Proceedings of the 11th International Scientific Conference Rural Development 2023
Edited by assoc. prof. dr. Judita Černiauskienė

ISSN 1822-3230 (Print)
ISSN 2345-0916 (Online)

Article DOI: http://doi.org/10.15544/RD.2023.022

DYNAMIC RETURN SPILLOVERS BETWEEN SUPRANATIONAL AND REGIONAL GREEN BOND MARKETS

Asta BENDORAITYTĖ, Department of Applied Economics, Finance and Accounting, Faculty of Bioeconomy Development, Vytautas Magnus University, address: K. Donelaičio str. 58, LT-44248 Kaunas, Lithuania, asta.bendoraityte@vdu.lt (*corresponding author)*
Vilija ALEKNEVIČIENĖ, Department of Applied Economics, Finance and Accounting, Faculty of Bioeconomy Development, Vytautas Magnus University, address: K. Donelaičio str. 58, LT-44248 Kaunas, Lithuania, vilija.alekneviciene@vdu.lt

Green bonds, as a new and innovative financial tool, interest investors by allowing them to achieve twofold aims. Firstly, investing in green bond market allows to diversify portfolio and increase its efficiency. At the same time, investing in green bonds is a sustainable investment option ensuring a positive impact on the environment. Numerous studies point to the connectedness effects between the returns of green bonds and conventional or green asset markets, but little attention has been paid to the assessment of the spillover effects between the green bond markets themselves. Our study seeks to address this gap by focusing on the dynamic return spillover between supranational green bond market and the biggest regional green bond markets in Europe, the US, and Asia. Using daily data covering the period of October 13, 2021, to January 31, 2023, we apply the vector autoregression model and use spillover method of Diebold and Yilmaz (2012) to determine the time-varying level of these markets' connectedness. We have found that the average level of return spillover is estimated at 42.46 percent. A clear distinction would be that supranational, the US, and the EU green bond markets are the net transmitters of spillover, while Asia's green bond market is the net receiver. Also, we have found that the supranational green bond market affects the region's green bond indices at different levels. Our finding provides systematic insights for international investors and policymakers on the possibilities of financial stability, risk assessment, and portfolio allocation in different green bond markets.

Keywords: *green bond, return spillover, regional markets, connectedness.*

INTRODUCTION

The rising concern about climate change led to higher interest of environmentally friendly activities and shift investors sentiments towards climate friendly and sustainable investment initiatives. This shift explains the rapid growth of green bond market. Development of this market allows to mobilise and channel financial resources to activities which benefit environmental goals. Green bonds are named as fundamental, but highly progressive market innovation (Broadstock et al., 2020). On one hand green bond differs from conventional bond by use of procced strictly directed to fund or refund eligible green projects, meaning activities which match the four core components of the Green Bond Principles (ICMA, 2021). Most commonly green bonds are used to finance projects that are focused on renewable energy, green buildings, clean infrastructure, and energy efficiency (Anderson, 2016; Naeem et al., 2021). On the other hand, the similarity of green bonds characteristics to the conventional bonds, made this instrument easy to use for both, the issuers, and investors (Maltais and Nykvist, 2020). So, this has catalysed market interest in green bonds, and adoption and popularity of green bonds is increasing over time (Flammer, 2021).

The first green bond emissions were issued by European Investment Bank in 2007 as The Climate Awareness Bond followed by World bank issuance in 2008. Since green bonds have gained significant popularity and importance among the various green financial instruments. The constant growth is visible in both, the number of issuers and the issuance amounts. According to King et al. (2021), cumulative green bond issuances around 1.5% of the global bond market in August 2021. When the regulation of green bonds was introduced, the issuance of green bonds had jumped from 36 bn USD in 2014 to almost 600 bn USD in 2021. After rapid and constant growth of green bond market, the first contraction of this market is seen in 2022 which was led by the global economic shock caused by the energy crisis, the end of significantly low interest rates period and bullish markets during the last year (CBI, 2022), though the level of green bond issuance in 2023 is expected to go back the previous levels of 2021 (Allen, 2023). The growth in this market relies on the increasing demand from investors for sustainable investment option and the need to look for diversification option, seeking for risk minimization and at the same time maximisation of returns (Ferrer et al., 2021a; Ferrer et al., 2021b; Hung, 2021).

Since the green bond market attracts more and more attention from investors as environmentally friendly investment tool, the connectedness of this assets with other assets classes needs to be assessed. Researchers pay more attention to connectedness between green and conventional assets classes (Arif et al., 2021; Ferrer et al., 2021a; Ferrer et al., 2021b; Naeem et al., 2021; Reboredo, 2018) or connectedness between green asset classes (Pham, 2021; Saeed et al., 2021). Major part of previous studies focusses on green bond market connectedness through the global or developed markets indexes such as US or EU (Reboredo and Ugolini, 2020). However, there is a lack of studies which investigate other geographical areas particularly emerging green markets, such Asian regions (Cortellini and Panetta, 2021). The amounts of green bond issues recently increase very fast in China that is why the researchers focused on this market more intensively (Long et al., 2022; Man et al., 2023). The Asia as a region still lacks attention (Cortellini and Panetta, 2021). Also, our research includes supranational green bond market, which is a new study dimension (Khamis and Aassouli, (2023) in green bond studies and especially in the assessment of regional green bond connectedness. So, this study addresses this gap and aims to assess the dynamic return spillover between supranational and three major regions of green bond markets in EU, US, and Asia.

Vector autoregression model (VAR) and spillover method of Diebold and Yilmaz (2012) is used to evaluate the connectedness between supranational and regional green bond market.

The paper is laid out as follows. The literature review is outlined in Section 2. Research data are described in Section 3. Research methods applied for the assessment of green bond markets' connectedness are presented in Section 4. Empirical results and discussion are provided in Section 5. Finally, Section 6 is dedicated to concluding remarks.

LITERATURE REVIEW

Analysis of green bond market links and connection with other assets classes developed in few analysis strands. Firstly, researchers focused on global market and included the most popular conventional asset classes such as treasury and corporate bond market, high yield bond market, energy, renewable energy markets, commodities, crude oil, or currency market, etc. Reboredo (2018) analysed green bond, corporate and treasury bond markets and noticed the highest co-moving between bonds markets and identified diversification opportunities of green bonds for investors in stock and energy markets. Using wavelet-based network approach Ferrer et al. (2021a) analyses the interdependence between green bonds and green stocks as the most widely used green finance instruments and list of conventional assets in October 2010 to 13 November 2020. Analysis involves well know instruments such as treasury, investment-grade and high-yield corporate bonds, general stocks, crude oil, and gold at different time horizons. Results indicate that green bonds are closely linked to treasury and investment-grade corporate bonds at different investments horizon. However, links with investment-grade bonds isn't identified. Meanwhile, green stocks are tightly linked to conventional stocks. This allows to make conclusion, that green investment instruments are similar to their corresponding conventional counterparts. Weak dependence is seen between green investment instruments and crude oil, indicating the independence between these markets. However, the strong links between green bonds and gold markets can be seen as safe-haven opportunities to invest in green bond market during market turmoil periods.

Ferrer, Shahzad et al. (2021) using the methodology represented by Baruník and Krehlík (2018) analyse time-frequency connectedness between return and price volatility of global green, treasury, corporate bonds, currency, crude oil, and renewable energy markets. Result of the research identifies higher return connectedness between analysed markets while investing for short time horizons (up to 5 days). The highest connectedness is seen between analysed bond markets, explaining these links by the similar characteristics of bonds. It means that green bond market can't be used as different asset class: these bonds are the "substitutes and/or supplements" to fixed income securities (Ferrer et al., 2021b). However, there is less links between the green bond market and conventional stocks. Crude oil or renewable energy equities provides the diversification benefits for investors.

While most studies focused on energy commodities, as having the highest links to green bonds, Naeem et al. (2021), using cross-quantilogram approach, extended the research by adding metals and agriculture commodities market next to energy market. Study results showed that investing in green bond market can create some diversification benefits to investment in natural gas, some industrial metals, and agriculture commodities markets. Also, it is stressed that these benefits increased investing for the long run to reach higher diversification benefits.

Arif et al. (2021) analysed the changes of connectedness between green assets, including green bond, market and other fixed income, equity, and energy markets in 2008 – 2020 period and subsample of COVID-19 period. Empirical results showed that green bond market is affected by treasury bonds market, and is the net receiver during all the sample, and during the pandemic period too. However, the links between green bond and energy markets are lower and authors stated the hedging options between these markets. Also, lover links are mentioned between green bonds and green stocks.

Second group of literature focused on the connectedness of green investment instruments. There most typically green stocks and renewable energy markets are included into analysis next to green bond markets. Pham (2021) used the NASDAX OMX green economy indexes of clean energy, green building, green transportation, and water markets to evaluate the dependence between these markets at different market conditions and different investment horizons. Results of the study showed that at normal market conditions the dependence between green financial market is small, meaning that investors can use these instruments to diversify the risk. However, at extreme market conditions green bonds and green stocks moves together and at a higher level, while green equities tend to transmit the change in prices and returns to green bond market, especially, in the short run.

Saeed et al. (2021) identified higher connectedness between green bond and energy, renewable energy, and crude oil markets at extreme market conditions. Empirical results showed that energy and renewable energy are the net transmitters to other asset classes, especially to crude oil. Green bond market is the net receiver of return spillovers in all markets conditions but is quite isolated considering the level of connectedness. So, these financial instruments can be used as diversification option.

Third group of literature involves green bond market in different regions and emerging countries, such China. Using wavelet-based methods and VAR model, Reboredo and Ugolini (2020) investigated the co-movement and connectedness of price among the green bond and conventional asset classes (treasury, company and high yield bond, stock, and energy markets) in EU and US. Research results showed that around 25 percent of changes of EU and US green bonds prices are explained jointly by the changes of treasury and corporate bonds in short investment horizons, while this level is about 20 percent in long-run. However, there is no opposite direction effects, meaning that green bonds are net receivers of price and returns shocks. There are weak connections between green bonds and high-yield bonds, stocks, and energy stocks in the short and long run investment horizons.

While employing quantile VAR model, Long et al. (2022) analyse green bond markets in three regions, namely US, EU and China and several uncertainties index such as economic policy (EPU), stock market (VIX), oil price (OVX), Twitter-based economic (TEU) uncertainties and geopolitical risks (GPR). Results of study identified that US market is net return transmitter, meanwhile China market acts like net receiver, and this market has the weakest connectedness to other markets. Analysing the uncertainty effects of green bond markets, VIX together with OVX have a greatest effect on analysed green markets. Also, authors stated that larger and more mature markets of green bonds with higher share of institutional investors, such US and EU, are more stable and less affected by the change in uncertainties. Man et al. (2023) employed GARCH model to determine the dynamic connectedness between China's green bonds and conventional asset, such as treasury bonds, stock, and crude oil markets. Also, there is identified that China's green bond market is linked to bond market, while less connected to stock and oil market.

Most studies focused on global green bond market and its connectedness with conventional asset classes such as treasury, companies and high yield bonds, conventional stocks, commodities, including energy and crude oil, markets, or currency market. Recently researchers' attention is focused on the largest regional green bond markets. Usually, US and Europe regions are analysed. We can identify the growing interest to China green bond market too, since the issuance of green bonds in this market is rapidly increasing. However, there is a lack of studies analysing the Asia region, not focusing on one country from the regions. Also, all the studies rely on indexes of green bond market, which includes mixed green bonds issued by private, institutional issuers and supranational organisation, not distinguish difference between them. In our study we focus on supranational green bond market as playing the key role in the development of green bonds as green investment instrument market in last years.

DATA

The beginner of green bonds issue was made by supranational organizations, but since 2014 the growth of this market is seen in major world regions. Figure 1 shows the changes of green bond market in different regions, comparing the issued amount of green bonds in 2014-2022. Over the whole analysis period, three main green bond regions stand out, with a combined share of over 70% of the world green bond market. As of 2019, these trends are even more striking, with green bonds issued in Europe, North America and the Asia-Pacific regions accounting for 90% of global issuance. Europe is the leading issuer of green bonds and has been a key driving force in green bond development since its inception in 2008 (Bos, 2023). By the end of 2026 EU indents to issue €250 billion of green bonds to finance its Next Generation EU program, which leads to economic recovery from the pandemic and green development (EC, 2021). Since 2021 Asia–Pacific, especially China, has witnessed growth jumps as the most active market of green bonds (CBI, 2023) since received interest from investors as a potential investment opportunity (Man et al., 2023).

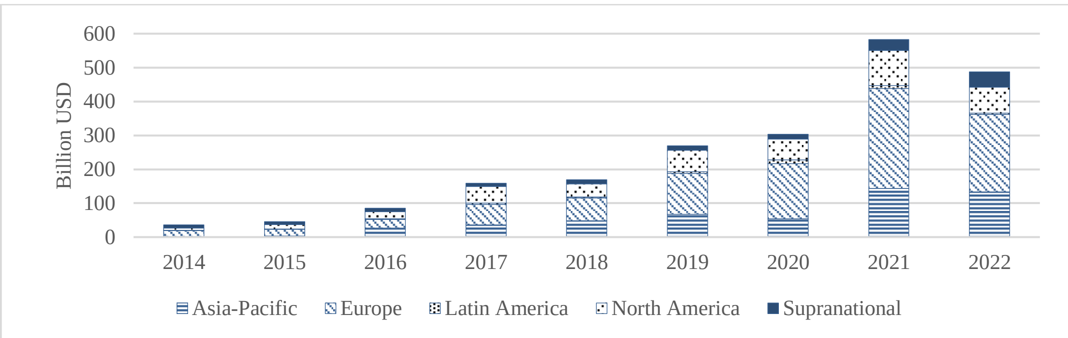

Fig. 1. Green bonds markets size in different regions in 2014-2022. Source: CBI database, 2023.

The biggest markets of green bonds are Europe region, with almost 50 percent of green bond issuance (leading countries Germany, France, and Netherlands), Asia-Pacific (leading China) and North America (leading US) with 25 and 18 percent respectively. Supranational green bond market witnessed steady growth.

To evaluate the dynamic return interconnectedness, we use daily closing prices of supranational and regional green bond indexes including Europe, the US and Asia. Green bond indexes reflect the fixed income securities issued to finance activities with positive environmental impact through their use of proceeds. Based on Bloomberg Barclays index family of green bond, MSCI ESG Research defines six eligible categories of use of proceed such as alternative energy, energy efficiency, pollution prevention and control, sustainable water, green building, and climate adaption.

Referring to the need include supranational green bonds in connectedness studies named by Khamis and Aassouli, (2023) we use Bloomberg supranational green bond index (GB_SUPR) seeking to represent the global green bonds issued by supranational organizations. Green bond regional markets included in the study involve Europe, the US, and Asia as the biggest markets of green bond in amount outstanding (CBI, 2023). Based on Billah et al. (2022) we use the Euro Green Bond Index (GB_EU) to represent the green bond market in Europe. Based on Reboredo et al. (2020) and Lin and Su (2022) US Green Bond Index (GB_US) index is used for US green bonds market. Bloomberg MSCI Asia excluding Japan Green Bond Index (BG_ASIA) is used to represent Asia green bond market and is designed to measure USD-denominated bonds issued by issuers in the Asia excluding Japan region to fund projects with direct environmental benefits. This index reflects green bonds issued in such countries as Bangladesh, China, S. Korea, India, Indonesia, Taiwan, Hong Kong, Philippines, Thailand, Malaysia, Vietnam, etc.

Daily data is extracted from Bloomberg database. The sample period cover period from October 13, 2021, to January 31, 2023, giving a total of 369 daily observations for each index. The initial data of analysed period is set according to the availability of daily data on the Asia excluding Japan green bond index.

Fig. 2 shows the time trend plots of levels of green bond markets indexes. The level of indexes is significant higher in the start of analysed period in all the green bond markets. Starting from 2022, the level of indexes was declining, which can be related to the inflation periods in the economies. The significant decline of index values is seen in the middle of 2022. This can be explained by the decision to increase the interest rate. This decision especially effected long term bonds, which majority is issued in green bond markets. The lowest indexes values are observed in October 2022. This decline also can be linked to expectations of changes in monitory policy.

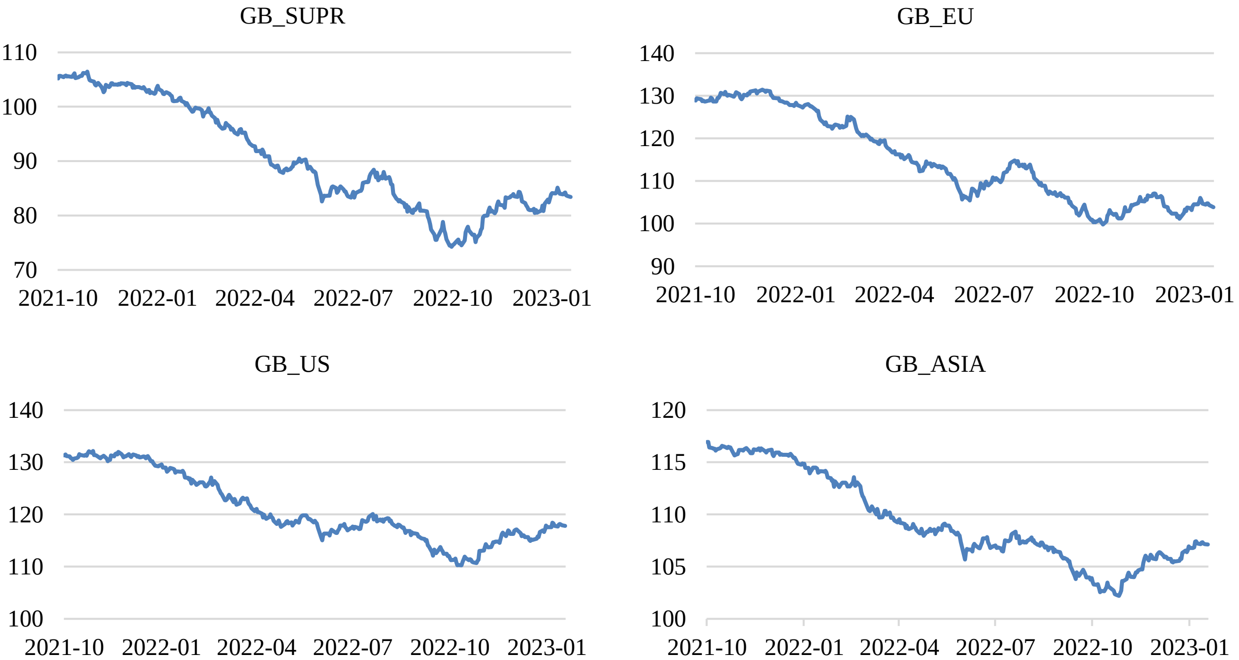

Fig. 2. Plots of levels of supranational and major regional green bond indexes

Calculation of the daily rate of return for green bond is carried out by transforming the variables into natural logarithmic form, using formula:

$$R_t = ln\left(\frac{P_t}{P_{t-1}}\right) \tag{1}$$

where P_t –value of the index at date t.

The plots of return of used indexes are represented in Fig. 3. In all the return series the fluctuation is seen. The highest return volatility is observed in supranational green bond market, while the lowest volatility is seen is Asia market of green bond. The lowest return in all green bond markets is seen on 10th June 2022. This date can be related to investors' concern in global equities related to high inflation, rising interest rates, and likelihood of recession.

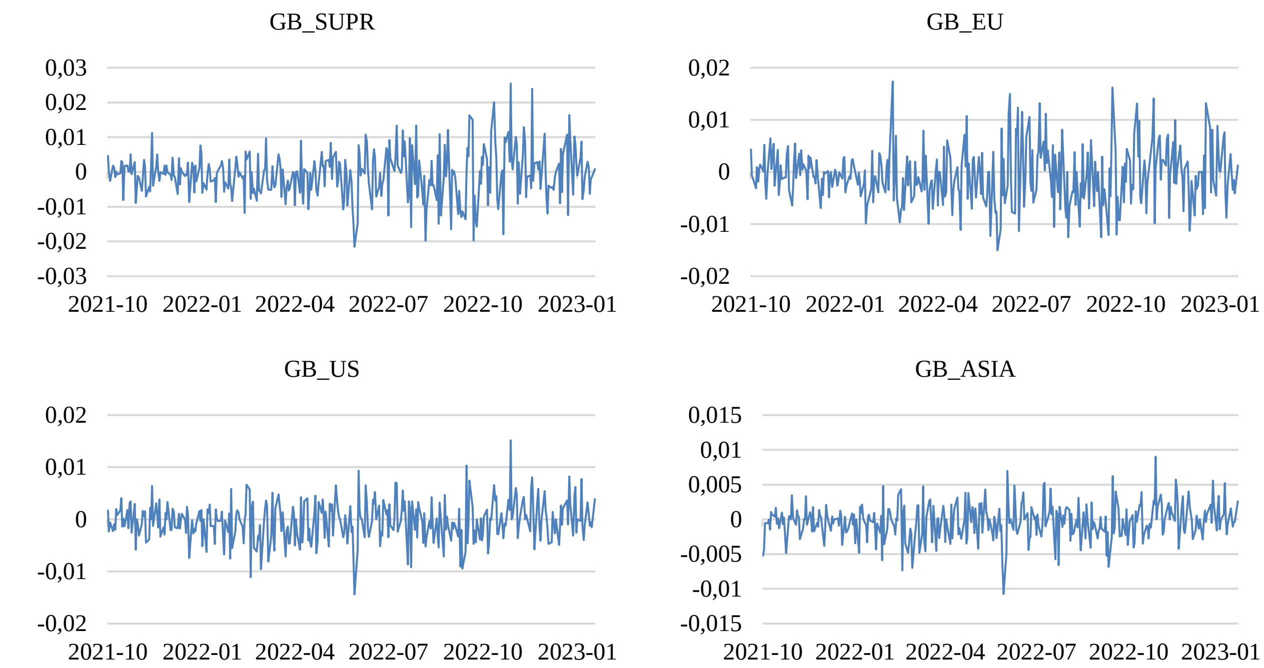

Fig. 3. Plots of returns of supranational and regional green bond indexes

The descriptive statistics is provided in Table 1 and presents the daily return series. The average returns of all analysed green bond markets are negative. GB_SUPR stands out with by having the lowest average return of − 0.068, while highest return is seen in GB_ASIA market. The highest return seeks -0.027. The highest standard deviation of 0.6863 seen in GB_SUPR market indicates the most volatile returns. While the most stable market with lowest standard deviation is GB_ASIA during analysed period. Return series of GB_SUPR, GB_EU, GB_US are positively skewed, only GB_ASIA is indicated as negatively skewed. The returns of all market are platykurtic. Augmented Dickey–Fuller test allows to evaluate the stationarity of time series and confirms absent of unit root for all return series. JB test indicates non-normality for all return series.

Table 1. Summary statistics and stationarity test results

Variable	Mean	Minimum	Maximum	Std. Dev.	Skewness	Ex. kurtosis	JB test	ADF test
GB_SUPR	-0.068	-2.1519	2.5453	0.6863	0.1460	1.0513	16.7675 ***	-5.9677 ***
GB_EU	-0.064	-1.5034	1.7365	0.5423	0.3525	0.4425	9.75801 ***	-5.5357 ***
GB_US	-0.031	-1.4390	1.5157	0.3784	0.0146	0.9064	11.5814 ***	-5.9736 ***
GB_ASIA	-0.027	-1.0752	0.9020	0.2527	-0.1055	1.1992	20.8781 ***	-6.2769 ***

Note: *** significance of 1%

Table 3 shows that the highest correlation is among green bond markets of Asia and US markets, while the lowest is seen between supranational and Asia green bond markets.

Table 3. Correlation between supranational and regional green bond markets

	GB_SUPR	GB_EU	GB_US	GB_ASIA
GB_SUPR	1			
GB_EU	0.7304 (***)	1		
GB_US	0.6445 (***)	0.6652 (***)	1	
GB_ASIA	0.5704 (***)	0.5828 (***)	0.9300 (***)	1

Note: The sample is 2021-10-13 - 2023-01-30 and covers 348 daily return data. *** significance of 1%.

The degree of correlation between supranational and regional green bond markets is highest in Europe, and lower with US green bond market. Similar correlation is seen between US and Europe, as it is to supranational market. Lowest correlations are indicated analysing Asia green bond markets, where similar degree of correlation of Asia market is seen to supranational and to Europe markets. This indicates that Asia market can see as most independent market and can have the diversification potential. After having identified the green bond indexes which represents supranational and 3 major markets, namely Europe, US, and Asia, we analyse average and time varying return connectedness between green bond markets.

RESEARCH METHODS

For the estimation of connectedness between supranational and regional green bond markets we apply methodology of Diebold and Yilmaz (2012, 2014). Spillover index in Diebold and Yilmaz's (2012) is a statistical tool used to analyse the transmission of returns across different financial markets or asset classes to describe how this transmission evolve in time. The spillover index measures the degree to which shocks in one market affect returns in another market. The spillover measure uses the generalized forecast error variance decomposition (GFEVD) of vector-autoregression model (VAR). For spillover index calculations VAR model need to be constructed following the formula bellow:

$$\mathrm{Y}_t = \mathrm{v} + \sum_{i=1}^{n} \phi_i Y_{t-i} + u_t \tag{2}$$

where Y_t – n-vector of dependent variables at time t;
v – n-vector of intercepts;
Φ(Y) – the matrix of lagged coefficients;
u_t – vector of error terms.

The GFEVD compilation follows the framework of Koop et al. (1996) and Pesaran and Shin (1998). Based on these methods, sequence of involving variables in the VAR model becomes invariant. So, this allows to solve the Cholesky-factor ordering issue. This decomposition means that each asset forecast error variance depends on two components or parts. Firstly, its own contribution is evaluated and secondly, impact from another asset, which correlate to asset. GFEVD for a forecast horizon H is calculated according to the formula presented below:

$$\theta_{ij}^{g}(H) = \frac{\sigma_{jj}^{-1} \sum_{h=0}^{H-1} e_i' h_h \sum e_j}{\sum_{h=0}^{H-1} e_i' h_h \sum e_j} \tag{3}$$

where $\theta_{ij}^{g}(H)$ – the contribution of the jth variable to the variance of forecast error of the variable ith at horizon H;
$\sum e_j$ – the variance matrix of the vector of errors;
σ_{jj} – the jth diagonal element of the Σ matrix;
e_i – a vector with a value of 1 for the ith element and 0 otherwise.

In addition, a normalization of the variance decomposition matrix is conducted as follow:

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

where $\tilde{\theta}_{ij}^{g}(H)$ – the directional spillover from variable j to i at forecast horizon H.

Next, the overall, TO, FROM, net directional and net pairwise spillover indexes are represented in Table 4.

Table 4. Description and calculation of spillovers indexes

Index	Formula	Description
Total spillover	$S^{g}(H) = \frac{\sum_{i,j=1, i\neq j}^{N} \tilde{\theta}_{ij}^{g}(H)}{\sum_{i,j=1}^{N} \tilde{\theta}_{ij}^{g}(H)} \times 100$	measure the total amount of spillover among all the variables in the system
TO spillover	$S_{i.}^{g}(H) = \frac{\sum_{j=1, j\neq i}^{N} \tilde{\theta}_{ij}^{g}(H)}{\sum_{i,j=1}^{N} \tilde{\theta}_{ij}^{g}(H)} \times 100$	measure the aggregated impact from variable j to all other variables in the system
FROM spillover	$S_{.i}^{g}(H) = \frac{\sum_{j=1, \neq j}^{N} \tilde{\theta}_{ji}^{g}(H)}{\sum_{i,j=1}^{N} \tilde{\theta}_{ij}^{g}(H)} \times 100$	measure the aggregated impact of all other variables in the system on j variable
Net directional spillover	$S_{i}^{g}(H) = S_{.i}^{g}(H) - S_{i.}^{g}(H)$	measure to the net flow of spillover effects between different variables

VAR model is constructed using lag order of one for VAR construction (based on Akaike's, Schwarz's and Hannan-Quinn's information criterions). Choi (2022) and Ozturk (2020) applied 50-days rolling-window and 10-step forecast horizon in GFEVD for assessment of dynamic spillover impact. 50-days rolling-window is suitable when the sample is relatively small. While checking the robustness of the results, 25-days rolling window and 5-step forecast horizon are used to identify the short-term dynamics of the spillovers (Xu and Li, 2023).

RESEARCH RESULTS AND DISCUSSION

Our empirical analysis consists of two steps. Firstly, the average total and directional return spillover indexes between supranational and regional green bond markets are determined. Secondly, the time-varying return spillover effects for total and directional spillover indexes are examined allowing to assess the spillover changes during the analysed period.

Estimated total and directional connectedness measures at VAR model are shown in Table 5. 42.46 percent level of total spillover index of return connectedness is identified between analysed supranational and regional green bond market. Additionally, each market was influenced by its own shoch of returns at high level. Supranational green bond market primary is influenced at very similar level by Europe and the US markets of green bond (21.81 and 21.45 percent respectively). However, supranational green bond market is the major transmitter of return spillover effects to other markets of green bonds. GB_US and GB_EU are characterized by the lover level of return spillover transmissions comparing to GB_SUPR but the level of these two regions is very similar (50.91 and 49.12 percent respectively).

GB_SUPR market has the highest impact on GB_EU (23.43 percent). Similar spillovers effects are seen of GB_EU to GB_US, and vice versa. While Europe green bond market is the largest return transmitter between the analysed regional markets, reaching 23.62 percent, meaning that EU market return shocks explain more than quarter of the US green bond returns. Similarly, US green bond market shocks explains slightly smaller share of return shocks (23.46 percent.). Identified links show strong correlation between these two green bond markets. During analysed period only one net receiver market is observed. Asia green bond market received highest net spillovers effects (-10.14 percent). The effect is not only negative, but also the highest between analysed markets. On the other hand, green bond market in Asia is the most independent market between all analysed ones, where 89.86 percent of return shocks are explained by itself, and only 11.84 percent by other markets.

Identified tendencies suggest that investors can benefit by using Asian green bond market as the hedging option when investing in the European or American green bond markets. This diversification would allow reduce investment risk and diversify investments decisions. The biggest influencer for Asia market is supranational market and at smaller level the US market.

Table 5. Return spillovers between supranational and regional green bond markets

	GB_SUPR	GB_EU	GB_US	GB_ASIA	FROM
GB_SUPR	49.23	21.81	21.45	7.50	50.77
GB_EU	23.43	51.03	23.46	2.08	48.97
GB_US	22.24	23.62	51.89	2.25	48.11
GB_ASIA	12.29	3.69	6.00	78.02	21.98
TO	57.95	49.12	50.91	11.84	169.83
Inc. Own	107.19	100.16	102.80	89.86	**TCI 42.46**
NET	**7.19**	**0.16**	**2.80**	**-10.14**	

Note: model is estimated with 1ag length criteria of order one and 10 step ahead generalized forecast error variance decomposition.

As state Long et al. (2022), there are two possible channels for major green bond markets. Firstly, it can be speculative arbitrage, which promotes the connectedness. In the periods of low yields, investors can redirect their investment to another green bond market and expect the convergence yields. The second channel is related to investor sentiments, which also can increase the connectedness. Sentiment is possible in the market situation when the green bond index of one market is growing. In this case investors' expectations increase for aggregate market demand growth because of the rising asset price (Shu et al., 2018). So, investors while seeing the growth of one green bond market, expect the same tendencies in other green bond market and direct investments here. Overall, these expectations lead to the growth of other green bond market indexes and thus making these markets interconnected.

Next, the time-varying return spillovers of supranational and regional green bond markets has been evaluated. Fig. 4 demonstrates the results of rolling window analysis. Total connectedness index varies between 39.35 percent and 71.24 percent during analysed period.

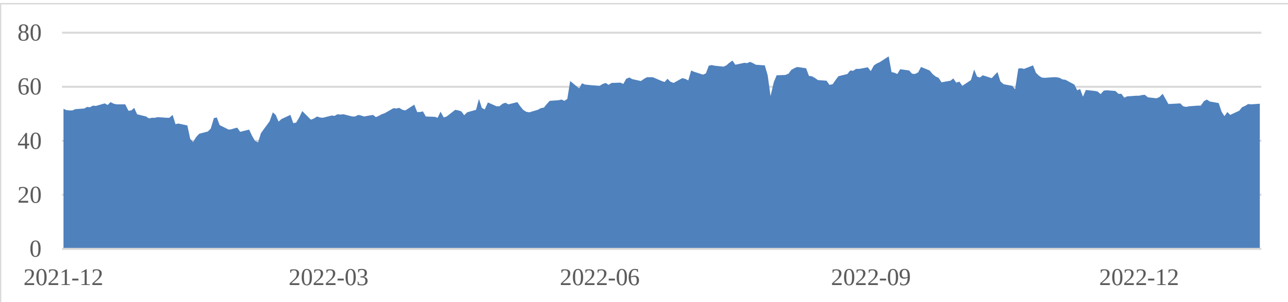

Fig.4. Time-varying total spillover index from October 13, 2021, to January 31, 2023

Since the beginning of analysed period till the middle of 2022, the total time-varying spillover index is lower comparing with rest of period. The average time-varying level of spillover is around 50 percent, while the average spillover index exceeds 60 percent after the middle of 2022. This can be related to the instability in finance markets. However, at the end of the period the decreasing tendencies of spillover index are seen.

The similar tendencies can be seen in fig. 5, where net spillover index is presented of supranational and each regional green bond markets is plotted. Since the beginning of the period the US green bond market is the biggest net transmitter, while supranational market spillover effect is not stable. Even in the period of net transmission of return shocks, the level of impact is lower comparing with GB_US. The change of the tendencies is seen since the start of May 2022. Starting from this moment, supranational green bond market is the highest net transmitter of shocks till the end of analysed period. Meanwhile GB_US shows changing patterns between transmitting and receiving shocks of returns. The changing directions can be seen in green bond market in Europe. Here just since the end of October 2022, market is the net transmitter of spillover effect. Also, the level of impact to other green bond markets increases significantly in the end of period. Analysing the net directional spillover index of Asia market, the spillover index is different. Asia green bond market is net receiver of the return shocks almost during all analysed periods.

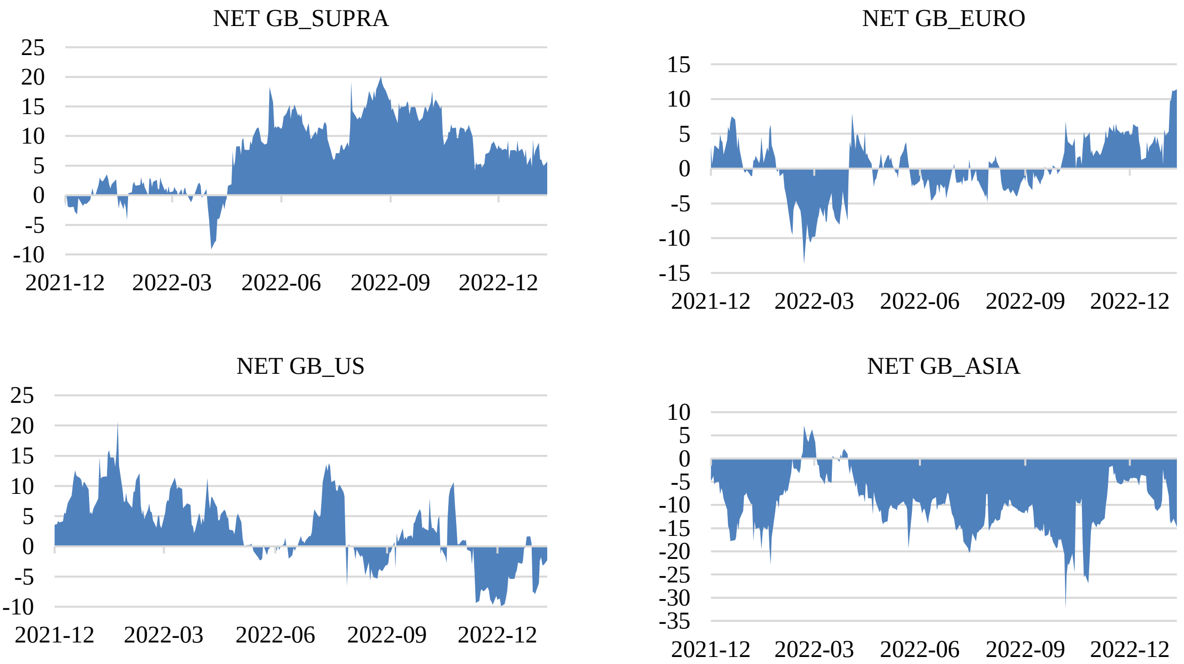

Fig.5. Time-varying net spillover index on October 13, 2021, to January 31, 2023

For checking of robustness, we apply various sizes of the rolling window and different forecast horizons. The rolling window of 25 days is used based on Xu and Li (2023) and forecast horizon is shortened to 5 days to repeat the analysis. Results of analysis is provided in Annex 1. They show that the pattern of TSI is not depending on the rolling window and the forecast horizon.

Our results are close to the tendencies identified by Long et al. (2022), where the similar effects on return shocks of Asia market, expressed using China as the main country of the region, are identified. Long et al. (2022) revealed that China market acts as the net receiver, which can be linked to maturity and size of this market comparing three analysed markets. Similar tendencies identified by Broadstock et al. (2020), while analysing Europe, US and China black and green bond markets: China green bond market acts as net receiver for the whole analysed period of 2016-2020. Opposite to that, Europe green bond market is a net transmitter for all periods. However, they pointed out that the transmission effect decreases starting from 2020 with the spike of COVID-19 pandemic. Our findings revealed that the spillover effect of Europe green bond market changes over the analysed period from net transmitter to net receiver, and opposite. These findings can be related to unstable economic situation in Europe during the analysed period. This period covers both COVID-19 pandemics and Russian-Ukrainian war and faces inflation periods, rising interest rates and likelihood of recessions. From one side, our results cover very short unstable period. From the other side, it opens the niche for future research trying to capture the main tendencies and drivers for return spillover. Finally, our research includes supranational green bond market which also affects the tendencies and directions of regional return spillovers.

CONCLUSIONS

Green bonds are one of the most popular instruments in financial markets allowing to fund the projects or activities with direct environmental benefits through their use of proceeds strictly related to climate friendly activities. Green bond market has been developing rapidly in the last decade. These instruments attract the attention of investors by allowing them to meet the interest at sustainable investment, and to provide the diversification benefits to investment portfolio. There is a need to analyse the connectedness between these markets because of the rapid growth green bond market in different regions, both developed and emerging.

Appling the vector autoregression model and using spillover method of Diebold and Yilmaz (2012), we determine the time-varying connectedness between green bonds of supranational organisations and three major regional green bond markets in EU, US, and Asia. Empirical results show the time-varying markets' connectedness, with estimated the average total return spillover at 42.46 percent. Time-varying analysis shows that total spillover effect between green bond markets started to increase with Russian-Ukrainian war. The peak (71.24 percent) was reached at the end of September 2022. This peak was also caused by inflation, increased interest rates and likelihood of recession. Supranational green bond market is a major return transmitter during the analysed period. It had the largest impact on the EU green bond market, a bit lower – on the US green bond market, and the lowest – on Asian green bond market. The US and the EU green bond markets are also net transmitters considering the average total return spillover. However, the time-varying spillover effect of the EU and the US green bond market changes over the analysed period from net transmitter to net receiver, and opposite. The findings revealed strong connection between the EU and US green bond markets. Our evidence also showed that Asia market is the only one net receiver during analysed period. In addition, this market is the most independent market between all analysed ones, where 89.86 percent of return shocks are explained by itself. The largest influencer for Asia market is a supranational market. Our empirical evidence revealed that Asia green bond market can be used as the hedging option for investors forming green bonds portfolios.

Our findings can be useful for investors making risk management decisions and/or return predictability. Moreover, the analysis of connectedness of green bond markets is useful for policymakers assuring financial stability and developing green bond market.

REFERENCES

1. Allen, T. 2023. Green bond growth to return in 2023. Available at https://Globalmarkets.Cib.Bnpparibas/Green-Bond-Growth-to-Return-in-2023/.
2. Anderson, J. 2016. Environmental finance. In *Handbook of environmental and sustainable finance* (pp. 307-333). Academic Press. https://doi.org/10.1016/B978-0-12-803615-0.00015-7
3. Arif, M., Hasan, M., Alawi, S. M., & Naeem, M. A. 2021. COVID-19 and time-frequency connectedness between green and conventional financial markets. *Global Finance Journal*, 49, 100650. https://doi.org/10.1016/j.gfj.2021.100650
4. Billah, M., Karim, S., Naeem, M. A., & Vigne, S. A. 2022) Return and volatility spillovers between energy and BRIC markets: Evidence from quantile connectedness. *Research in International Business and Finance*, 62, 101680. https://doi.org/10.1016/j.ribaf.2022.101680 .
5. Bos, B. 2023. Green Bonds: Connecting Fixed Income Capital to the Global Climate Transition. Available at https://www.gsam.com/responsible-investing/en-INT/professional/insights/articles/green-bonds-connecting-fixed-income-capital-to-the-global-climate-transition .
6. Broadstock, D. C., Chatziantoniou, I., & Gabauer, D. 2022. Minimum connectedness portfolios and the market for green bonds: Advocating socially responsible investment (SRI) activity. In *Applications in Energy Finance*: *The Energy Sector, Economic Activity, Financial Markets and the Environment* (pp. 217-253). Cham: Springer International Publishing. https://doi.org/10.2139/ssrn.3793771
7. CBI. 2022. Sustainable Debt Global State of the Market. Available at https://www.climatebonds.net/files/reports/cbi_sotm_2022_03e.pdf .
8. CBI. 2023. Sustainable market report. Summary 2023. Available at https://www.climatebonds.net/resources/reports/h1-market-report-2023 .
9. Choi, S.Y. 2022. Dynamic volatility spillovers between industries in the US stock market: Evidence from the COVID-19 pandemic and Black Monday. *The North American Journal of Economics and Finance*, 59, 101614. https://doi.org/10.1016/j.najef.2021.101614 .
10. Cortellini, G., & Panetta, I. C. 2021. Green Bond: A Systematic Literature Review for Future Research Agendas. *Journal of Risk and Financial Management*, 14(12), 589. https://doi.org/10.3390/jrfm14120589 .
11. Diebold, F. X., & Yilmaz, K. 2012. Better to give than to receive: Predictive directional measurement of volatility spillovers. *International Journal of Forecasting*, 28(1), 57–66. https://doi.org/10.1016/j.ijforecast.2011.02.006 .
12. EC (2021). Questions and Answers: Next Generation EU first green bond issuance. Available at https://Ec.Europa.Eu/Commission/Presscorner/Detail/En/Qanda_21_5211 .
13. Ferrer, R., Benítez, R., & Bolós, V. J. 2021 (a). Interdependence between green financial instruments and major conventional assets: Awavelet-based network analysis. *Mathematics*, 9(8). https://doi.org/10.3390/math9080900 .
14. Ferrer, R., Shahzad, S. J. H., & Soriano, P. 2021 (b). Are green bonds a different asset class? Evidence from time-frequency connectedness analysis. *Journal of Cleaner Production*, 292, 125988. https://doi.org/10.1016/j.jclepro.2021.125988 .
15. Flammer, C. 2021. Corporate green bonds. *Journal of Financial Economics*, 142(2), 499–516. https://doi.org/10.1016/j.jfineco.2021.01.010 .
16. Hung, N. T. 2021. Green Bonds and Asset Classes: New Evidence from Time-varying Copula and Transfer Entropy Models. *Global Business Review*, 1–20. https://doi.org/10.1177/097215092110340 .

17. ICMA. 2021. Green Bond Principles Voluntary Process Guidelines for Issuing Green Bonds. Available at https://www.icmagroup.org/assets/documents/Sustainable-finance/2022-updates/Green-Bond-Principles_June-2022-280622.pdf .
18. Khamis, M., & Aassouli, D. 2023. The Eligibility of Green Bonds as Safe Haven Assets: A Systematic Review. *Sustainability*, 15(8), 6841. https://doi.org/10.3390/su15086841 .
19. King, D., Clatworthy, R., Collins, L., & Palmucci, F. 2021. The green bond market. Is the fixed Income fulcrum tilting Green?. Available at https://Www.Lgim.Com/Landg-Assets/Lgimetf/Files/Green-Bond-Market---Collaboration-Lgim--Cbi.Pdf .
20. Koop, G., Pesaran, M. H., & Potter, S. M. 1996. Impulse response analysis in nonlinear multivariate models. *Journal of Econometrics*, 74(1), 119–147. https://doi.org/10.1016/0304-4076(95)01753-4 .
21. Lin, B., & Su, T. 2023. Uncertainties and green bond markets: Evidence from tail dependence. *International Journal of Finance & Economics*, 28(4), 4458-4475, https://doi.org/10.1002/ijfe.2659 .
22. Long, S., Tian, H., & Li, Z. 2022. Dynamic spillovers between uncertainties and green bond markets in the US, Europe, and China: Evidence from the quantile VAR framework. *International Review of Financial Analysis*, 84, 102416. https://doi.org/10.1016/j.irfa.2022.102416 .
23. Maltais, A., & Nykvist, B. 2020. Understanding the role of green bonds in advancing sustainability. *Journal of Sustainable Finance & Investment*, 1–20. https://doi.org/10.1080/20430795.2020.1724864 .
24. Man, Y., Zhang, S., & Liu, J. 2023. Dynamic connectedness, asymmetric risk spillovers, and hedging performance of China's green bonds. *Finance Research Letters*, 56, 104083. https://doi.org/10.1016/j.frl.2023.104083
25. Naeem, M. A., Nguyen, T. T. H., Nepal, R., Ngo, Q.-T., & Taghizadeh–Hesary, F. 2021. Asymmetric relationship between green bonds and commodities: Evidence from extreme quantile approach. *Finance Research Letters*, 43, 101983. https://doi.org/10.1016/j.frl.2021.101983 .
26. Ozturk, S. S. 2020. Dynamic Connectedness between Bitcoin, Gold, and Crude Oil Volatilities and Returns. *Journal of Risk and Financial Management*, 13(11), 275. https://doi.org/10.3390/jrfm13110275 .
27. Pesaran, H. H., & Shin, Y. 1998. Generalized impulse response analysis in linear multivariate models. *Economics Letters*, 58(1), 17–29. https://doi.org/10.1016/S0165-1765(97)00214-0 .
28. Pham, L. 2021. Frequency connectedness and cross-quantile dependence between green bond and green equity markets. *Energy Economics*, 98. https://doi.org/10.1016/j.eneco.2021.105257 .
29. Reboredo, J. C. 2018. Green bond and financial markets: Co-movement, diversification and price spillover effects. *Energy Economics*, 74, 38–50. https://doi.org/10.1016/j.eneco.2018.05.030 .
30. Reboredo, J. C., & Ugolini, A. 2020. Price connectedness between green bond and financial markets. *Economic Modelling*, 88, 25–38. https://doi.org/10.1016/j.econmod.2019.09.004 .
31. Reboredo, J. C., Ugolini, A., & Aiube, F. A. L. 2020. Network connectedness of green bonds and asset classes. *Energy Economics*, 86, 104629. https://doi.org/10.1016/j.eneco.2019.104629 .
32. Saeed, T., Bouri, E., & Alsulami, H. 2021. Extreme return connectedness and its determinants between clean/green and dirty energy investments. *Energy Economics*, 96. https://doi.org/10.1016/j.eneco.2020.105017 .
33. Shu, C., He, D., Dong, J., & Wang, H. 2018. Regional pull vs global push factors: China and US influence on Asian financial markets. *Journal of International Money and Finance*, 87, 112–132. https://doi.org/10.1016/j.jimonfin.2018.04.004 .
34. Xu, Y., & Li, X. 2023. Green or grey stocks? Dynamic effects of carbon markets based on Chinese practices. *Empirical Economics*, 1-27. https://doi.org/10.1007/s00181-023-02439-1 .