	0.06	0.01	0.16	0.95	0.00
CS/GB.CH	0.04	0.09	0.00	0.17	0.96	0.00	UTL/GB.CH	0.05	0.12	0.00	0.26	0.94	0.00
CS/BM	0.61	0.24	0.16	0.98	0.21	0.00	UTL/BM	0.71	0.20	0.37	1.00	0.06	0.19
CS/CG	0.25	0.25	0.00	0.76	0.36	0.00	UTL/CG	0.45	0.26	0.05	0.88	0.24	0.00
CS/FIN	0.70	0.25	0.22	1.00	0.05	0.27	UTL/CS	0.58	0.22	0.19	0.91	0.20	0.00
CS/HC	0.46	0.25	0.01	0.88	0.34	0.00	UTL/FIN	0.67	0.20	0.33	0.97	0.14	0.00
CS/INDS	0.45	0.30	0.00	0.99	0.19	0.00	UTL/HC	0.57	0.19	0.24	0.88	0.22	0.00
CS/OG	0.85	0.15	0.55	1.00	0.04	0.41	UTL/INDS	0.56	0.25	0.13	0.96	0.17	0.00
CS/TECH	0.85	0.18	0.47	1.00	−0.03	0.56	UTL/OG	0.87	0.11	0.68	1.00	0.01	0.85
CS/TELE	0.37	0.20	0.04	0.70	0.64	0.00	UTL/TECH	0.75	0.18	0.40	0.99	0.09	0.04
CS/UTL	0.42	0.22	0.09	0.81	0.55	0.00	UTL/TELE	0.41	0.24	0.06	0.82	0.30	0.00

Results are based on Kroner and Ng (1998).

Next, investigating the hedging effectiveness captured by the minimum correlation portfolio, results are exhibited in Table 14. In the minimum correlation portfolio panel, it is clearly seen that if, on average, we invest 16%, 14%, 13%, and 10% in GB.CH (highest), GB.EU, GB.US and GB.GL respectively in green bond investments, while in case of Islamic sectors, if we invest 10% in OG, 9% in TELE, 7% in TECH, 6% in UTL, 5% in FIN and HC, 3% in CS, 2% in CG, 1% in BM, and 0% in INDS, then their contribution towards volatility of each asset in this portfolio would be statistically fell. Here, it is interesting to see that GB.US, GB.GL and GB.CH are having negative HE values, inferring that if investors invest in these suggested assets in the stated proportion, it will contribute towards the volatility in the investment portfolio (Ejaz et al. 2022). Finally, according to MCoP results, investing in US, China, and EU green bonds as well as OG, TELE, HC, CS, TECH and UTL can reduce asset volatility significantly. However, adding GB.US, GB.GL and GB.CH to the portfolio can increase volatility.

Subsequently, we examined the reward against volatility ratio results, which are illustrated in Table 15. The Sharpe ratio findings enhance the comprehension of risk-return tradeoffs for investors when allocating to various market indices

Table 14. Multivariate portfolio weights.

	Mean	Std.Dev.	5%	95%	HE	p-value
Minimum Variance Portfolio (MVP)						
GB.US	0.10	0.05	0.02	0.20	0.75	0.00
GB.EU	0.44	0.24	0.00	0.89	0.59	0.00
GB.GL	0.02	0.03	0.00	0.08	0.83	0.00
GB.CH	0.35	0.18	0.06	0.69	0.45	0.00
BM	0.00	0.01	0.00	0.02	0.98	0.00
CG	0.00	0.01	0.00	0.02	0.97	0.00
CS	0.01	0.01	0.00	0.02	0.98	0.00
FIN	0.00	0.00	0.00	0.01	0.98	0.00
HC	0.01	0.01	0.00	0.03	0.97	0.00
INDS	0.03	0.03	0.00	0.11	0.98	0.00
OG	0.00	0.00	0.00	0.01	0.99	0.00
TECH	0.00	0.01	0.00	0.02	0.99	0.00
TELE	0.03	0.03	0.00	0.10	0.95	0.00
UTL	0.01	0.01	0.00	0.02	0.96	0.00
Minimum Correlation Portfolio (MCP)						
GB.US	0.18	0.03	0.15	0.24	−1.81	0.00
GB.EU	0.12	0.04	0.07	0.19	−3.55	0.00
GB.GL	0.08	0.05	0.00	0.15	−0.88	0.00
GB.CH	0.09	0.03	0.04	0.16	−5.02	0.00
BM	0.03	0.04	0.00	0.10	0.77	0.00
CG	0.01	0.03	0.00	0.08	0.65	0.00
CS	0.05	0.04	0.00	0.12	0.79	0.00
FIN	0.03	0.04	0.00	0.10	0.82	0.00
HC	0.05	0.04	0.00	0.11	0.68	0.00
INDS	0.02	0.05	0.00	0.15	0.74	0.00
OG	0.11	0.04	0.03	0.17	0.90	0.00
TECH	0.06	0.07	0.00	0.17	0.86	0.00
TELE	0.11	0.03	0.07	0.15	0.46	0.00
UTL	0.05	0.03	0.00	0.09	0.61	0.00
Minimum Connectedness Portfolio (MCoP)						
GB.US	0.11	0.03	0.06	0.16	−2.73	0.00
GB.EU	0.12	0.03	0.06	0.16	−5.03	0.00
GB.GL	0.09	0.03	0.00	0.12	−1.49	0.00
GB.CH	0.07	0.04	0.00	0.13	−6.99	0.00
BM	0.03	0.05	0.00	0.14	0.69	0.00
CG	0.05	0.05	0.00	0.15	0.54	0.00
CS	0.06	0.04	0.00	0.12	0.72	0.00
FIN	0.06	0.04	0.00	0.13	0.76	0.00
HC	0.07	0.04	0.00	0.15	0.57	0.00
INDS	0.00	0.01	0.00	0.00	0.65	0.00
OG	0.12	0.04	0.04	0.17	0.87	0.00
TECH	0.09	0.06	0.01	0.19	0.81	0.00
TELE	0.09	0.04	0.03	0.16	0.28	0.00
UTL	0.06	0.03	0.00	0.11	0.48	0.00

Results of MVP, MCP and MCoP are based on Stuart and Markowitz (1959), Christoffersen et al. (2014) and Broadstock et al. (2020), respectively.

Table 15. Sharpe ratio.

	MVP	MCP	MCoP
Mean	0.0075	0.0069	0.0116
Std.Dev.	0.0984	0.4234	0.5153
Sharpe Ratio	0.0760	0.0163	0.0224

Results are based on Sharpe (1994).

and sectors amid changing market conditions. The MCoP technique exhibits the most average returns followed by MVP and MCO. In total, MVP portfolio shows the highest reward to risk (Sharpe Ratio) and outperformed MCP and MCoP portfolios.

Succeeding, to profound understanding about the investment implications of this study, we demonstrated dynamic portfolio weights in Figure A1 We focus on the specific asset weights; we witness that in all the three panels, MVP is behaving differently than MCP and MCoP. While

MCP and MCoP have some similarities and some differences as well. Let us discuss MVP first. Objectively, we want to design a portfolio that should have minimum variance, but here in Figure A1a, weights of the portfolio are highly volatile for green bond US, global, and China, while GB.EU and Islamic sectors show negligible movement in the weights, except during COVID-19 and Russian tussle with Ukraine. Next, in Figure A1b INDS is not showing any variation in weights, while all remaining assets express constant movement in the weights of the portfolio over time. Finally, in the case of MCoP, huge transformations can be observed in portfolio weights during the oil crisis in 2016 and COVID-19.

Next, we discuss the constructed investment portfolios with the help of three approaches, namely MVP (green), MCP (red), and MCoP (blue), which are depicted in Figure A1c From all the three portfolios, it can clearly be observed that initially, in 2014 to till the starting of 2015, all three techniques are generating almost similar portfolio returns. But after that, the MVP portfolio shows a sustained upward trajectory till 2020, and then a steady return is being generated. On the other hand, MCP and MCoP generated negative returns during the oil crisis in 2016 till mid-2017. Afterwards, identical growth trajectory experienced by MCP and MCoP portfolios returns except for three deeps in 2018, 2019, and 2022. Conclusively, MVP is a better performing approach than MCP and MCoP.

Performance of multivariate portfolios during COVID-19 period

According to Figures A2 and A3, we evaluated the performance of all multivariate portfolios in light of full sample and COVID-19 using MVP, MCP, and MCoP techniques. Contrary to the overall sample findings, MCoP performed the best, closely followed by MCP, with MVP lagging behind. Although MCP and MCoP experienced a slight decline in performance at the beginning of the pandemic, they gradually improved due to government stimulus, adaptation to lockdowns, and the long-term fundamentals of green bonds and Islamic sectors. However, in 2022, there was a noticeable decline following the Russian invasion of Ukraine.

V. Conclusion and policy implications

The green bond market and Islamic bonds are two unconventional yet emerging asset classes that offer investment opportunities for socially responsible and environmentally conscious investors. While both markets are considered safe-haven instruments against conventional financial instruments, there is limited evidence concerning their interconnectedness (Arif et al. 2021). Therefore, this study aimed to investigate the interplay between the four major green bond indexes and Islamic sectors and their hedging potential.

The findings of this study suggest that there is an elevated level of downside risk connectivity and spillover across various risk situations. Moreover, the short-term connection has a greater influence compared to long-term connectedness. The downside risk connectedness and spillover exhibit time-varying patterns, which are influenced by significant events such as the Shale Oil Revolution, US–China trade war, COVID-19 pandemic, and Russia-Ukrainian conflict.

Moreover, the multivariate portfolio construction techniques, including MVP, MCP, and MCoP, were used to construct various bivariate and multivariate portfolios. The study found that the MVP technique outperformed the MCP and MCoP portfolios during the full period of the study, while during the COVID-19 MCoP technique proved its worthiness and outperformed MVP and MCP portfolios. The Sharpe ratio results confirmed that when coupled strategically, green bonds and Islamic sectors may be excellent portfolio diversifiers that improve risk-adjusted returns.

Investors can diversify portfolio risk by reducing fluctuations in volatility by investing in green bonds and Islamic sectors. Policymakers can use these findings to formulate policies that facilitate the advancement of green bonds and Islamic markets, fostering the development of a sustainable financial system. The study also highlights the need for standardization of green bond market practices across different countries to enhance transparency, instilling greater confidence among issuers and investors globally in these markets.

However, the study's limitation lies in its scope, which is limited to green bond markets and Islamic sectoral markets. Future studies can be carried out to examine the interconnectedness and hedging potential of green bonds and non-Islamic sectoral markets or green bonds and developing markets.

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Appendix

A.1.1 Portfolio implications

To discern hedging potential of green bonds against Islamic sectoral markets, portfolio back testing approach has been employed. We constructed various portfolios through varied portfolio estimation approaches that includes both conventional and recent connectedness approaches and then performance of the portfolios are examined. The portfolio construction and hedging potential analysis has been performed with few underlying assumptions. First, market participants prefer investing only in green bond and Islamic sectors and they are willing to allocate funds in both the markets. Second, the market participants can make direct investment in the index. These assumptions are sufficient for accomplishing the stated objectives using various portfolio estimation techniques as explained below:

A.1.2 Bilateral hedge ratios and portfolio weights

This is the first and the conventional technique used for portfolio estimation. As suggested by Kroner and Sultan (1993) dynamic hedge ratio can be explained as:

$$\beta_{ij,t} = \frac{\Sigma_{ij,t}}{\Sigma_{jj,t,}} \tag{A1}$$

where, $\Sigma_{ij,t}$ signifies conditional covariance between series i and j for time t and $\Sigma_{jj,t,}$ signifies conditional covariance of series $jfortimet$.
The optimal bilateral portfolio weights of index $iandj$ are stated below following Kroner and Ng (1998):

$$\omega_{ij,t} = \frac{\Sigma_{ii,t} - \Sigma_{ij,t}}{\Sigma_{ii,t} - 2\Sigma_{ij,t} + \Sigma_{jj,t}}, \tag{A2}$$

with

$$\omega_{ij,t} = \begin{cases} 0, & if\ \omega_{ij,t} < 0 \\ \omega_{ij,t}, & if\ 0 \le \omega_{ij,t} \le 1 \\ 1, & if\ \omega_{ij,t} > 1 \end{cases} \tag{A3}$$

where, $\omega_{ij,t}$ signifies weight of series i in the 1$ portfolio comprising series $iandj$ for time t and 1-$\omega_{ij,t}$ signifies weight of series j in the portfolio comprising series $iandj$ for time t. Also $\omega_{ij,t}$ shall fulfil the following conditions:

A.1.3 Minimum Variance Portfolio (MVP)

The most widely used approach for portfolio construction and analysis is Minimum Variance Portfolio (MVP) approach that aims to construct portfolio with minimum volatility i.e. least conditional covariances. As suggested by Stuart and Markowitz (1959), the portfolio weights are calculated as follows:

$$\omega_{\Sigma t} = \frac{\sum_t^{-1} I}{I \sum_t^{-1} I} \tag{A4}$$

$\omega_{\Sigma t}$ is the weight vector for $K \times 1$ dimensional portfolio, I denotes K dimensional vector of ones and Σ_t represents conditional variance-covariance matrix for $K \times K$ dimensional portfolio for time t.

A.1.4 Minimum Correlation Portfolio (MCP)

Another portfolio estimation approach that is being used recently is Minimum Correlation Portfolio. As the name suggests, MVP, introduced by Christoffersen et al. (2014), aims to construct portfolio with weights obtained by minimizing conditional correlation instead of minimizing conditional covariances as done in MVP. The portfolio weights under MCP are calculated as follows:

$$R_t = diag(\Sigma_t)^{-0.5} H_t diag(\Sigma_t)^{-0.5} \tag{A5}$$

$$\omega_{Rt} = \frac{R_t^{-1} I}{I R_t^{-1} I} \tag{A6}$$

where ω_{Rt} is the weight vector for $K \times 1$ dimensional portfolio, R_t represents conditional correlation matrix for $K \times K$ dimensional portfolio for time t and I denotes K dimensional vector of ones.

A.1.5 Minimum Connectedness Portfolio (MCoP)

Next, we construct portfolio using Minimum Connectedness Portfolio (MCoP) approach that involves generating pairwise connectedness of indices. With an aim to obtain a portfolio with minimum bilateral interconnectedness, the weights of assets within a portfolio are determined based on how much an asset influences other and is influenced by other assets. Thus, the constructed portfolio will be least affected by the network shocks and the assets that do not influence other assets, also do not get influenced by other assets will have the higher weight in that portfolio. The weights will be calculated as follows:

$$\omega_{Ct} = \frac{PCI_t^{-1} I}{I PCI_t^{-1} I} \tag{A7}$$

where, ω_{Ct} is the weight of the asset in the portfolio with minimum interconnectedness, PCI_t represents the pairwise connectedness index matrix during time t and I signifies the identity matrix.

A.1.6 Portfolio evaluation

The portfolio's performance is evaluated using two criteria, the Sharpe Ratio (SR) and the Hedging effectiveness (HE). The Sharpe ratio as given by Sharpe (1994) compares the return of a portfolio of investment against the risk of the portfolio. It is also known as reward to volatility ratio. Sharpe ratio is calculated as:

$$SR = \frac{\bar{r}_p}{\sqrt{var(r_p)}} \quad (A8)$$

where, *Accessisdenied* signifies return of the portfolio given that the risk-free rate of return is zero, *AccessisdeniedAccessisdenied* represents the variance of the portfolio.

Sharpe ratio provides a metric for return of the portfolio given the risk involved. It helps in comparing various portfolios and the best portfolio will be the one with highest SR value i.e. highest return with the same level of risk.

The second criteria used for evaluating portfolio's performance is Hedging Effectiveness (HE). It tells the percentage of risk that is getting reduced by investing in a particular portfolio as compared to investing in a single asset i. The significance of the reduction percentage is investigated using HE test statistics as given by Antonakakis et al. (2020b), as shown below:

$$HE_i = 1 - \frac{var(r_p)}{var(r_i)} \quad (A9)$$

where, HE_i denotes the hedging effectiveness i.e. the reduction in risk by adopting portfolio p against investing in asset i,. Moreover, $var(r_p)$ is the variance of the portfolio and $var(r_i)$ is the variance of the unhedged position i.e. variance of asset i. Additionally, A high (low) risk reduction would be through a high (low) HE indexes.

A.2.1 Determinants of quantile frequency connectedness

After assessing the level of variability using quantile frequency spillovers of tail risks, a second-level analysis was conducted to identify the causes of spillovers. We use a modified version of the conventional gravity model for global trade and asset market returns. Our predictions indicate that spillover may be minimal in larger marketplaces. Additionally, global influences are considered as additional gravitational factors.

It is believed that a number of variables will inevitably impact the effect of shocks on Islamic sectoral markets and green bonds at the 50th, 5th, and 95th quantiles of different frequency spillovers. These variables include CLMT, OVX, VIX, GFS, EMV, GVZ, GMNS, and EPU.[1] Recognized regression models for green bonds and Islamic sectoral markets have been defined in recent research papers, including Balli et al. (2019), Balli et al. (2021), Billah et al. (2023b), and Billah et al. (2023d). In this case, a pooled OLS regression model is used with modifications to include variables related to global indices. The following are taken into consideration as gravity factors:

$$TSI_{ij,t} = \alpha_0 + a{*}X_t + \varepsilon_{it} \quad (A10)$$

The dependent variable $TSI_{ij,t}$ is created in nine different ways, using the 50th, 5th, and 95th quantiles of tail risk spillovers between Islamic sectoral markets i and green bonds j. These spillovers are categorized into different frequencies, such as total, short, and long-term, and the data is sourced from DataStream. The term X_t is a matrix that includes the determinants of tail risk connectedness, such as $EPU, VIX, OVX, GVZ, GFS, EMV, andGMNS, aswellasCLMT$. EPU stands for economic policy uncertainty index, and VIX is a real market index. OVX is an estimate of the expected 30-day crude oil volatility, while GVZ is an estimation regarding the 30-day volatility of returns on the SPDR Gold Shares ETF. Equity Market Volatility (EMV) is the market volatility tracker. Details of these variables and others are presented in the Appendix Table.

[1]The variables that we have used in this study, is being used in previous studies (such as, Hoque et al. 2023; Saeed, Bouri, and Alsulami 2021; Saeed, Bouri, and Tran 2020; Tabash et al. 2022), and these variables are daily basis. Understanding the economic and financial factors that affect the interconnection between Islamic banks and commodities is crucial in making informed investment and risk management decisions. This knowledge enhances investors' awareness and helps them make better decisions. Moreover, to understand the variables further, we have provided the explanations for each variables in the Appendix A.1. On the other hand, we have checked the correlation between these variables and found there is no multicollinearity issue (Appendix A.2.).

Table A1. Variables to determine the spillovers.

Variable	Description
EPU	EPU index shows the relevant consistency of own-country newspaper information in which consist of a threesome of conditions referring to the economy (E), policy (P) and uncertainty (U). Former investigations indicate an inverted connection among transformations in EPU and other financial market returns (Balli et al. 2020). Therefore, the negative sign will be expecting from EPU.
VIX	The VIX is a real-time market index that meets market assumptions for volatility over the next 30 days. Considering the Islamic banks and Fintech market prices, rises in the degree of the VIX possess an adverse effect on Islamic banks and Fintech markets, which decreases the TSI. As a result, we anticipate. an adverse indication for the VIX.
OVX	OVX is the expected 30-day crude oil volatility estimate since the US Oil Fund (USO) set the price. Rises in the degree of the OVX come with a negative effect on stock market prices (Saeed, Bouri, and Alsulami 2021), which results in a decrease in the degree of the TSI. Therefore, the negative sign will be expected from OVX.
GVZ	GVZ is an estimation regarding the anticipated 30-day volatility of returns on the SPDR Gold Shares ETF (GLD).
GFS	Anticipated through Bank of America Merrill Lynch, the Global Financial Stress Index is a method regarding cross-market risk, demand protection, and financial investment flows in the worldwide financial process.
EVZ	The CBOE Euro Currency Volatility Index tracks near-term projected volatility of the euro/U.S. dollar exchange rate. It measures the market's expectation of 30-day volatility of the EUR/USD exchange rate by applying the VIX methodology to options on the Currency Shares Euro Trust (FXE).
EMV	Baker et al. (2019) developed an index which is called Equity Market Volatility (EMV) tracker, and it is being based on the 11 major U.S. newspapers. Moreover, this index closely moves with the VIX and with realized volatility on the S&P 500.
CLMT	The MSCI World Climate Change Index (CLMT) is accorded to the MSCI World Index, it is relative index, and consists of substantial and mid-cap securities across 23 Developed regions. The index aims to represent the efficiency of an investment strategy that re-weights securities based upon the opportunities and risks connected with the transition to a lower carbon economy, although looking for to reduce exemptions from the relative index.

Table A2. Correlation coefficients of explanatory variables.

Explanatory variables	EPU	VIX	OVX	GVZ	GFS	EVZ	EMV	CLMT
EPU	1.00							
VIX	0.16	1.00						
OVX	0.14	0.44	1.00					
GVZ	0.12	0.41	0.26	1.00				
GFS	−0.19	0.07	0.34	0.15	1.00			
EVZ	0.25	−0.07	0.29	−0.23	−0.17	1.00		
EMV	0.13	0.17	−0.06	0.12	−0.36	0.18	1.00	
CLMT	0.05	0.39	0.25	0.22	0.37	−0.06	−0.18	1.00

(a) Minimum Variance Portfolio (MVP)

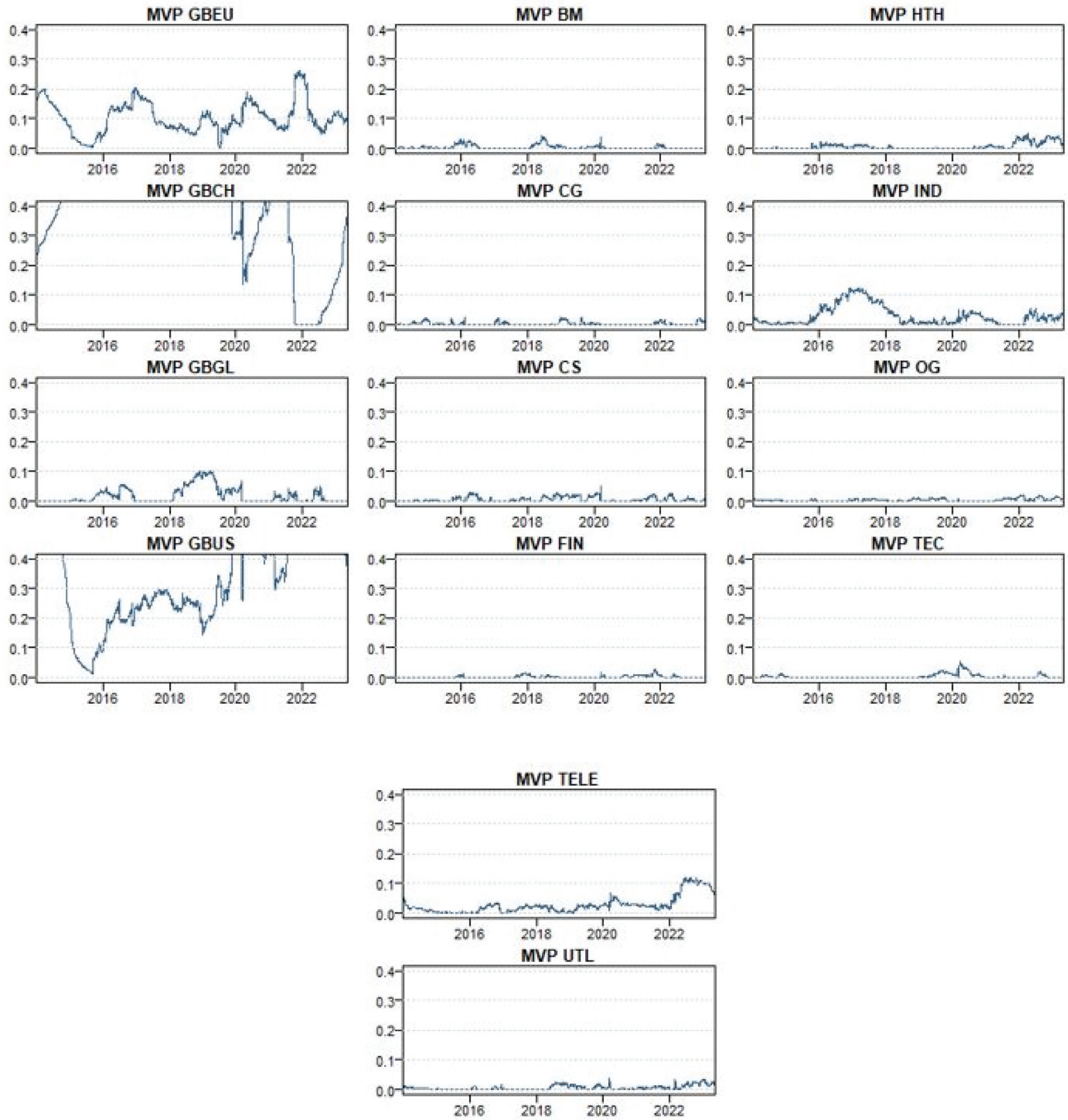

Figure A1. Dynamic multivariate portfolio weights. Results of MVP, MCP and MCoP are based on Stuart and Markowitz (1959), Christoffersen et al. (2014) and Broadstock et al. (2020), respectively.

(b) Minimum Correlation Portfolio (MCP)

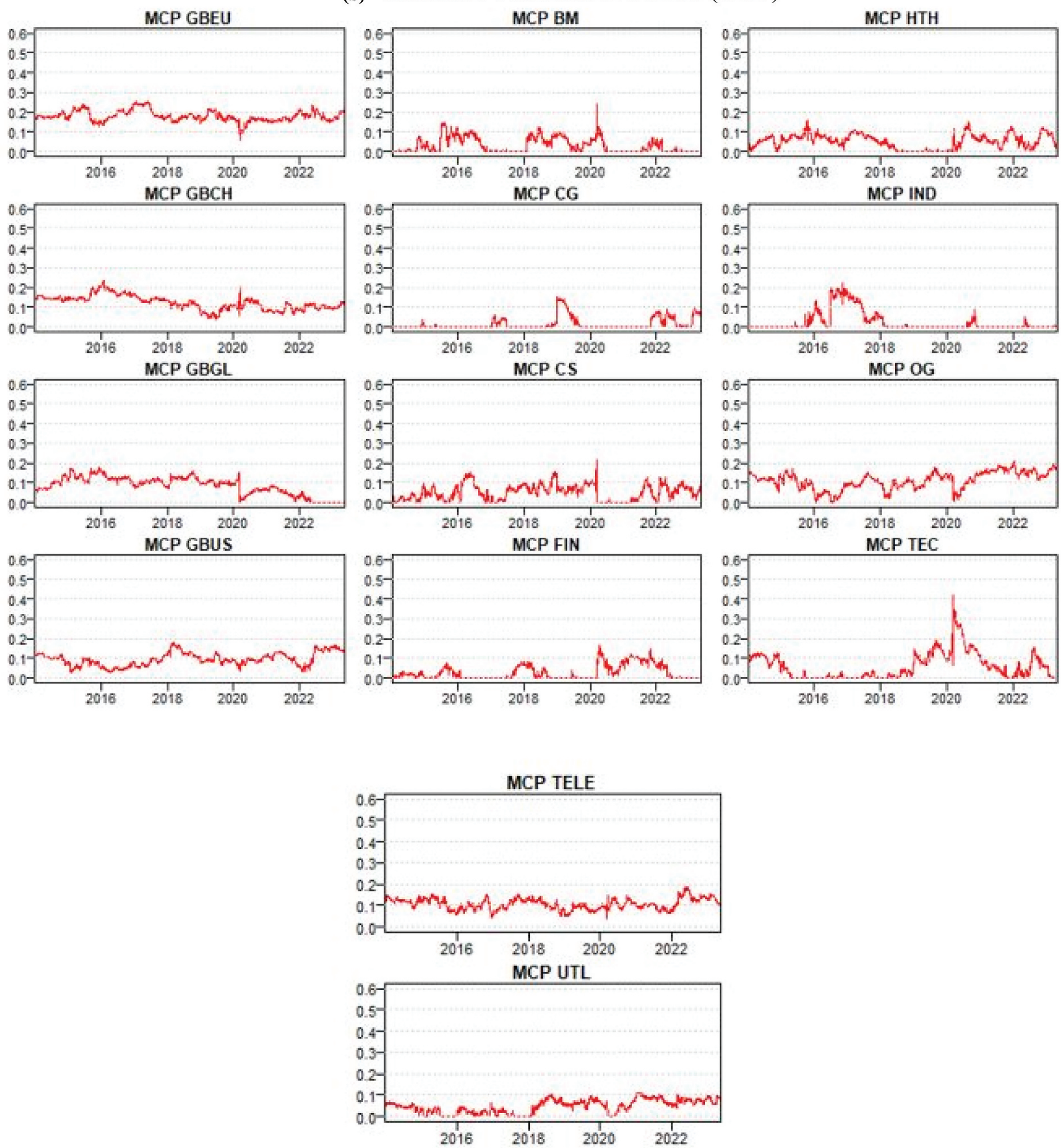

Figure A1. (Continued).

(c) Minimum Connectedness Portfolio (MCoP)

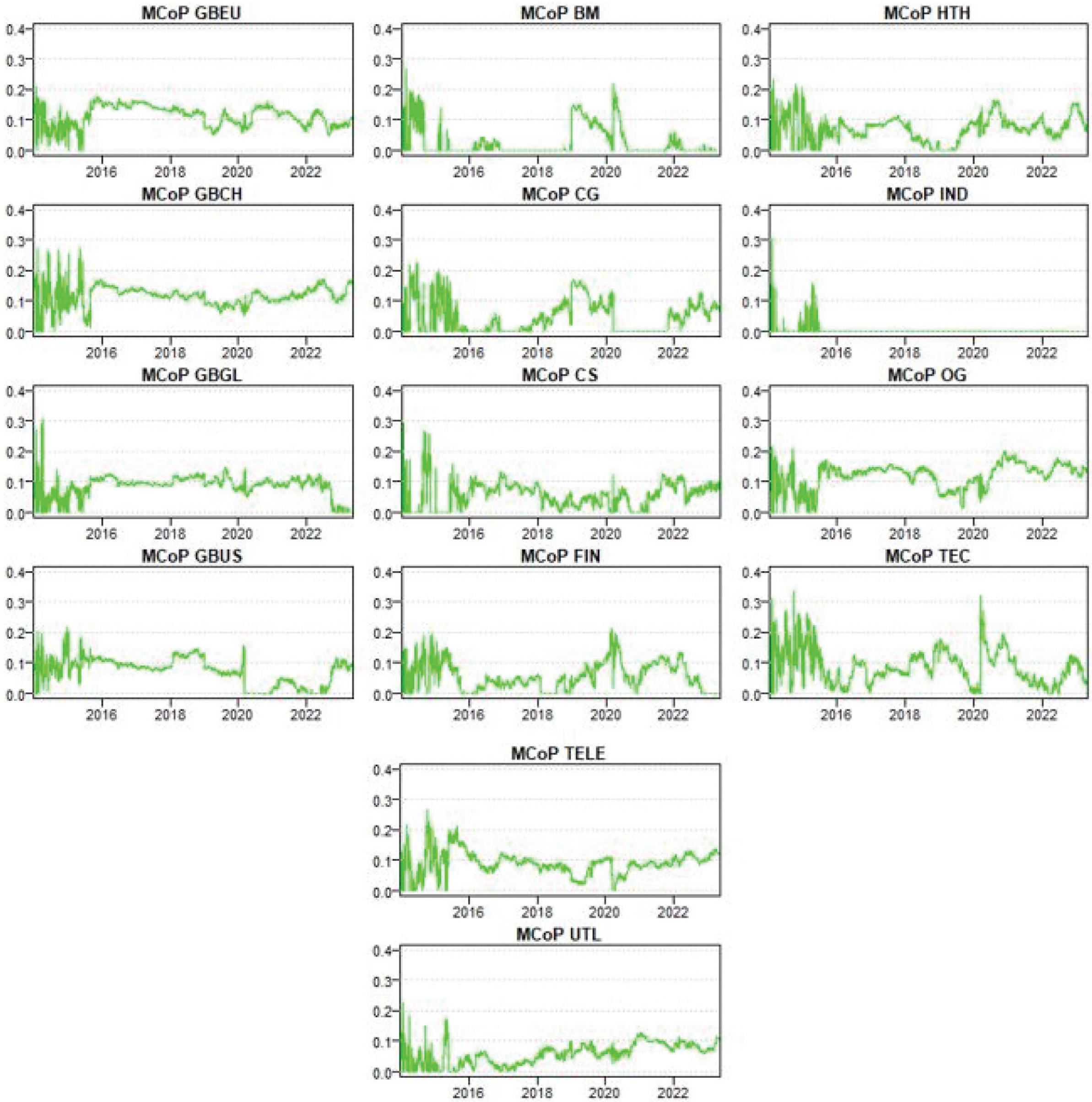

Figure A1. (Continued).

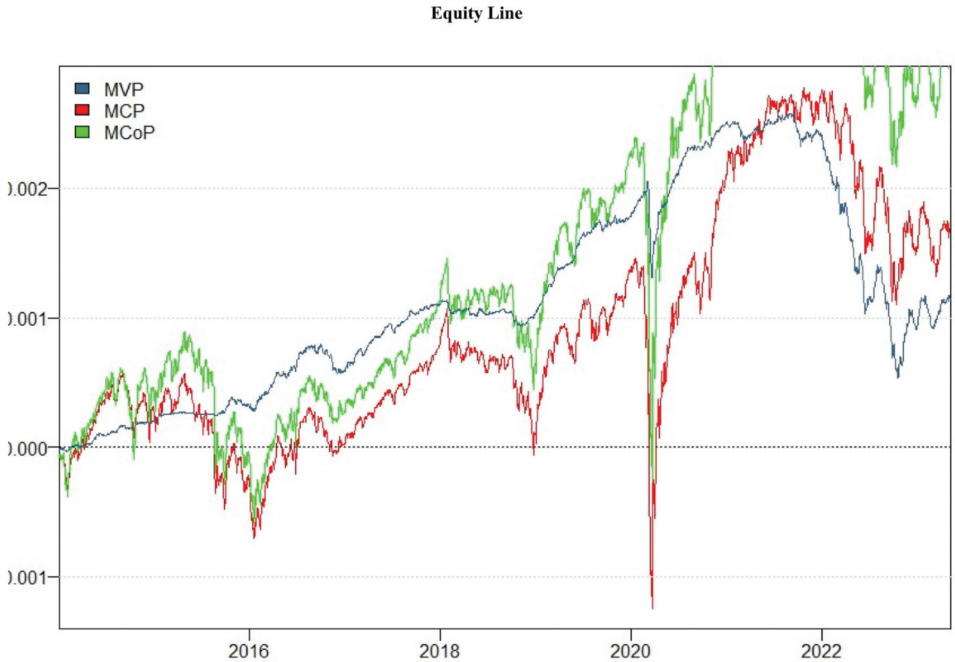

Figure A2. The series illustrate the cumulative sum of portfolio returns. MCoP denotes the minimum connectedness portfolio, MVP stands for minimum variance portfolio, and MCP for minimum correlation portfolio.

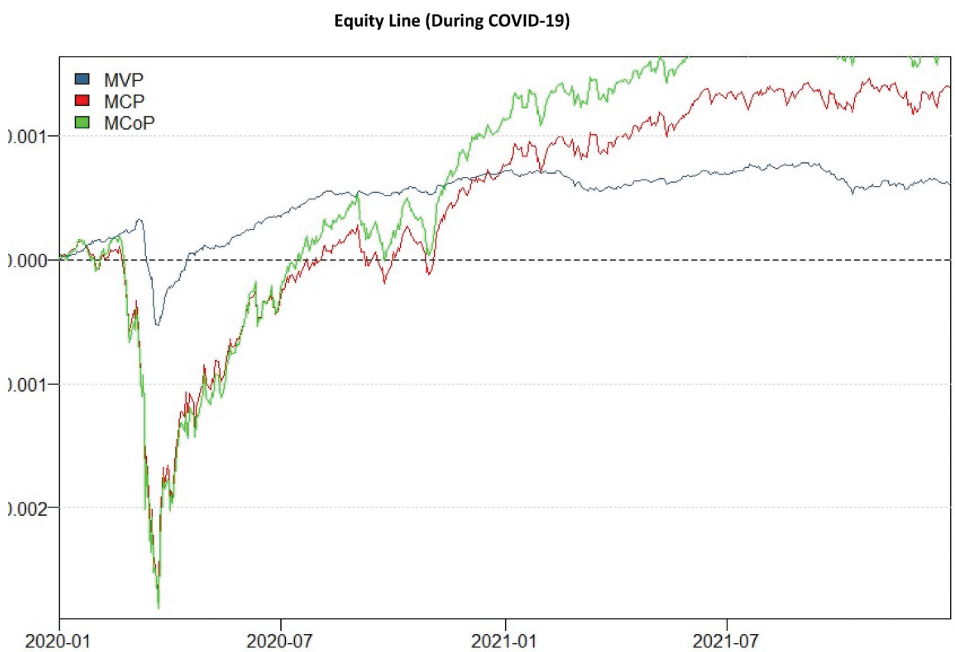

Figure A3. The series illustrate the cumulative sum of portfolio returns. MCoP denotes the minimum connectedness portfolio, MVP stands for minimum variance portfolio, and MCP for minimum correlation portfolio.