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Original Paper

Can Islamic Financial Markets Maintain Its Elegance Amidst the Waves of the Fourth Industrial Revolution?

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Abstract

Islamic financial assets adhere to the principles of Shariah, which serve not only as constraints but also as protective mechanisms. However, in the wave of alternative investment opportunities brought about by the Fourth Industrial Revolution (FIR) and the impact of pressure events, building an investment portfolio based on Islamic financial assets still remains challenging. This paper uses a Quantile VAR (QVAR) connectedness framework that considers frequency domains to investigate the return spillover between Islamic financial assets and various FIR assets from April 30, 2018, to September 8, 2023. The results indicate that: (1) From a median perspective, the overall and short-term connectedness are 58.41% and 45.72%, respectively, suggesting a relatively close association between Islamic financial markets and FIR markets. (2) The outbreak of COVID-19 and the release of Chatgpt4.0 led to connectedness surpassing 65% across all quantiles, pushing the spillover to higher peaks. (3) The storm led by Chatgpt has had a more pronounced longer-term impact on the system compared to the pandemic and the Russia-Ukraine conflict. (4) In terms of spillover roles, Islamic stocks have been more proactive in embracing the FIR, while Islamic bonds tend to play a more passive role.

Keywords

Islamic and FIR financial markets, QVAR, Connectedness, Quantile spillover, Frequency spillover

1. Introduction

The international integration and regional economic blocs have significantly accelerated the global financial market's unification and standardization, intensifying the interaction and penetration mechanisms among financial assets. However, market integration does not necessarily imply system stability. In fact, under the stimulation of external shocks, risks may have a higher chance of spreading through the highly interactive market. For example, COVID-19 has changed asset prices and investor preferences, leading to increased transmission of cross-market risks (Adekoya et al., 2022). Additionally, during the Russia-Ukraine conflict, systemic financial risks and overall connectedness also soared (Yang et al., 2023). Nevertheless, there are still many investors construct diversified investment portfolios to seek an optimal solution for risk and profit. Within these portfolios, ethically-driven Islamic financial

assets are widely incorporated as they often elegantly avoid risks in most cases (Yarovaya et al., 2021; Asl et al., 2023). At the same time, the attention from investors and managers has also contributed to the rapid development of Islamic financial markets. According to the 2022 report published by the IFSB, the total value of the global Islamic financial industry has risen from $10 billion in 1985 to $3.06 trillion in 2021. In the above context, it is crucial to focus on issues such as interdependencies and spillover effects between Islamic financial assets and other assets. Moreover, a comprehensive understanding of market volatility and contagion would help market regulators and policymakers further improve the financial systems.

The Islamic financial industry must fully respect the principles of Islamic law, particularly the three pillars of Islamic law, which are the prohibition of interest (Riba), excessive risk-taking (Gharar), and gambling (Maysir). The abolition of interest is fundamental, requiring economic benefits to be accompanied by entrepreneurial risks. Abandoning excessive risk-taking limits the principle of information asymmetry, thus reducing the possibility of fraud. In addition, the prohibition of gambling is aimed at improving welfare from a broad sense of professional ethics, rather than engaging in behavior that is getting something for nothing. Therefore, the principles of Shariah have greatly protected Islamic finance from the persecution of non-performing assets and reckless behavior, which are the main factors causing financial crises (Elsayed et al., 2023). Sheltered by high-standard protective mechanisms, Islamic financial assets carry distinctive features, including risk mitigation, low leverage effects, and small and single market (Dewandaru et al., 2014). Given these benefits, some advocates believe that the performance of Islamic financial sectors in terms of risk-return is more excellent even outside economic turbulence (Akhtar & Jahromi, 2017; Rizvi & Arshad, 2018; Ahmed & Elsayed, 2019). Therefore, incorporating Islamic financial products into asset allocation is conducive to strengthening risk-sharing capabilities, which may be an important means of helping investors get out of high-risk situations (Taera et al., 2023).

However, faith-based investments are also generally criticized for not complying withthe principles of the Markowitz 1952 efficient investment theory cited by Dhrymes (2017) (Sherif, 2020). On the other hand, due to the fact that such investments are only a subset of investment portfolios and have low levels of diversification, their long-term performance may be inferior to other markets (Goodchild et al., 2002; Bauer et al., 2005). It should be noted that the Fourth Industrial Revolution (FIR), which currently represents technological innovation, has not only improved people's lifestyles but also developed a series of new financial services and alternative assets, including artificial intelligence (AI), robotics, and blockchain (Muhammad et al., 2022). This indicates that the FIR is innovating diversified investment portfolios with technology dividends and investment opportunities. However, the linkage between FIR assets and Islamic finance assets has not yet been demonstrated.

Therefore, it is uncertain whether the Islamic finance market that lives in the wave of the FIR can still maintain an elegant posture to avoid risks and make long-term investments. In addition, intelligent technologies from the FIR are expected to break through to new heights in the economic and financial

system with their powerful computing capabilities (Machkour & Abriane, 2020). For example, AI machines can achieve financial risk control and flexible automation of industrial economies (Venturini, 2019; Yuan et al., 2021). And Blockchain can extend technology to areas such as e-commerce, encrypted transactions, and credit (Thakor, 2020). Given the increasingly prominent influence of FIR services and assets, we believe that incorporating them as investment choices will be a trend in the future . Furthermore, it is worth emphasizing that modeling of a robust investment portfolio comes from an understanding of the dependency structure during bear and bull markets, namely, the degree of correlation between assets and the strength of information spillover (Mensi et al., 2016). Therefore, exploring the volatility spillover effects between Islamic finance assets and FIR assets is important and has long-term significance.

In general, it is still unclear whether Islamic financial instruments under the FIR can meet investors' expectations in both the short and long terms. Additionally, recent events such as the pandemic and geopolitical conflicts have impacted the current financial markets, leading to a new round of volatility spillovers. Therefore, it is necessary to consider the relationship between Islamic financial assets and FIR assets. Based on the above discussion, this article investigates the dynamic connectedness between Islamic stocks, Islamic bonds, and FIR assets (internet, cybersecurity, artificial intelligence and robotics, disruptive technologies, and blockchain). Specifically, by a frequency-based quantile autoregression (QVAR) connectedness framework, we find that: Firstly, the overall and short-term total connectedness between Islamic financial assets and FIR assets is 58.41% and 45.72% , respectively, indicating a relatively close system integration. At the same time, Islamic stocks have consistently played an important role in propagating shocks, but they need to pay long-term decay costs. Secondly, under the stimulation of external events, the total connectedness exhibits an expansion behavior, which is to some extentrelated to the nature of the event. It should be emphasized that the official release of ChatGPT 4.0 resulted in connectedness almost consistently ranging from 70% to 80% across all quantiles, which is a key finding in this case. In conclusion, Islamic bonds tend to play a more passive role in the FIR, while Islamic stocks are the main net emitters.

The main contributions of this study are as follows: To the best of our knowledge, this is the first investigation into the transmission mechanisms between Islamic financial assets and alternative assets brought about by the Fourth Industrial Revolution. This study not only complements the understanding of the relationship between Islamic financial assets and FIR assets but also discusses the systemic spillover behavior under external shocks; in addition to the median QVAR model, frequency dynamics are used to examine short-term and long-term spillovers, revealing the long-term or short-term impacts caused by recent pressure events; this study verifies that the new direction led by ChatGPT is exacerbating the risk contagion between Islamic finance and the broader financial system.

The structure of this paper is as follows: In Section 2, we provide a literature review on Islamic finance and spillover patterns. Then, in Section 3, we introduce the empirical methodology. Section 4 presents data and descriptive statistics. Section 5 consists of results and findings. Finally, we conclude the paper and provide relevant recommendations in Section 6.

2. Literature Review

The volatility of financial assets depends on the speed of information flow, and shocks in individual markets can trigger cross-market spillover behavior (Ross, 1989). This implies that the volatility transmission is a key element in modeling investments. Additionally, studies by Yarovaya et al. (2021) and Zhao et al. (2023) suggest that market interdependence becomes significant under external pressures, which may lead to stronger risk spillovers. For investors, the fear always revolves around asset losses, whether in stable or turbulent periods. Therefore, a large amount of empirical research focuses on examining the co-movement between financial markets and continuously searching for more efficient alternative assets to achieve optimal solutions for risk mitigation and profit. In this process, Islamic finance has emerged as a new class of assets attracting both investors and researchers. On one hand, Islamic financial assets are considered as substitutes for conventional financial assets due to their shared movements in terms of low returns, enabling risk hedging. Such viewpoints have brought about discussions on the hedging benefits (Mensi et al., 2022). On the other hand, the Islamic financial market lacks diversification and is a subset of market investments. With the emergence of new markets, holding Islamic stocks in the long term may not be superior to other assets (Goodchild et al., 2002; Bauer et al., 2005). This has derived the perception that there is little difference between the Islamic financial market and other markets. Therefore, conflicting opinions have sparked considerations regarding the following three questions:

·Are there synergistic behaviours between Islamic financial markets and some newly developed markets in terms of risk spillovers?

·If propagation mechanisms exist, is the stimulation of different external event impacts on system connectedness a pattern?

·Can Islamic financial assets maintain safe haven status in alternative assets?

In the past, some scholars have expressed their views and insights on these three issues. In a study by Nazlioglu et al. (2015), the GARCH method was used to support the existence of risk transfer between Islamic stock markets and conventional stock markets. Similarly, Mensi et al. (2022) found clear short-term contagion and underlying long-term effects between Islamic bonds and stocks and the conventional stock market. Al-Yahyaee et al. (2020) provided a description based on a temporal perspective. They applied the CAPM-EGARCH model and wavelet method to find inconsistent relationships between the Islamic sector and the conventional sector in the full sample and sub-samples. They also suggested that portfolios comprising utility, Islamic, and conventional industries can best withstand risks. In addition to conventional products, some newly developed markets can also be found in studies related to Islamic financial instruments. For example, Tiwari et al. (2023) suggested that green bonds can effectively hedge against Islamic stocks, especially during downturns. Through the GARCH family models, Taera et al. (2023) captured relatively lower risks in Islamic financial assets and ESG indices, and they indicated that global investors need to incorporate these two asset groups into their portfolios for greater advantages. Elsayed et al. (2023) found that shocks are transmitted between traditional markets and currency markets,

while Islamic markets act as net recipients throughout the sample period, based on their findings using the DECO-GJR-GARCH model. Recently, stimulated by the Fourth Industrial Revolution, some scholars have also attempted to carry out explorations of Islamic financial assets and the FIR industry. Delle Foglie et al. (2021) investigated the impact of blockchain technology on the global sukuk industry and suggested that it could be a new opportunity for the standardisation of Islamic finance. Zhao et al. (2023) verified the existence of blockchain technology interacting with Islamic technology by TVP-VAR. However, AI's mishandling of data or related decisions could create ethical issues that could lead to shifts in Islamic markets (Shahzad et al., 2023). As found by Shahzad et al. (2023) with quantile regression and causality, AI is the cause of Islamic based industries. This shows that there is a high probability of interactive behaviour between the Islamic financial market and some FIR markets, which can affect the volatility profile of the Islamic financial market itself.

On the other hand, thanks to the communication framework developed by Diebold and Yilmaz (2009), research on market interdependencies and cross-market spillovers has rapidly advanced (Hkiri et al., 2017; Mensi et al., 2017; Yang et al., 2023). It is worth noting that when estimating volatility transmission using this framework, one must go through the standard VAR model. However, Ando et al. (2018) demonstrated the presence of tail spillover behavior in network topology, which necessitates modeling with quantile connectedness. Following Ando et al. (2018), Chatziantoniou et al. (2021) introduced an alternative method for tail behavior, which is to construct a QVAR model to estimate spillovers. QVAR not only inherits the second-moment spirit of the standard VAR model but also incorporates quantile tools for more detailed spillover examination, making it favored by researchers. Although the new approach provides a more systematic investigation of spillovers, the standard VAR and QVAR primarily extract impulse spillovers in the time and statistical domains, neglecting considerations in the frequency domain. To address the implicit relationship in the frequency domain overlooked by the standard VAR and QVAR, Chatziantoniou et al. (2022) allow for the detection of different frequencies at a given quantile and different quantiles at a given frequency by combining the frequency connectedness components from Baruník and Křehlík (2018) with QVAR. According to their study, frequency-aware QVAR simultaneously connects the statistical, time, and frequency domains, resulting in stronger conclusions with greater comprehensiveness. In the discussion on volatility linkages between Islamic financial markets and other markets, we have not found studies that simultaneously consider the statistical, time, and frequency domains. If a more comprehensive approach is taken within the volatility spillover framework, further optimization in terms of completeness and granularity can be achieved in investigations concerning Islamic financial markets.

3. Empirical Methodology

We apply the connectedness framework based on the quantile vector autoregression (QVAR) developed by Chatziantoniou (2021) to examine spillovers among different markets. Compared to the VAR model, the QVAR model possesses the advantage of quantiles. In specifically, QVAR allows for an investigation

of the structural behavior of tail sequences (extreme quantiles). The QVAR(p) model with lags p is given as follows:

$$R_t = \mu_t(\tau) + \sum_{j=1}^{p} C_j(\tau) R_{t-j} + u_t(\tau) \tag{1}$$

where, $R_t = (R_{1t}, R_{2t}, \cdots, R_{Nt})^T$ is an N×1 dimensional column vector consisting of endogenous variables; $\tau \in [0,1]$ indicates the quartiles set in advance; $C_j(\tau)$ is an N×N dimensional coefficient matrixof the regression model; $\mu_t(\tau)$ and $u_t(\tau)$ denote the N×1 dimensional conditional mean vector and the error term at the corresponding quantile, respectively; $\sum(\tau)$ is the variance-covariance matrix of $u_t(\tau)$.

Then, following Wold's theory, the QVAR(p) model can be rewritten into QVMA(∞):

$$R_t = \mu_t(\tau) + \sum_{i=1}^{\infty} \psi_i(\tau) u_{t-i} \tag{2}$$

Then, the generalised prediction error variance decomposition (GFEVD) matrix for the advance H-steps can be constructed by the generalised impulse function proposed by Pesaran and Shin (1998):

$$\theta_{ij}(H) = \frac{\left(\sum(\tau)\right)_{jj}^{-1} \sum_{h=0}^{H} \left(\left(\psi_h(\tau)\sum(\tau)\right)_{ij}\right)^2}{\sum_{h=0}^{H} \left(\psi_h(\tau)\sum(\tau)\psi_h^T(\tau)\right)_{ii}} \tag{3}$$

In order to organise the GFEVD matrix, we make use of normalisation, thus quantifying the fraction of shocks that variable j passes on to variable i:

$$\tilde{\theta}_{ij}(H) = \frac{\theta_{ij}(H)}{\sum_{j=1}^{N} \theta_{ij}(H)} \tag{4}$$

Next, the method of component summation is applied to compute the total propagation index (TO) and total reception index (FROM) of market i as follows:

$$TO_i(H) = \sum_{j=1, i\neq j}^{N} \tilde{\theta}_{ji}(H) \tag{5}$$

$$FROM_i(H) = \sum_{j=1, i\neq j}^{N} \tilde{\theta}_{ij}(H) \tag{6}$$

Then, the pairwise connectedness index (NPDC) is calculated as shown in the following equation. If the value of NPDC is positive, variable j is dominant in the interrelationship; otherwise, variable j is weak.

$$NPDC_{ij}(H) = \tilde{\theta}_{ij}(H) - \tilde{\theta}_{ij}(H) \tag{7}$$

Similarly, the net directional connectedness index (NET) is calculated as follows:

$$NET_{ij}\left(H\right)=TO_{i}\left(H\right)-FROM_{i}\left(H\right) \tag{8}$$

Finally, the total connectedness index (TCI) of the system is given below:

$$TCI\left(H\right)=N^{-1}\sum_{i=1}^{N}TO_{i}\left(H\right)=N^{-1}\sum_{i=1}^{N}FROM_{i}\left(H\right) \tag{9}$$

However, the connectedness frameworks based on the standard VAR or QVAR only utilize knowledge from the statistical and time domains, neglecting the frequency domains. As empirical samples are essentially time series, connectedness can be extended from the perspective of the frequency domains. According to Stiassny's (1996) spectral decomposition technique for structural VARs, we consider the Fourier transform of QVMA(∞):

$$S_{R}\left(\omega\right)=\sum_{h=-\infty}^{\infty}E\left(R_{t}R_{t-h}^{T}\right)e^{-i\omega h}=\psi^{T}\left(e^{+i\omega h}\right) \tag{10}$$

In the above equation，$\psi\left(e^{-i\omega h}\right)=\sum_{h=0}^{\infty}e^{-i\omega h}\psi_{h}$ is a frequency response function, where $i=\sqrt{-1}$. And ω is the spectral density of R_{t} used at frequency ω. Similarly, the spectral density based GFEVD matrix and its normalised matrix are constructed:

$$\theta_{ij}\left(\omega\right)=\frac{\left(\Sigma\left(\tau\right)\right)_{jj}^{-1}\left|\sum_{h=0}^{\infty}\left(\psi\left(\tau\right)\left(e^{-i\omega h}\right)\Sigma\left(\tau\right)\right)_{ij}\right|^{2}}{\sum_{h=0}^{\infty}\left(\psi\left(\tau\right)\left(e^{-i\omega h}\right)\Sigma\left(\tau\right)\psi\left(\tau\right)\left(e^{-i\omega h}\right)\right)_{ii}} \tag{11}$$

$$\tilde{\theta}_{ij}\left(\omega\right)=\frac{\theta_{ij}\left(\omega\right)}{\sum_{j=1}^{N}\theta_{ij}\left(\omega\right)} \tag{12}$$

where, $\tilde{\theta}_{ij}\left(\omega\right)$ denotes the portion of variable j that passes the shock to variable i at the specified frequency. Next, short-term and long-term levels of connectedness are defined by aggregating all frequencies within a certain range:

$$\tilde{\theta}_{ij}\left(d\right)=\int_{a}^{b}\tilde{\theta}_{ij}\left(\omega\right)d\omega \tag{13}$$

$$d=\left(a,b\right),a,b\in\left(-\pi,\pi\right),a<b \tag{14}$$

where, $\tilde{\theta}_{ij}\left(d\right)$ is a generalisation of connectedness over a certain frequency range. Then, following the methods of Diebold and Yilmaz (2009), different indices can be formed to measure connectedness:

$$NPDC_{ij}\left(d\right)=\tilde{\theta}_{ij}\left(d\right)-\tilde{\theta}_{ij}\left(d\right) \tag{15}$$

$$TO_i(d) = \sum_{j=1, i \neq j}^{N} \tilde{\theta}_{ji}(d) \tag{16}$$

$$FROM_i(d) = \sum_{j=1, i \neq j}^{N} \tilde{\theta}_{ij}(d) \tag{17}$$

$$NET_{ij}(d) = TO_i(d) - FROM_i(d) \tag{18}$$

$$TCI(d) = N^{-1} \sum_{i=1}^{N} TO_i(d) = N^{-1} \sum_{i=1}^{N} FROM_i(d) \tag{19}$$

According to the strategy proposed by Chatziantoniou et al. (2022), connectedness at short-term and long-term horizons can be calculated by aggregating across a certain range of frequencies. Short-term connectedness is computed by setting the range from 1 to 5 days (d_1), while long-term connectedness is set from five days to infinity (d_2). It is important to emphasize that the connectedness based on the standard VAR (Diebold & Yilmaz, 2009) is an aggregation of frequency-domain connectedness (Baruník & Křehlík, 2018), which can be expressed as:

$$NPDC_{ij}(H) = \sum_d NPDC_{ij}(d) \tag{20}$$

$$TO_i(H) = \sum_d TO_i(d) \tag{21}$$

$$FROM_i(H) = \sum_d FROM_i(d) \tag{22}$$

$$NET_{ij}(H) = \sum_d NET_{ij}(d) \tag{23}$$

$$TCI(H) = \sum_d TCI(d) \tag{24}$$

4. Data Description

We collected daily data samples from April 30, 2018 to September 8, 2023 from sources including Investing, S&P Global, and DataStream databases, resulting in a total of 1,350 observations. In terms of Islamic financial assets, we considered the Dow Jones Islamic Market World Index (DJIMW) as it provides comprehensive information on Islamic stocks and is widely used by scholars (Tiwari et al., 2023; Abakah et al., 2023). Additionally, the Dow Jones Sukuk Index (Sukuk) was selected to track the performance of global Islamic bonds. For FIR assets, we collected five global indices, including the Nasdaq Internet index (QNET), Nasdaq CTA Cybersecurity index (NQCYBR), Nasdaq CTA Artificial Intelligence and Robotics index (NQROBO) (Demiralay et al., 2021), Nasdaq Global Disruptive Technology Benchmark Index (NYDTB), and Nasdaq Blockchain Economy index (RSBLCN). To facilitate the analysis in this study, logarithmic differences of two consecutive prices were calculated to compute daily returns for all indices. Notably, all price indices were denominated in US dollars. The

original series and return series for each market are shown in Figure 1.

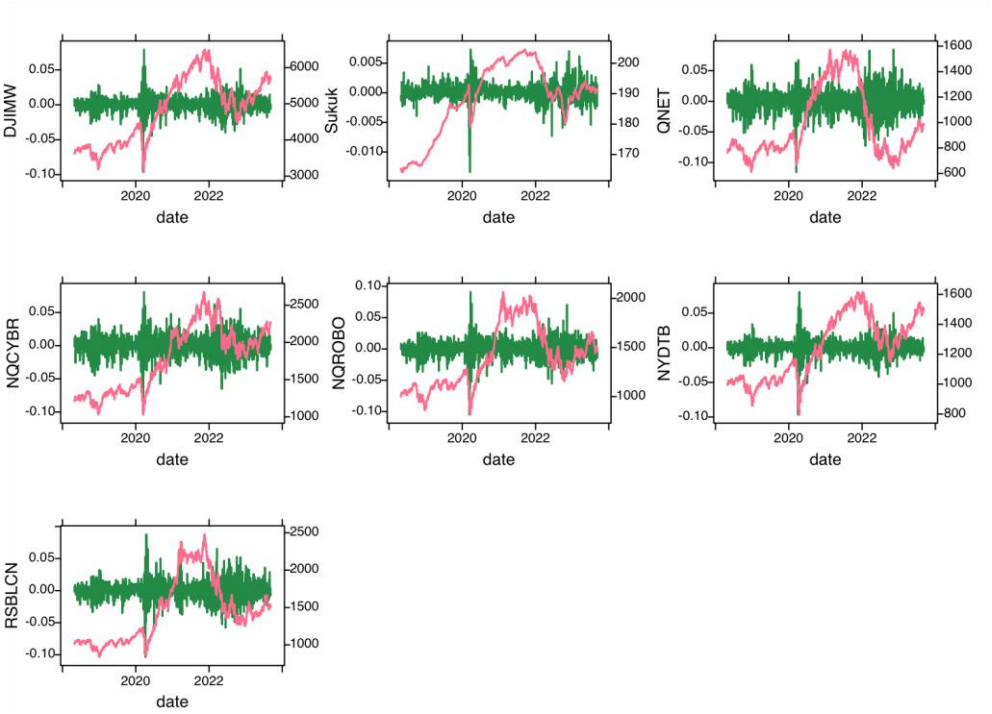

Figure 1. Original and Return Series. The Pink Colour Represents the Original Series and the Green Colour Indicates the Corresponding Series of Returns

From Figure 1, it can be observed that all original series displayed a similar pattern in early 2020: a cliff like decline followed by a rebound. In March 2020, COVID-19 officially entered the public's attention, and coupled with multiple circuit breakers triggered in the US stock market, fear permeated global financial markets. Under the chain reactions caused by the crisis, the seven markets entered a high volatility period, as reflected in their return series (see Figure 1). Subsequently, although all the original series experienced a rapid recovery, the outbreak of the Russo-Ukrainian conflict in February 2022 led to another downturn for each series. In general, both COVID-19 and the Russo-Ukrainian conflict had brought negative impacts on Islamic financial markets and FIR assets, which should not be underestimated.

Table 1 displays the statistics of daily returns for our financial markets and FIR assets, with all means being 0. According to the results, except for QNET, all kurtosis of the returns for the other assets exceed 3, indicating that they have fat-tailed distributions. Additionally, all values skewness are negative, suggesting a departure from the traditional Gaussian distribution. Based on the results of the Augmented Dickey-Fuller (ADF) test statistics, it is found that the return series for all assets are stationary at the 1% significance level. With these findings, the QVAR model can be used to test the interrelationships among the variables.

Table 1. Descriptive Statistics of Returns

	DJIMW	Sukuk	QNET	NQCYBR	NQROBO	NYDTB	RSBLCN
Mean	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Median	0.001	0.000	0.001	0.002	0.001	0.001	0.001
Max	0.079	0.007	0.085	0.081	0.091	0.081	0.088
Min	-0.096	-0.013	-0.116	-0.104	-0.105	-0.096	-0.103
Std.Dev.	0.011	0.002	0.019	0.016	0.015	0.012	0.016
Skewness	-0.753	-1.130	-0.335	-0.522	-0.493	-0.789	-0.200
Kurtosis	10.557	10.674	2.681	3.924	5.735	10.986	4.722
Jarque-Bera	6392.252***	6690.512***	429.107***	926.822***	1903.535***	6924.414***	1262.248***
ADF	-9.942***	-8.921***	-10.254***	-10.630***	-9.660***	-10.219***	-10.121***
Q(10)	54.346***	321.499***	17.278**	31.780***	41.824***	57.624***	17.865***
$Q^2(10)$	816.598***	715.570***	372.874***	583.663***	439.716***	906.909***	420.033***

Note. **, *** indicate significance at the 5% and 1% levels, respectively.

5. Empirical Findings

In this section, we investigated the volatility transmission among seven indices at different frequencies of given quantiles and different quantiles of given frequencies. At the same time, this case observes the efforts made by Islamic finance in response to the Fourth Industrial Revolution from both systemic and individual connectedness perspectives. Furthermore, it elucidates the additional impact of external shocks on the relationship between the two sides.

5.1 Median Static Connectedness Analysis

Table 2 reports the average spillovers based on different frequencies of medians over the entire sample period. The main diagonal of the table represents the cumulative impact of shocks that shocks bring to the variables themselves, while the off-diagonal elements describe the mutual spillovers between variables. The net spillover (NET) of an individual variable is obtained by taking the difference between the total outflow (TO) and the total inflow (FROM). Additionally, the total contagiousness index (TCI) of the system is also presented in the results, which is a weighted average of TO or FROM.

Table 2A utilizes the median-based QVAR to calculate the spillover contagion. In Table 2A, the TCI is 58.41%, which can be interpreted as each market on average transmitting 58.41% of its own variance to other markets. Therefore, there is a high level of integration relationship between the Islamic financial markets and the FIR markets. Specifically, in terms of the forecast error variance received by DJIMW

(71.00%), QNET, NQCYBR, NQROBO, NYDTB, and RSBLC account for shares of 22.02%, 19.09%, 23.61%, 2.64%, and 2.16%, respectively, summing up to a significant proportion. In other words, shocks in FIR assets have a substantial impact on the overall forecast results of the Islamic stock market. This indicates that the behaviors of the Islamic stock market have been influenced by the internet, cybersecurity, artificial intelligence, and robot-related businesses, while the impact of disruptive technologies and blockchain services is minor. Artificial intelligence and robot technology, emerging with the development of the internet, have been applied not only in traditional manufacturing industries but also in market trading, medical diagnostics, and corporate operations through robots (Webster & Ivanov, 2020). Hence, the advancement of new technologies brings about superior trading strategies and faster adjustment strategies, which partially explains the fluctuations in the stock market. Additionally, in terms of the forecast error variance received by Sukuk (26.87%), QNET, NQCYBR, NQROBO, NYDTB, and RSBLC account for shares of 5.50%, 5.45%, 6.47%, 1.29%, and 1.23% respectively. In comparison, Sukuk receives much less spillover. This evidence suggests that the overall forecast results of Islamic bonds are less easily affected under the same shocks from FIR assets and other external factors. In conclusion, FIR assets have a significant impact on Islamic stocks, but a minor impact on Islamic bonds. Furthermore, according to the results of NET, Sukuk plays the role of a net spillover absorber in the entire system (-19.35%), while Islamic stocks are the primary propagators of shocks (9.94%), which is consistent with the findings of Ahmed et al. (2019). The conclusions regarding the forecast error variance can still be validated from the frequency domain perspective (see Table 2B and Table 2C).

Table 2. Average Connectedness during the Full-sample Period

Panel A: Overall								
	DJIMW	Sukuk	QNET	NQCYBR	NQROBO	NYDTB	RSBLCN	FROM
DJIMW	29.00	1.49	22.02	19.09	23.61	2.64	2.16	71.00
Sukuk	6.94	73.13	5.50	5.45	6.47	1.29	1.23	26.87
QNET	22.66	1.16	29.63	20.63	21.24	2.32	2.37	70.37
NQCYBR	20.81	1.37	21.68	31.21	20.96	2.15	1.82	68.79
NQROBO	23.99	1.54	20.95	19.62	29.31	2.42	2.16	70.69
NYDTB	3.49	0.82	2.81	2.36	3.05	49.68	37.80	50.32
RSBLCN	3.05	1.15	3.37	2.38	3.14	37.72	49.19	50.81
TO	80.94	7.52	76.33	69.53	78.48	48.52	47.53	TCI
NET	9.94	-19.35	5.96	0.74	7.79	-1.80	-3.28	58.41
Panel B: Short-run								
	DJIMW	Sukuk	QNET	NQCYBR	NQROBO	NYDTB	RSBLCN	FROM
DJIMW	23.03	1.14	17.21	15.14	18.63	1.95	1.58	55.66
Sukuk	4.28	54.67	3.54	3.54	4.06	0.69	0.72	16.83

QNET	19.00	0.98	24.55	17.15	17.63	1.85	1.91	58.53
NQCYBR	17.10	1.13	17.65	25.29	17.01	1.62	1.40	55.91
NQROBO	18.69	1.21	16.16	15.24	22.62	1.77	1.58	54.66
NYDTB	2.42	0.61	1.99	1.64	2.13	39.81	30.12	38.91
RSBLCN	2.19	0.94	2.49	1.68	2.21	30.06	39.22	39.56
TO	63.69	6.01	59.05	54.39	61.66	37.95	37.31	TCI
NET	8.03	-10.82	0.51	-1.51	7.00	-0.96	-2.25	45.72

Panel C: Long-run

	DJIMW	Sukuk	QNET	NQCYBR	NQROBO	NYDTB	RSBLCN	FROM
DJIMW	5.97	0.35	4.80	3.95	4.97	0.68	0.58	15.34
Sukuk	2.66	18.46	1.96	1.91	2.41	0.59	0.51	10.04
QNET	3.66	0.18	5.08	3.48	3.61	0.47	0.45	11.84
NQCYBR	3.71	0.24	4.03	5.92	3.96	0.53	0.41	12.88
NQROBO	5.30	0.33	4.80	4.38	6.70	0.64	0.58	16.03
NYDTB	1.06	0.21	0.82	0.72	0.93	9.86	7.68	11.41
RSBLCN	0.86	0.21	0.88	0.70	0.94	7.66	9.97	11.25
TO	17.25	1.52	17.29	15.13	16.82	10.57	10.21	TCI
NET	1.91	-8.52	5.44	2.26	0.79	-0.84	-1.03	12.69

Note. Connectedness are expanded for a given median (quantile=0.5) and are shown for the short and long term.

In addition, we differentiate the transmission mechanisms in the frequency domain into short-term effects (see Table 2B) and long-term effects (see Table 2C). In the long-term effects (Table 2C), the FROM value and To value of DJIMW are 15.34% and 17.25%, respectively. However, under the short-term effects (Table 2B), they increase to 55.66% and 63.69%, approximately 3.5 times higher. Therefore, the larger gap reduces the net spillover of DJIMW from 8.03% in the short term to 1.91%. This strong result demonstrates that the Islamic stock market has always been an important shock propagator, even though it incurs a significant time decay cost. Unlike DJIMW, Sukuk shows a more moderate pattern. As shown in the results, although Sukuk's position weakens over time (TO value from 6.01% to 1.52%, FROM value from 16.83% to 10.04%), the difference between short-term net spillover (-10.82%) and long-term net spillover (-8.52%) is small. Therefore, in the context of the internet industry, Sukuk not only receives shocks but also seems unaffected by significant long-term or short-term masking. To discuss this issue in more detail, we focus on the interrelationship between the two markets from the perspective of dynamic total connectedness (TCI).

5.2 Dynamic Total Connectedness Analysis

5.2.1 Dynamic Total Connectedness

Average dynamic connectedness is static, implying that transient shocks occurring internally have been masked. Therefore, we separately test the overall, short-term, and long-term dynamic connectedness, which is captured based on the median-based VAR and frequency framework. According to Figure 2, differences in time-varying connectedness emerge, particularly in the highlighted areas. This study finds that TCI exhibits an expanding trend under certain external events. For example, with the official declaration of the COVID-19 by the World Health Organization on March 11, 2020, the world plunged into a health crisis. During this period, all values of TCI skyrocketed, a result consistent with the findings of Yang et al. (2023). It is worth emphasizing that the outbreak of COVID-19 not only led to the growth of overall and long-term TCI (both exceeding 50%) but also significantly elevated long-term TCI. Consequently, the pandemic exacerbated the contagion between Islamic financial markets and FIR financial markets. Furthermore, on January 31, 2021, the UK officially withdrew from the European Union. However, Brexit is not considered a beneficial decision. Existing research has demonstrated that Brexit will not only directly cause significant economic losses for the UK and the EU but also potentially indirectly affect stock, bond, and commodity markets through social media, sentiment, and public opinion (Latorre et al., 2020; Hudson et al., 2020). As a result of a series of chain reactions, both overall and short-term connectedness experienced largely growth and exceeded 40%. It is noteworthy that the level of shock caused by long-term overflow during this period was obviously weaker than that during the COVID-19 period. In terms of impact, Brexit is inferior to the pandemic because the pandemic is a truly global upheaval. From the perspective of long-term connectedness, our results also support this viewpoint. Subsequently, stimulated by the Russia-Ukraine conflict in February 2022, global geopolitics entered a new round of risk. Umar et al. (2022) stated that the Russia-Ukraine conflict has affected global financial markets, including gold, stock markets, and bonds. In this context, both overall and short-term TCI gained momentum once again. At the same time, long-term TCI experienced a small peak. Therefore, the Russia-Ukraine conflict also affected these two market categories and had significant long-term impacts. Lastly, with OpenAI's announcement on March 15, 2023, regarding the launch of ChatGPT 4.0, artificial intelligence and internet technology have reached new heights, greatly advancing related business expansion (Kraus et al., 2023; Akter et al., 2023). This implies that more industries expecting greater profits will shift towards the internet. In terms of long-term overflow, this storm synergizes with unprecedented enormous impact. Perhaps in the near future, Islamic financial markets will face greater risks due to the rapid development of the internet industry. Overall, due to the impact of external events, the relationship is becoming increasingly tight, undoubtedly leading to a higher possibility of contagion risk.

It is not difficult to observe that simply analyzing the overall TCI cannot distinguish between short-term and long-term effects. In the system we studied, the long-term effects triggered by the release of ChatGPT 4.0 show a huge peak, but this is not very evident in the short-term TCI (as shown in Figure 2). Thus, the

frequency spillover model complements the standard VAR overflow framework well, particularly as researchers can use the changes in long-term connectedness to determine whether there have been significant structural changes in the entire market (Chatziantoniou et al., 2021b). Therefore, adopting both the VAR overflow approach and the frequency overflow approach may be an effective method to optimize the overflow framework based on the standard VAR. Additionally, the results also indicate that different external events that the stimulation to the system's connectedness should not be regarded as a single pattern since crises have different natures. For example, Brexit and the Russia-Ukraine conflict are essentially geopolitical risks, so their impact on the overall and long-term indices is not as pronounced as that of global pandemics and technological emergence.

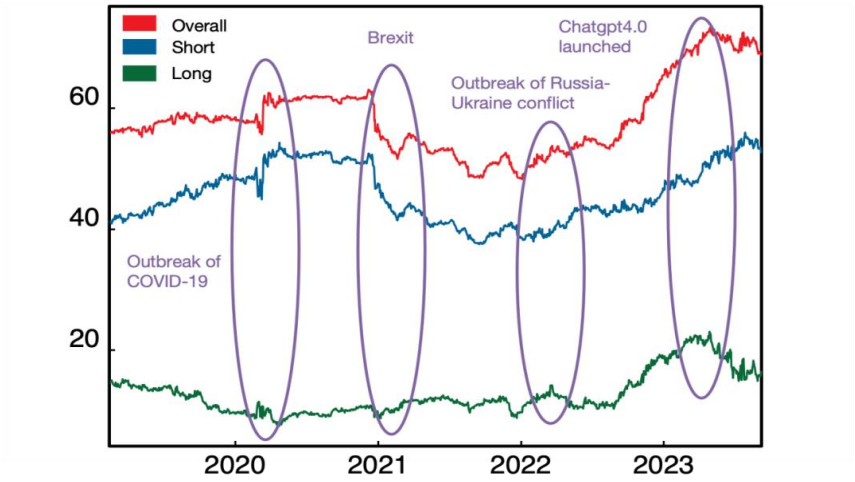

Figure 2. Short-term, long-term and overall dynamic TCI. 200-day rolling windows are applied to the QVAR model and the GFEVD is tested using a 100-step-ahead, which is based on the median. Spillovers are expanded for a given quantile and are shown for the short and long term. On 11 March 2020, WHO states that 114 countries and territories worldwide are affected by COVID-19, which is a result of a threefold increase over the past two weeks; on 31 January 2021, the United Kingdom formally leaves the European Union; and on 24 February 2022, the Russian-Ukrainian War officially kicks off; on 15 March 2023, OpenAI announced the launch of ChatGPT 4.0.

5.2.2 Dynamic Total Connectedness over Quantiles

Previous work focused on the median, but understanding the situation of other quantiles is also important. Therefore, we adjusted the quantile connectedness configuration through the QVAR model to obtain more complete conclusions. On the other hand, although the spillover framework based on the median can detect exceptional situations, it only has an advantage in describing the central tendency. That is to say, the investigation of volatility spillover based on the median may have biases, which means that a comprehensive QVAR is needed to improve the accuracy of the results (Chatziantoniou et al., 2022). Therefore, this section reports the total connectedness driven by quantiles and time, including the middle and tails, as shown in Figure 2. In this heatmap, the degree of connectedness increases with warmer

colors. Globally, the system's TCI is more than 50% higher in most cases, and even some areas exceed 85%. This provides considerable evidence for the close relationship between the Islamic finance market and the FIR market. Interestingly, the connectedness of low and high quantiles is stronger than that of the middle regions, indicating that tail behavior is very intense. The heterogeneity of connectedness in the middle and tail regions in this case is consistent with Ha's findings (2023). Additionally, the results also indicate that connectedness is symmetric about the median, which is similar to the results obtained by Chatziantoniou et al. (2022).

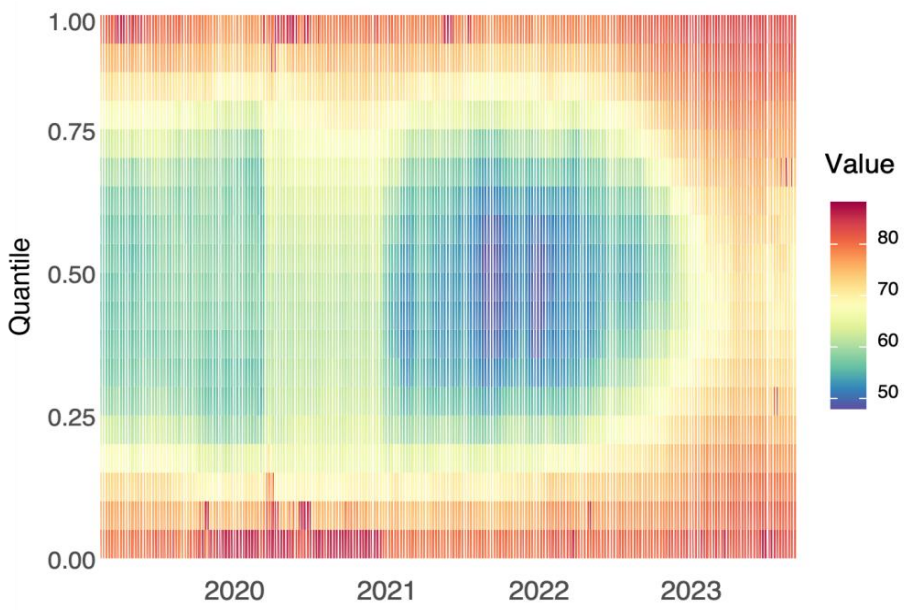

Figure 3. Dynamic TCI over quantiles. The results are from overall frequency-based QVARs with different quantiles, requiring a rolling window of 200 and a GFEVD 100 steps ahead. The degree of connectedness is enhanced as the colour transitions from cool to warm.

In addition, in this work, the outbreak of COVID-19 in 2020 and the emergence of powerful language models in 2023 can be clearly identified. When the epidemic broke out, tail connectedness approached 90%, especially in the low quantile section. Meanwhile, the connectedness of the middle region increased from around 55% to 65%. Similar phenomena appeared recently, when ChatGPT 4.0 was officially announced in 2023, and connectedness on all quantiles was almost uniformly within the range of 70% to 80%, which is a key finding of this case. It is obvious that the distance between FIR assets and Islamic finance assets is getting closer, which implies risk overflow is easy to occur. Because of the stunning performance of ChatGPT 4.0 in the world, innovation and technology are full of unprecedented vitality, and the market has great expectations for the related value chain. In this case, the possibility of risk contagion between Islamic finance assets and FIR assets is very high. Therefore, once the current stage of the FIR industry collapses, even Islamic finance assets, which are known as safe havens, may not be able to avoid losses.

5.3 Net Total Directional Connectedness

This section focus on analyzing the spillover effects of individual assets to investigate changes in the position of each asset within the system. Figure 4 presents the overall, short-term, and long-term investigation results based on the median. In the figure, positive values represent net transmitters of spillover in the structure, while negative values represent net receivers of spillover. We observe that Sukuk's flow is the most notable, with all its components consistently below zero. This means that the Islamic bond are not only net receivers of short-term shocks, but also in the long-term impact. Therefore, Islamic bonds tend to play a more passive role in the FIR. On the other hand, the performance of Islamic stocks contrasts sharply with the formation of Sukuk. At the overall and short-term levels, the net connectedness of Islamic stocks remains positive, indicating that they are net transmitters of system shocks. However, in the long-term perspective, the Islamic stock temporarily become net receivers around 2020 and 2022. This indicates that the COVID-19 pandemic and the Russia-Ukraine conflict have had a lasting impact on Islamic stocks, and this stimulating phenomenon is also evident in the long-term spillover of Sukuk. It is due to the differences in transmission between the short and long term that we expand on the viewpoint of Naifar (2023), which states that Islamic bonds are not easily affected by COVID-19 or related content in the overall and short term, but the long-term impact is latent. Nevertheless, Islamic bonds can be considered as an alternative to Islamic stocks, which may bring better diversified returns (Mensi et al., 2022).

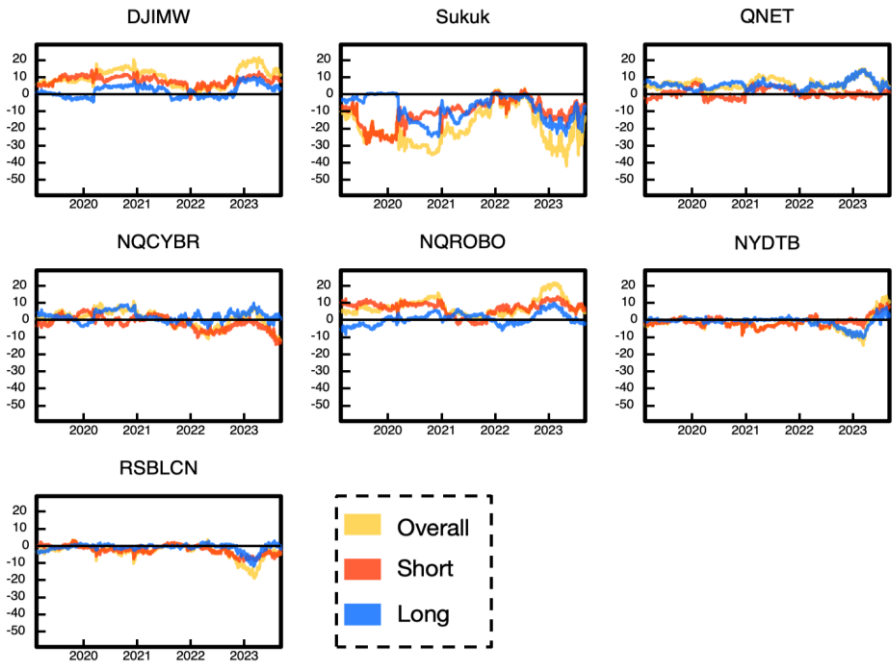

Figure 4. Net total directional connectedness. The yellow line shows the overall net directional connectedness; the red line is the short-run net directional connectedness; and the blue line is the long-run net directional short-run. When below a value of 0, the variable is a net receiver of shocks; otherwise it is a net propagator.

We note that the impact of the artificial intelligence and robotics indices in the FIR industry has brought significant overall and short-term net spillovers to the system, especially around 2020 and 2023. On the one hand, the social distancing caused by the pandemic has led people to expect a more virtual existence, which further accelerates the development of robotics and AI companies (Demiralay et al., 2021). Therefore, the fluctuations of the AI and robotics indices during the pandemic are more significant, and this conclusion is consistent with Huynh et al. (2020) and Demiralay et al. (2021). On the other hand, the research results of AI companies, mainly OpenAI, have shocked the world, and research and applications related to it have actively impacted all walks of life. In the long term, the internet index dominates the net spillover of FIR assets in this case. This may be because all alternative assets triggered by the Fourth Industrial Revolution need to rely on the internet. Secondly, the network security index is a net receiver in the short term and a shock transmitter in the long term. In addition, the disruptive technology index and the blockchain index alternate around zero, and they start to move significantly only around 2023. The reason for this abnormal phenomenon is that the disruptive technology index and the blockchain index were launched on April 29, 2018, and November 29, 2017, respectively, which means that they need a lot of time to fully adapt to the market environment. The extension of disruptive technology and blockchain depends heavily on innovation and technological development (Delle Foglie et al., 2021; Zhu et al., 2022). Therefore, the lag in technological innovation caused by the pandemic has to some extent affected their spillover changes. With the rapid development of market integration and technology, the disruptive technology index and the blockchain index begin to disrupt the entire system and briefly become net receivers around 2023.

5.4 Net Pairwise Connectedness

The visualization of the dynamic net pairwise connectedness indices between Islamic financial assets and FIR assets is shown in Figure 4, with black, pink, and green colors representing overall, short-term, and long-term net cross-sectional spillovers, respectively. In the "x-y" panel, if the value of the net cross-sectional connectedness is greater than 0, it means that x is a net transmitter to y; similarly, a negative value indicates that x is a net receiver from y. For the Islamic stock market, it act as net transmitters of short-term risk for most FIR indices. However, the Islamic stock market behave as net receivers of shocks from the internet index and the network security index at the long-term level. This is because more efficient information in the market helps better predict stock prices and optimize investment strategies, and the internet has always been a major disseminator of market information (Agarwal et al., 2019). As for the Islamic bond market, they consistently act as net receivers of shocks from the internet index, the network security index, and the AI and robotics index, both in the time and frequency domains. When facing the disruptive technology index and the blockchain index, the Islamic bond market undergo a change in their short-term spillover position. Specifically, in the Sukuk-NYDTB panel, the Islamic bond market were net transmitters in 2021 and 2022, while in the Sukuk-RSBLCN panel, they transitioned to net transmitters in 2020, 2021, and 2022. Considering the overall attitude of the Islamic bond market towards the FIR and the current development of technology, it is likely that the Islamic bond market will

consistently remain as volatile receivers in the future. Furthermore, our research results suggest a strong connectedness between the Islamic stock market and the Islamic bond market.

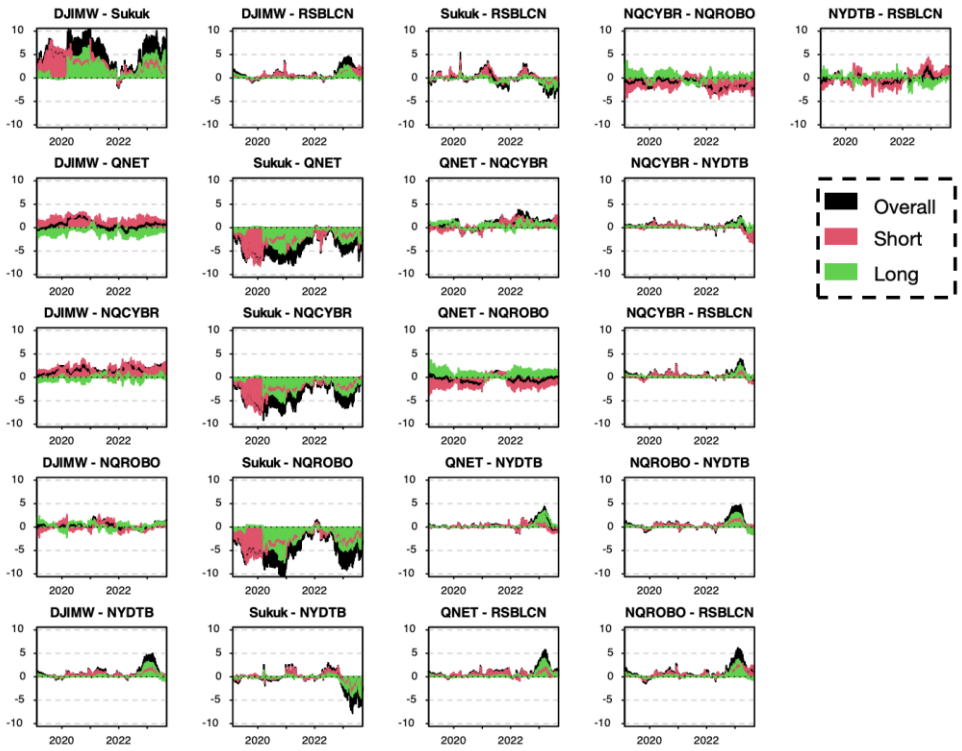

Figure 5. Dynamic net pairwise directional connectedness. Black, pink and green colours represent the overall, short-run and long-run net pairwise spillovers, respectively. For example, "x-y", if their net pairwise connectedness value is greater than 0, it means that x causes a volatility spillover to y; on the contrary, a negative value means that x is hit by y.

6. Conclusion

Given the significant impact of the pandemic and geopolitical conflicts on financial markets, as well as the future uncertainties, there is reason to believe that the morally guided Islamic financial market will become one of the most popular markets. With the Fourth Industrial Revolution (FIR) facilitating the rapid circulation of information, the impact of financial assets can quickly result in cross-market spillover effects, thereby participating in the volatility processes of other markets. This implies that systemic financial risks could become quite severe. Therefore, this paper discusses the spillover effects of volatility between the Islamic financial market and several other markets, which is of great significance for investors' future trading strategies.

This article considers the frequency-based quantile autoregression (QVAR) as an evaluation method for spillover effects between markets, and discusses the transmission mechanisms between the Islamic financial market and five FIR markets from April 30, 2018 to September 8, 2023. According to the results, the overall connectedness between the two types of markets reached 58.41%, indicating a high level of integration

between the Islamic financial market and FIR markets. The Islamic stock market are the main propagators, and Sukuk play the role of net spillover absorbers. Secondly, under the impact of some external events, connectedness tends to expand. Specifically, COVID-19, Brexit, and Russia-Ukraine conflict led to different degrees of growth in overall and short-term connectedness, while the launch of ChatGPT 4.0 pushed long-term connectedness to the highest point in the sample period. It can be seen that the stimulation of system connectedness by external event shocks should not be viewed as a pattern because the nature of crises varies. In addition, we found that during the phase when ChatGPT 4.0 was officially announced, the connectedness on all quantiles was almost consistently within the range of 70% to 80%, which is a key finding of this case. Clearly, the wave of ChatGPT 4.0 has brought FIR assets closer to Islamic financial assets, significantly increasing the likelihood of risk spillover. Finally, in terms of net spillover of variables, Sukuk tend to play a passive role in the FIR, both in the long and short term, and have always been net receivers of shocks from internet index, cybersecurity index, and artificial intelligence and robotics index, while the Islamic stock market are only net propagators in overall and short-term levels. When the pandemic and Russia-Ukraine conflict broke out, Islamic stocks received long-term impacts.

In addition, our research also provides some insights for investors and managers: (i) when major economic or geopolitical events occur, such as COVID-19, Brexit, and the Russia-Ukraine conflict, we believe that it is necessary to judge or predict the degree of market changes based on the nature of events. (ii) ChatGPT is pushing the Fourth Industrial Revolution to its climax, which will bring huge impacts to the financial system, not only happening on all quantiles, but also showing in both short and long term perspectives. (iii) Combining the frequency domain with the time domain is a highlight when examining the influence mechanisms among multiple markets, which helps investors to consider both long and short-term factors.

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