Eduvest – Journal of Universal Studies
Volume 4 Number 11, November, 2024
p- ISSN 2775-3735- e-ISSN 2775-3727

RETURN SPILL-OVER OF GREEN BOND FROM VARIOUS ECONOMIC GROUP COUNTRIES DURING ECONOMIC POLICY UNCERTAINTY

Andrean Filemon[1], Zaäfri Ananto Husodo[2]
[1,2] Fakultas Ekonomi dan Bisnis, Universitas Indonesia, Depok, Indonesia
Email: andrean.d@ui.ac.id, z.husodo@ui.ac.id

ABSTRACT

This research analyzes the return spill-over of green bonds issued among several categories of countries and relation of its return spill-over to various global economic conditions. The research employs a time-varying parameter vector autoregression (TVP-VAR) methodol-ogy to account for the return spill-over among countries, and wavelet coherence analysis (WCA) for relation between return spill-over and global economic policy uncertainty (GEPU) index. This study utilizes yield data from green bonds issued from January 2014 to February 2024. This period chosen based on the commencement of green bond issuance in several Emerg-ing Market (EM), Frontier Market (FM) and Least Developed Market (LDM). The findings of this research is the green bonds issued from Developed Market (DM) gives bigger return spill-over effect to the green bonds issued from EM, rather than to FM and to LDM. This spill-over effect from DM to EM raises due to the high GEPU Index, which means the more uncertain the global economics policy, investor rather to safe in stable financial instrument such as green bonds issued in DM and EM.

KEYWORDS *Green Bonds, Economic Policy Uncertainty, Return Spill-Over, TVP-VAR, Wavelet Coherence Analysis.*

INTRODUCTION

Green bonds become the emerging favorable financial instrument to solve the challenges in climate change such as global warming, pollution, and creating green economies, rather than other financial in-struments (Elsayed et al., 2022). United Nations through its Sustainable Develop-ment Goals (SDG) is prioritizing the eco-nomics growth amongst environmental issue. Therefore, the de-veloped countries tend to direct the investment in capital market through green bonds, as part of green financing & green economies (Ren et al., 2022).

How to cite:	Andrean Filemon. (2024). Return Spill-Over Of Green Bond from Various Economic Group Countries During Economic Policy Uncertainty. *Journal Eduvest. 4*(11): 9935-9952
E-ISSN:	2775-3727
Published by:	https://greenpublisher.id/

Green bonds are considered as new asset with the environmental concerns and pull attraction from investors due to the low connectedness with conventional assets in such volatile financial environment. The increasing popularity of green bonds is based on investors' outlook that according to survey, the pre-dicted to increase 18-20% in 2024, as part of driver for 10-15% growth in the sustainable bond (Rukundo, 2024). Even tough green bonds is a booming phenomenon, this market still contributing as small part in overall fixed income market (1.3%), so there are plenty of opportunities for green bonds as potential new investment (Ferrer et al., 2021).

The uncertainty from developed countries' government policy to the global economics, which is ex-pressed in Economic Policy Uncertainty (EPU) index, causes limitation in project funding and increasing market risk, brings impact to the fluctuation in money market including green bonds (Syed et al., 2022). The global EPU affects the return of green bonds, especially green bonds in developed countries (Syed et al., 2022). The green bonds' return in developed coun-tries is allegedly bring the spill-over effect to green bonds' return in developed countries.

EPU as representative of economics environment, is part of investors' considerations to anticipate any fluctuation/volatility from investing in green bonds. Previous study found that adjustment in eco-nomic policy deliver the influence to investor regarding the increasing behaviour of irrational invest-ment. Moreover, this condition affects the fluctuation in green bonds market. The influence of EPU to green bonds market, shows that green bonds are the promising indicator to the economic policies and conditions, thus investor should put more attention in green bonds investment and arrange strategy for investment (Syed et al., 2022).

Research conducted by Pham & Nguyen, 2022, with the Markov Switching Dynamic Regression (MSDR) found that in the low-state of financial and economic uncertainty through EPU, Oil Volatility Index (OVX), and Stock Market Volatility Index (VIX), the spill-over effect to green bonds market are smaller but more persistent than high-state uncertainty. This result leads to conclusion that the hedging from green bonds during high-state uncertainty is less benefit. During low-state uncertainty, green bonds can deliver hedging benefit (Pham & Nguyen, 2022).

Based on recent studies, spill-over of green bonds are compared to the conventional bonds for the purpose of multiple asset allocation strategies. This research showed that portfolio which is consisted of green bonds has a better risk-return profile rather that portfolio which is just filled with only convention-al bonds, therefore suggested green bonds as part of optimal diversification portfolio (Han et al., 2022). Other study examined the return spill-over of green bonds from several countries as part of portfolio's diversification, found that Hong Kong and Japanese green bonds market are the major receiver of spill-over from the USA green bonds market, while Denmark is representative as spill-over transmitter from Euro green bonds market to other countries' market (Rehman et al., 2023). Research regarding dynamic spill-over using Quantile Vector Auto Regression (QVAR), found that China green bonds market depends on the rest of green bonds market, because it is often play role as net recipient of spill-over from other green bonds market (Long et al., 2022).

From previous research, author find there is a gap to find between EPU and the spill-over effect among green bonds market from countries worldwide. Due to the limited chosen countries to examine the spill-over, hence broadening the scope and/or numbers of countries is part of the gap.

The purpose of this study is to find the green bonds' return spill-over from several economic classifi-cation countries (developing countries, emerging markets, frontier markets, least developed countries), and its spill-over condition during certain state of global EPU (GEPU). The limitation of this study is the green bonds' yield data acquired from January 2014 to January 2024, due to the commencement of green bonds issuance from developing countries (emerging markets, frontier markets, least developed coun-tries) started in 2014. The economic classification of countries using the data from International Monetary Fund. The methodology utilized in this research is Time-Varying Parameter Vector Autor Regression (TVP-VAR) to examine the connectedness between green bond markets with the with the variance of value over period of time. The Impulse Response Function between green bond markets derived from TVP-VAR, is connected to the EPU Index with Wavelet Coherence to find the relation.

RESEARCH METHOD

The research utilizes the data period from January 2014 until February 2024, by extracting green bonds issue date, issuer, issuer's country, and yield data from Refinitiv Eikon. The countries then are classified into developed countries (DC), emerging markets (EM), frontier markets (FM), and least developed mar-kets (LDM). The data generated from Refinitiv Eikon consisted of 7152 International Securities Identifica-tion Number (ISIN) of green bond in 73 countries. The list of countries that issued green bond from Janu-ary 2014 to February 2024 are:

Table 1. List of Countries as Green Bonds Issuer and its Classification

No.	Country	Classification
1	Argentina	FM
2	Australia	DM
3	Austria	DM
4	Belgium	DM
5	Bermuda	DM
6	Brazil	EM
7	Canada	DM
8	Cayman Islands	DM
9	Chile	EM
10	China	EM
11	Colombia	FM
12	Croatia	FM
13	Cyprus	FM
14	Czech Republic	EM
15	Denmark	DM
16	Egypt	EM
17	Finland	DM
18	France	DM

No.	Country	Classification
19	Georgia	FM
20	Germany	DM
21	Greece	EM
22	Honduras	LDM
23	Hong Kong	DM
24	Hungary	FM
25	Iceland	FM
26	India	EM
27	Indonesia	EM
28	Ireland	DM
29	Italy	DM
30	Ivory Coast	FM
31	Japan	DM
32	Laos	LDM
33	Latvia	FM
34	Liechtenstein	DM
35	Lithuania	FM
36	Luxembourg	DM
37	Macao	EM
38	Malaysia	EM
39	Malta	FM
40	Mauritius	FM
41	Mexico	EM
42	Netherlands	DM
43	New Zealand	DM
44	Nigeria	FM
45	Norway	DM
46	Pakistan	FM
47	Panama	FM
48	Peru	EM
49	Philippines	EM
50	Poland	EM
51	Portugal	DM
52	Romania	FM
53	Russia	EM
54	Saudi Arabia	EM
55	Serbia	FM
56	Singapore	DM
57	Slovakia	FM
58	Slovenia	FM
59	South Africa	EM
60	South Korea	EM
61	Spain	DM
62	Sweden	DM
63	Switzerland	DM
64	Taiwan	DM
65	Thailand	EM

No.	Country	Classification
66	Turkey	EM
67	Ukraine	FM
68	United Arab Emirates	EM
69	United Kingdom	DM
70	United States	DM
71	Venezuela	EM
72	Vietnam	FM
73	Virgin Islands (British)	DM

This research examines the two focuses: the spill-over effect amongst various group of countries using TVP-VAR, aggregating the countries based on economic classification to determine the spill-over from TVP-VAR relation, and then find the relation between the FROM & TO of the spill-over and global EPU using Wavelet Coherence Analysis.

TVP-VAR Method

TVP-VAR examines the connectedness between variable over its variance during period of time, which allows the enhancement of accuracy to capture the potential variation in observed data, better than the rolling-window specification of normal VAR method. This enhancement contributes to less sensitivity to the outliers, makes it to eliminate the determination of rolling-window size. It ensures that all observations are not omitted during the calculation of its dynamic measurement (Antonakakis et al., 2020). TVP-VAR is measured through equations as follow:

$$y_t = c_t + B_{1,t\,Yt-1} + \cdots + B_{k,t\,Yt-k} + u_t,\ \ t = 1, \ldots, T$$

where $B_{i,t}$, i = 1, . . . , k, are n × n matrices of time varying coefficients, a random vector $u_t \in R^n$ contains heteroskedastic unobserved shocks with a covariance matrix Ω_t. The covariance matrix Ω_t is defined via a decomposition :

$$A_t \Omega_t A_t^T = \Sigma_t \Sigma_t^T$$

where A_t is a lower triangle matrix and $\Sigma_t = \text{diag}(\sigma_{1,t}, \ldots, \sigma_{n,t})$ is a diagonal matrix (Belomestny et al., 2020).

Total directional connectedness TO others measures how much a shock in a variable (e.g variable i) transmitted to other variable (e.g variable j):

$$TO_{it}(H) = \sum_{i=1, i\neq j}^{N} \widetilde{C_{\jmath\imath t}}\,(H)$$

Total directional connectedness FROM others measures how much a variable (e.g variable i) receives a shock from other variable (e.g variable j) (Diebold & Yilmaz, 2012; Yousaf et al., 2023):

$$FROM_{it}(H) = \sum_{j=1, i\neq j}^{N} \widetilde{C_{\imath\jmath t}}\,(H)$$

Wavelet Coherence Analysis

This method analyse the coherence between two time-series. Before presenting the wavelet coherence, the continuous wavelet shall be transformed into single time series. The projection of particular wavelet ψ(●)ϵL^2(R) on time-series x_t ϵL^2(R) can be expressed as the following transformation of continuous wavelet:

$$W_x(u,s) = \int_{-\infty}^{\infty} x(t) \frac{1}{\sqrt{s}} \overline{\psi\left(\frac{t-u}{s}\right) dt}$$

From this equation, u denotes the position in exact point of the wavelet and s denotes a scale parameter. When a continuous wavelet transform is applied to the time series xt, a matrix of wavelet coefficients is produced with u = 1,…, N rows and s = 1,…, J columns, where u and s represent scale (frequency) and time position, respectively. Each coefficient, $Wx(u,s)$, denotes the local energy (i.e., variance) at a specific position s and scale u. Subsequently, the time series xt can be reconstructed using these wavelet coefficients:

$$x(t) = \frac{1}{C_\psi} \int_0^{\infty} \left[\int_{-\infty}^{\infty} W_x(u,s) \psi_{u,s}(t) du \right] \frac{ds}{s^2}, s > 0$$

The reconstruction of the time series xt is facilitated through the inverse of the continuous wavelet transform, which integrates over all scales the product of the wavelet coefficients $Wx(u,s)$ and the complex conjugate of the wavelet function $\psi u,s$, normalized by the scale parameter ss, and adjusted by the constant $C\psi$, where $C\psi$ is determined by the admissibility condition that ensures the wavelet function has zero mean in the frequency domain.

Torrence and Compo (1998) describe the cross wavelet transform of two time series, xt and yt, as the product of the wavelet transform of one with the complex conjugate of the other. This results in $Wxy(u,s)$=$Wx(u,s)Wy*(u,s)$, representing local covariance at scale u.

$$W_{xy}(u,s) = W_x(u,s)\overline{W_y(u,s)}$$

Additionally, the squared wavelet coherence coefficients, $R^2(u,s)$, which quantify the correlation between the two series at each scale, are computed as the squared magnitude of the cross wavelet spectrum normalized by the product of the individual wavelet power spectra. The coherence values range between 0 and 1, indicating the strength of the local correlation, with 1 indicating high correlation and 0 indicating no correlation. The degree of coherence is visualized in the wavelet coherence plot, with warmer colors denoting higher values.

$$R^2(u,s) = \frac{\left| S\left(s^{-1} W_{xy}(u,s)\right) \right|^2}{S(s^{-1}|W_x(u,s)|^2)\, S\left(s^{-1}\left|W_y(u,s)\right|^2\right)}$$

However, the wavelet coherence coefficients do not provide the directionality of the relationship. To discern this, the phase difference is obtained through the wavelet coherence phase, which identifies the relative timing between the oscillations of the series, offering insight into lead-lag relationships between them.

$$\varphi_{xy}(u,s) = \tan^{-1}\left(\frac{I\left\{S\left(s^{-1}W_{xy}(u,s)\right)\right\}}{r\left\{S\left(s^{-1}W_{xy}(u,s)\right)\right\}}\right)$$

From that equation, I and r denote the imaginary and real part operators, respectively. The term $\varphi_{xy}(u,s)$ refers to phase differences, which are visualized with arrow direction in the wavelet coherence plot. The data processing used R Studio software with Connectedness Approach package and Biwavelet package (Cunado et al., 2024).

RESULT AND DISCUSSION

As precedence to the data processing through TVP-VAR and Wavelet Coherence Analysis, we begin with identifying the Descriptive Statistics of dataset, after removing the outlier using interquartile method by smoothing the x< Q1 and x > Q3, and using the difference to improve the stationarity of the data.

Table 2. Descriptive Statistics of Green Bond's Yield from Each Country

No.	Country	Mean	Median	Mode	Standard Deviation	Skewness	Kurtosis	Jarque-Bera Test
1	Argentina	1.64	0.79	0.79	1.33	1.16	-0.40	389.39
2	Australia	1.08	0.28	0.79	1.45	1.31	0.16	518.89
3	Austria	0.86	0.42	0.02	1.15	1.76	1.66	1534.56
4	Belgium	0.63	0.16	0.00	1.09	1.79	1.55	1609.76
5	Bermuda	1.88	1.64	0.79	1.23	0.76	-0.59	98.25
6	Brazil	1.23	1.30	0.79	0.74	0.35	0.01	47.24
7	Canada	0.91	0.37	0.79	1.37	1.64	1.19	1241.90
8	Cayman Islands	0.85	0.33	0.79	1.12	2.19	3.89	2841.60
9	Chile	1.46	1.02	0.79	1.45	1.13	-0.13	382.89
10	China	0.72	0.26	0.00	0.90	1.28	0.24	521.33
11	Colombia	0.71	0.69	0.79	0.28	1.17	1.17	99.84
12	Croatia	4.06	4.11	4.06	0.20	-0.98	0.50	5.69
13	Cyprus	1.22	0.79	0.79	0.76	1.78	2.66	664.02
14	Czech Republic	2.10	1.61	0.79	1.52	0.12	-1.56	73.51
15	Denmark	0.84	0.10	0.07	1.34	1.47	0.51	658.20
16	Egypt	1.64	0.79	0.79	1.43	1.10	-0.71	200.01
17	Finland	0.76	0.08	0.01	1.26	1.49	0.61	780.15
18	France	0.76	0.35	0.79	1.11	1.86	2.06	1942.71
19	Georgia	1.59	0.79	0.79	1.37	1.15	-0.62	166.89
20	Germany	0.60	0.02	0.00	1.21	1.87	1.91	1838.33
21	Greece	1.40	0.79	0.79	1.14	1.79	2.01	788.23
22	Honduras	0.08	0.05	0.01	0.07	0.85	-0.83	240.08
23	Hong Kong	1.13	0.68	0.79	1.35	1.29	0.26	341.25
24	Hungary	0.45	0.09	0.79	0.83	3.24	11.00	15369.17
25	Iceland	0.57	0.57	0.68	0.14	-0.98	1.31	418.06
26	India	1.00	0.79	0.79	1.02	1.63	2.14	1020.02
27	Indonesia	1.39	0.22	0.79	1.70	0.76	-1.23	202.13
28	Ireland	0.68	0.07	0.00	1.21	1.81	1.89	1750.49
29	Italy	0.78	0.31	0.79	1.12	2.32	4.11	3107.94

No.	Country	Mean	Median	Mode	Standard Deviation	Skewness	Kurtosis	Jarque-Bera Test
30	Ivory Coast	0.00	0.00	0.00	0.00	0.16	-0.31	12.37
31	Japan	0.64	0.58	0.79	0.66	2.06	7.23	6993.77
32	Laos	0.06	0.05	0.14	0.05	0.79	-0.68	236.59
33	Latvia	0.17	0.18	0.24	0.05	-0.12	-1.32	128.68
34	Liechtenstein	0.01	0.01	0.00	0.01	0.62	-0.84	160.81
35	Lithuania	0.16	0.12	0.33	0.12	0.53	-1.13	159.82
36	Luxembourg	1.17	0.43	0.79	1.26	1.23	-0.12	431.06
37	Macao	0.03	0.03	0.04	0.00	0.03	1.45	138.14
38	Malaysia	1.57	0.79	0.79	1.15	1.09	-0.28	342.62
39	Malta	0.59	0.61	0.69	0.10	-1.14	0.73	136.81
40	Mauritius	2.23	0.98	0.79	1.63	0.36	-1.76	292.09
41	Mexico	0.10	0.07	0.01	0.09	1.07	-0.12	437.07
42	Netherlands	0.55	0.19	0.79	0.90	2.73	7.70	9504.85
43	New Zealand	0.49	0.21	0.79	0.73	3.79	16.30	34605.22
44	Nigeria	0.02	0.01	0.00	0.02	0.47	-1.52	155.19
45	Norway	1.43	0.79	0.79	1.23	1.36	0.71	761.98
46	Pakistan	0.02	0.03	0.05	0.01	0.20	-0.87	74.85
47	Panama	0.85	0.40	0.01	0.91	1.02	-0.56	317.79
48	Peru	1.34	1.74	0.00	0.81	-0.92	-0.94	170.64
49	Philippines	0.76	0.70	0.79	0.82	2.78	8.60	6947.92
50	Poland	1.72	1.37	0.79	1.16	1.09	0.00	174.80
51	Portugal	0.55	0.79	0.79	0.81	3.73	16.39	17121.16
52	Romania	0.34	0.36	0.11	0.28	0.55	-0.36	54.77
53	Russia	0.93	0.83	0.09	0.46	0.05	-1.34	55.08
54	Saudi Arabia	0.04	0.05	0.02	0.01	-0.80	-1.24	91.64
55	Serbia	0.76	0.84	0.03	0.26	-2.17	3.61	695.69
56	Singapore	0.65	0.30	0.79	0.80	3.18	10.62	14976.59
57	Slovakia	1.16	1.07	1.94	0.33	1.84	1.79	236.73
58	Slovenia	0.57	0.57	0.57	0.00	-0.24	-1.88	7.00
59	South Africa	0.62	0.16	0.00	0.96	1.70	0.99	733.92
60	South Korea	1.17	0.91	0.79	0.91	1.77	3.20	2327.24
61	Spain	0.75	0.07	0.03	1.21	1.44	0.47	741.80
62	Sweden	0.62	0.12	0.79	1.06	2.41	4.94	4707.66
63	Switzerland	0.59	0.20	0.02	0.69	1.06	-0.62	331.16
64	Taiwan	1.38	1.12	0.39	1.09	0.67	-0.87	123.70
65	Thailand	0.49	0.19	0.79	0.75	3.90	16.10	27068.37
66	Turkey	0.54	0.47	0.00	0.39	0.63	-0.94	51.89
67	Ukraine	0.37	0.48	0.20	0.15	-0.15	-1.88	28.47
68	United Arab Emirates	0.18	0.03	0.01	0.46	3.25	9.56	12910.78

No.	Country	Mean	Median	Mode	Standard Deviation	Skewness	Kurtosis	Jarque-Bera Test
69	United Kingdom	0.66	0.02	0.79	1.28	2.04	2.77	2597.11
70	United States	1.12	0.79	0.79	0.90	1.04	0.84	500.88
71	Venezuela	1.37	0.90	0.79	1.19	0.95	-0.07	118.91
72	Vietnam	0.27	0.31	0.09	0.08	-0.78	-0.83	87.20
73	Virgin Islands (British)	1.15	0.79	0.79	1.03	0.84	-0.21	95.21

The provided descriptive statistics table offers a succinct summary of the statistical properties of data for a range of countries. The measures of central tendency (mean, median, mode) alongside the disper-sion (standard deviation) indicate the general behavior of the data distribution. Skewness values inform about the asymmetry, with deviations from zero suggesting non-normal distributions. The kurtosis val-ues indicate the heaviness of tails and sharpness of the peak in the data distribution compared to a nor-mal distribution. Finally, the Jarque-Bera test provides a hypothesis test for normality of the distribution, with the test statistic indicating the degree of deviation from normality and the p-value suggesting the statistical significance of this deviation. Collectively, these statistics suggest varying degrees of disper-sion, symmetry, and conformity to normal distribution across different countries.

Spill-Over Analysis

Analysis of FROM Others, TO Others, and NET

As result from TVP-VAR modelling, presented in Table 3 (provided in Appendix), amongst 73 coun-tries, Japan acts as the highest receiver of spill-over (FROM Others) by scoring 99.76 index, followed by Iceland (99.68 index), Laos (99.67 index), Panama (99.64 index), and Latvia (99.62 index). Meanwhile Slovenia acts as the lowest receiver by scoring 97.97 index followed by Hong Kong (97.98 index), Austria (98 index), France (98.03 index), and USA (98.05 index). Japan receives the most spill-over from other coun-tries, in terms of green bonds' yield, due to highly developed financial market and its deep liquidity have made it an attractive destination for green bond investments. The Tokyo Stock Exchange, one of the larg-est in the world, provides a stable and efficient platform for trading green bonds, enhancing their appeal to both domestic and international investors. This liquidity ensures that green bonds can be easily traded, thereby facilitating the transmission of return spillover from global markets to Japan (Umar, Hadhri, Abakah, Usman, & Umar, 2024).

In the opposite, Austria acts as the highest transmitter of spill-over (TO Others) by scoring 132.15 in-dex, followed by Taiwan (129.66 index), New Zealand (129.01 index), South Korea (128.62 index), France (128.33 index). Meanwhile Latvia acts as the lowest transmitter of spill-over by scoring 28.4 index, fol-lowed by Iceland (30.14 index), Cayman Islands (31.92 index) Japan (31.93 index), Laos (32.87 index). Aus-tria delivers the most spill-over to other countries. Austria has consistently been at the forefront of green bond issuance, demonstrating strong market leadership. The country's commitment to environmental sustainability and its proactive issuance of green bonds have made it a pivotal player in the global mar-ket. Austrian green bonds are frequently oversubscribed, indicating high investor confidence and robust demand. This high demand ensures that returns from Austrian green bonds have significant influence on global markets. The strong performance of these bonds creates spillover effects, impacting returns in oth-er countries' green bond markets (Bachelet, Manfredonia, & Becchetti, 2019).

As a result from the difference between TO Others minus FROM Others, the parameter Net Direc-tional Connectedness is obtained. Move forward to the Net Directional Connectedness (NET), Austria acts as the highest Net Transmitter by scoring 34.15 index, followed by Taiwan (31.54 index), New Zea-land (30.84 index), South Korea (30.41 index), France (30.3 index). Meanwhile Latvia acts as the lowest Net Receiver by scoring -71.23 index, followed by Iceland (-69.55 index), Japan (-67.83 index), Cayman Islands (-67.36 index), Laos (-66.8 index).

Analysis of Influence

The spillover effect generates mutual influence among countries, implying that each country im-pacts others concerning the spillover phenomena observed from 2014 to 2024. When two countries exhibit mutual influence, an increase in green bond returns (through yield) in one country will affect the green bond returns in the other country via the spillover mechanism. Similarly, a decrease in returns will also transfer its impact to another country through this spillover process. Consequently, the results of this research provide a ranked list of countries based on their influence in the spillover effect, from the least to the most influential, as presented in Table 4.

Table 4. The Influence of Green Bonds Return Spill-Over between Countries

No.	Country	Influence Index
1	Thailand - Cayman Islands	0.16
2	Thailand - Russia	0.16
3	Thailand - Panama	0.17
4	Russia - Greece	0.19
5	Russia - Peru	0.2
6	Russia - Egypt	0.2
7	Cayman Islands - Egypt	0.21
8	Laos - Macao	0.21
9	Latvia - Macao	0.21
10	Japan - Cayman Islands	0.22
11	Japan - Honduras	0.22
12	Laos - Ivory Coast	0.22
13	Cayman Islands - Macao	0.22
14	Japan - Norway	0.22
15	Cayman Islands - Peru	0.22
16	Russia - Taiwan	0.22
17	Cayman Islands - Argentina	0.23
18	Cayman Islands - Greece	0.23
19	Panama - Greece	0.23
20	Laos - Lithuania	0.23
21	Japan - Pakistan	0.23
22	Iceland - Philippines	0.23
23	Laos - Philippines	0.23
24	Russia - Argentina	0.24
25	Panama - Ivory Coast	0.24
26	Laos - Japan	0.24
27	Laos - Malaysia	0.24
28	Japan - Panama	0.24
29	Latvia - Philippines	0.24
30	Russia - Portugal	0.24

The list of 30 pairs countries with the least influence in return spill-over, are the recommendation to buy green bonds from those listed countries, when investor would like to develop a portfolio of green bonds investment. This least influence means lower risk if a return on a specific country is dropping, then it would radiate less spill-over phenomena to green bonds from other country, if the influence index is tiny. Therefore, it helps investor to maximize the profit, mitigating risk, and optimize the portfolio.

Green Bonds' Return Spill-Over Phenomena after Aggregation to Economic Classification

As result from Aggregated Connectedness in TVP-VAR modelling, presented in Table 5, all countries are put into classification: DM, EM, FM, LDM. In this classification, LDM plays role as the highest receiv-er of spill-over (FROM Others) by scoring 96.38 index. Meanwhile DM scores as the lowest receiver by scoring 60.92 index. This means the return spill-over of green bonds issued by LDM are relatively ease to be influenced/affected through spill-over effect from other economic classification. On the other hand, DM tend to be less affected from other economic classification. EM and FM act in similar index value in FROM Others and TO Others, which mean both EM and FM affected and give influence in nearly identi-cal contagion.

Table 5. Spillover between Economic Classification

	Frontier Markets	Emerging Markets	Developed Markets	Least Developed Markets	FROM Others
Frontier Markets	31.38	27.47	38.06	3.09	68.62
Emerging Markets	30.33	28.46	38.24	2.97	71.54
Developed Markets	29.06	29.04	39.08	2.81	60.92
Least Developed Markets	31.32	27.46	37.61	3.62	96.38
TO Others	90.71	83.97	113.91	8.87	297.46
Inc.Own	122.09	112.43	152.99	12.49	cTCI/TCI
NET	22.09	12.43	52.99	-87.51	99.15/74.37
NPT	2	1	3	0	

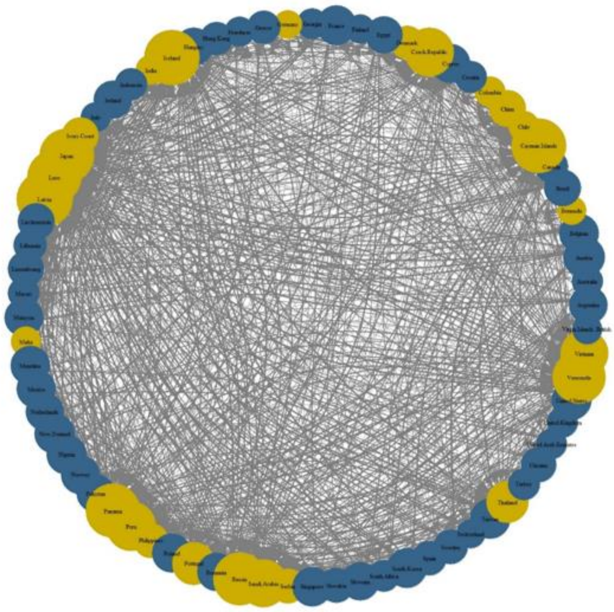

Figure 1. Network Plot of Return Spill-Over from Green Bonds' Countries Issuer Around the World

Relation of Global EPU to Spill-Over through Wavelet Coherence

After data aggregation through Aggregated Connectedness package, the spill-over from each economic classification is compared with the Global EPU index with wavelet coherence method. The wavelet coherence plots are presented on Figure 2 until Figure 4.

Spill-Over from Developed Markets to Emerging Markets

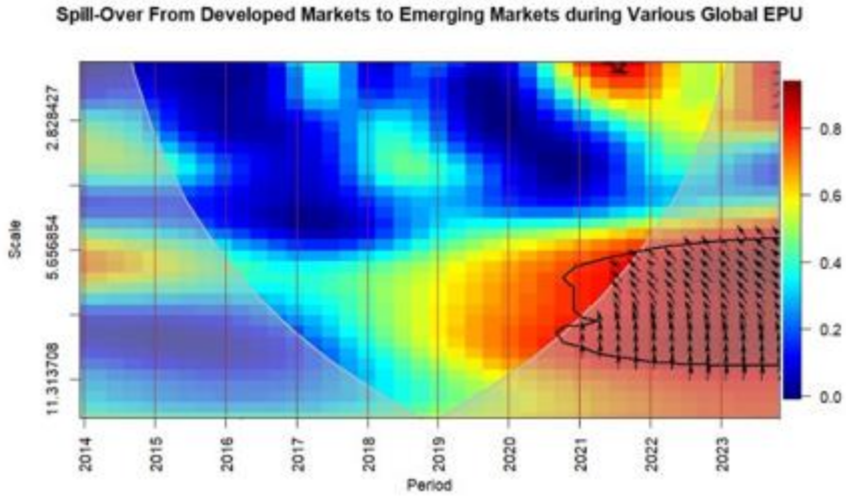

Figure 2. Wavelet Coherence Plot of Green Bonds' Return Spill-Over from Developed Markets to Emerging Markets during Various Global Economic Policy Uncertainty

In this wavelet coherence graph (Figure 2), the areas marked in red and yellow at higher time and fre-quency scales indicate high coherence levels, suggesting a strong correlation (with an R2 correlation range of 0.6 – 0.8 as depicted on the right side of the graph) between the two time series. This indicates that during the period from 2019 to 2024, the dynamics of green bond return spill-over from Developed Markets to Emerging Markets were significantly influenced by Global Economic Policy Uncertainty (GEPU). Investments during this period show that the impact of GEPU on return spill-over was more significant compared to previous periods.

The arrows visible in the graph, especially from 2021 to 2024, point upwards. This direction indi-cates that GEPU and return spill-over from Developed Markets to Emerging Markets are positively corre-lated. If the GEPU index increases, then the return spill-over from Developed Markets to Emerging Mar-kets also increases. This condition suggests that when global economic policy uncertainty rises, the re-turns or yields of green bonds issued by Developed Markets will impact and in-crease the returns or yields of green bonds from Emerging Markets. Conversely, with this positive correlation, if the GEPU index decreases, then the return spill-over from Developed Markets to Emerging Markets also decreases. This implies that when global economic policy uncertainty declines, the returns or yields of green bonds issued by Emerging Markets are less likely to be influenced by the movements of green bond returns or yields from Developed Markets.

High coherence is concentrated at the frequency scale of 5.65 – 11.31. This frequency scale is ob-tained from the wavelet coherence calculations for the sample GEPU index and the return spill-over in-dex used. The high-frequency scale indi-cates that the coherence of the GEPU index and the return spill-over index variables occurs over a long period and may extend beyond 2024, demonstrating a sustained and significant impact of economic policy uncertainty on the dynamics of return spill-over from Devel-oped Markets to Emerging Markets. This aligns with the fact that Emerging Markets still rely heavily on capital flows from Developed Markets and how Emerging Markets are easily affected by global economic conditions.

Spill-Over from Developed Markets to Frontier Markets

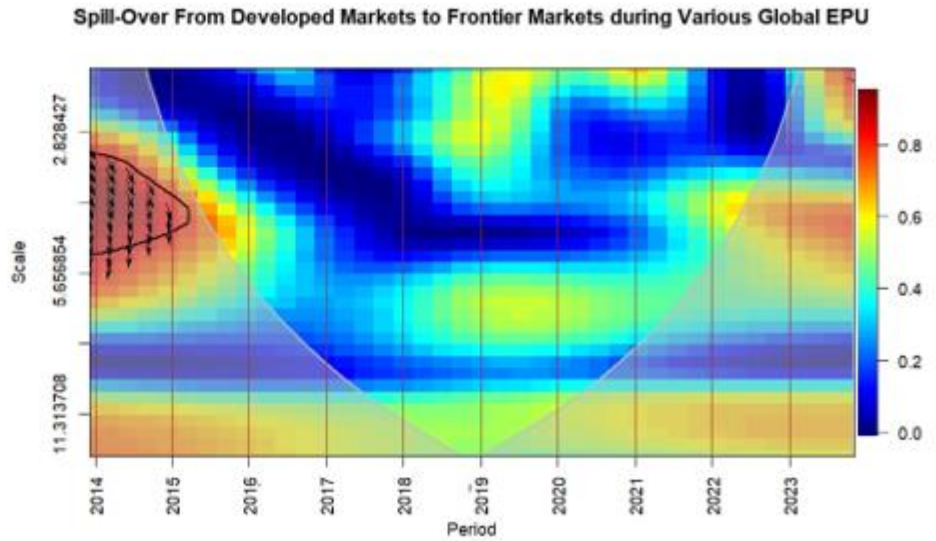

Figure 3. Wavelet Coherence Plot of Green Bonds' Return Spill-Over from Developed Markets to Frontier Markets during Various Global Eco-nomic Policy Uncertainty

In this wavelet coherence graph (Figure 3), the areas marked in red and yellow at higher time and frequency scales indicate high coherence levels, suggesting a strong correlation (with an R2 correlation range of 0.6 – 0.8 as depicted on the right side of the graph) between the two time series. This indicates that during the period from 2014 to 2016, the dynamics of green bond return spill-over from Developed Markets to Frontier Markets were significantly influenced by Global Economic Pol-icy Uncertainty (GEPU). Investments during this period show that the impact of GEPU on return spill-over was more significant compared to the subsequent period.

The arrows visible in the graph, especially from 2014 to 2015, point down-wards. This direction indicates that GEPU and return spill-over from Developed Markets to Frontier Markets are negatively correlated. If the GEPU index increases, then the return spill-over from Developed Markets to Frontier Markets decreases. This condition suggests that when global economic policy uncertainty rises, the re-turns or yields of green bonds issued by Developed Markets will impact and de-crease the returns or yields of green bonds from Frontier Markets. Conversely, with this negative correlation, if the GEPU in-dex decreases, then the return spill-over from Developed Markets to Frontier Markets increases. This implies that when global economic policy uncertainty declines, the returns or yields of green bonds is-sued by Frontier Markets are more likely to be influenced by the movements of green bond returns or yields from Developed Markets. This can occur because when economic policy uncertainty decreases, Developed Markets tend to invest more or transfer funds to Frontier Markets, such as by purchasing green bonds from Frontier Markets.

High coherence is concentrated at the frequency scale of 2.82 – 5.65. This frequency scale is obtained from the wavelet coherence calculations for the sample GEPU index and the return spill-over index used. The low-frequency scale indicates that the coherence of the GEPU index and the return spill-over index variables occurs over a short period, demonstrating a temporary and less significant impact of economic policy uncertainty on the dynamics of return spill-over from Developed Markets to Frontier Markets. This may be due to Frontier Markets being relatively new and less developed, with globalization not as extensive as in Emerging Markets, making them less influenced by global economic conditions over the long term.

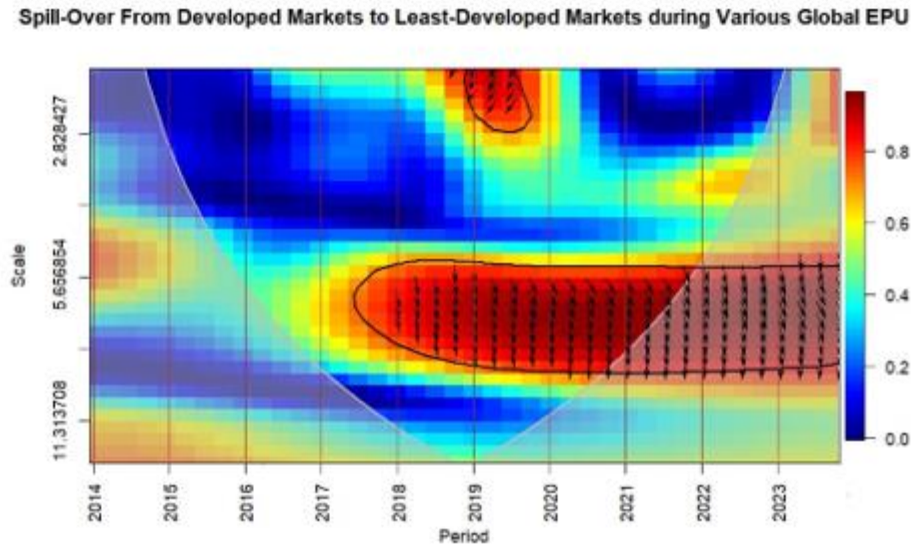

Figure 4. Wavelet Coherence Plot of Green Bonds' Return Spill-Over from Developed Markets to Least-Developed Markets during Various Global Economic Policy Uncertainty

In the wavelet coherence graph, regions marked in red and yellow on the larger time and fre-quency scales indicate high coherence levels, suggesting a strong correlation (with an R^2 correlation scale ranging from 0.6 to 0.8 as depicted on the right side of the graph) between the two time series. This demonstrates that from 2017 to 2024, the return spill-over dynamics of green bonds from Developed Markets to Least Developed Markets were significantly influenced by GEPU. Investments during this period show that the impact of GEPU on return spill-over is more pronounced compared to subsequent periods.

The arrows visible in the graph, especially from 2018 to 2015, point downward. This direction in-dicates a negative correlation between GEPU and the return spill-over from Developed Markets to Least Developed Markets. When the GEPU index rises, the return spill-over from Developed Markets to Least Developed Markets decreases. This condition suggests that when global economic policy uncertainty increases, the returns or yields of green bonds issued by Developed Markets negatively impact the re-turns or yields of green bonds from Least Developed Markets (Nguyen et al., 2020). Conversely, with this negative correlation, if the GEPU index declines, the return spill-over from Developed Markets to Least Developed Markets increases. This can be interpreted as a decrease in global economic policy uncertainty making the returns or yields of green bonds issued by Least Developed Markets more susceptible to the movement of green bond returns or yields from Developed Markets. This occurs because, with reduced economic policy un-certainty, Developed Markets tend to invest more or transfer funds to Least Developed Markets, such as by purchasing green bonds from these markets.

The high coherence is concentrated in the frequency range of 5.65 – 9.45. This frequency scale is de-rived from the wavelet coherence calculations for the GEPU index and the return spill-over index used. The high frequency scale indicates that the coherence between the GEPU index and the return spill-over index persists over a long period, demonstrating a significant and sustained impact of EPU on the return spill-over dynamics from Developed Markets to Least Developed Markets. This could be because Least Developed Markets often have less stable political and economic conditions, making it challenging for them to maintain stability when the global economy experiences shocks.

CONCLUSION

This study investigates the return spill-over of green bonds among different economic classifications of countries during periods of global economic policy uncertainty (GEPU) using the Time-Varying Pa-rameter Vector Auto-Regression (TVP-VAR) and Wavelet Coherence Analysis (WCA). The findings indi-cate that green bonds issued by Developed Markets (DM) exert a significant spill-over effect on those issued by Emerging Markets (EM), while the impact on Frontier Markets (FM) and Least Developed Mar-kets (LDM) is less pronounced. The coherence between return spill-over and GEPU is especially strong between Developed and Emerging Markets, suggesting a positive correlation where higher GEPU leads to increased spill-over effects. This relationship underscores the interconnectedness of global financial markets and the influence of economic policy uncertainty on green bond returns.

The study's results have several important implications for investors and policymakers. For inves-tors, understanding the spill-over dynamics and the impact of GEPU can inform portfolio diversification strategies, particularly in selecting green bonds from countries with different economic classifications. The significant spill-over from Developed to Emerging Markets suggests that investors should consider the stability of Developed Market green bonds as a buffer against uncertainty in Emerging Markets. For policymakers, the findings highlight the need for coordinated international financial regulations and pol-icies to manage the volatility and interconnectedness of green bond markets. Enhancing the stability and predictability of economic policies can mitigate the adverse effects of spill-over during periods of high uncertainty.

Future research should expand the scope by including more granular data on green bond issuances and incorporating other factors such as political stability, environmental regulations, and market maturi-ty. Additionally, exploring the role of technological advancements and innovations in green finance could provide deeper insights into the evolving dynamics of green bond markets. Investors are advised to con-tinuously monitor global economic policy developments and adjust their portfolios to manage risk and optimize returns effectively. Policymakers should consider developing frameworks that promote trans-parency and stability in green bond markets to attract sustainable investments.

This study is limited by the data range from January 2014 to February 2024, which may not capture longer-term trends and dynamics in green bond markets. The classification of countries based on eco-nomic categories may also overlook the unique characteristics and developments within individual coun-tries. Future studies should consider integrating additional methodological approaches and longer data periods to validate and extend the findings.

REFERENCES

Antonakakis, N., Chatziantoniou, I., & Gabauer, D. (2020). Refined measures of dynamic connectedness based on time-varying parameter vector autoregressions. *Journal of Risk and Financial Management*, *13*(4), 84.

Belomestny, D., Krymova, E., & Polbin, A. (2020). Estimating TVP-VAR models with time invariant long-run multipliers. *ArXiv Preprint ArXiv:2008.00718*.

Cunado, J., Gabauer, D., Gupta, R., & Lee, C.-C. (2024). On the propagation mechanism of international real interest rate spillovers: evidence from more than 200 years of data. *Applied Economics*, 1–15.

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.

Elsayed, A. H., Naifar, N., Nasreen, S., & Tiwari, A. K. (2022). Dependence structure and dynamic connectedness between green bonds and financial markets: Fresh insights from time-frequency analysis before and during COVID-19 pandemic. *Energy Economics*, *107*, 105842.

Ferrer, R., Shahzad, S. J. H., & Soriano, P. (2021). Are green bonds a different asset class? Evidence from time-frequency connectedness analysis. *Journal of Cleaner Production*, *292*, 125988.

Han, Y., Li, P., & Wu, S. (2022). Does green bond improve portfolio diversification? Evidence from China. *Evidence From China (January 9, 2022)*.

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.

Nguyen, C. P., Le, T.-H., & Su, T. D. (2020). Economic policy uncertainty and credit growth: Evidence from a global sample. *Research in International Business and Finance*, *51*, 101118.

Pham, L., & Nguyen, C. P. (2022). How do stock, oil, and economic policy uncertainty influence the green bond market? *Finance Research Letters*, *45*, 102128.

Rehman, M. U., Zeitun, R., Vo, X. V., Ahmad, N., & Al-Faryan, M. A. S. (2023).

Green bonds’ connectedness with hedging and conditional diversification performance. *Journal of International Financial Markets, Institutions and Money*, *86*, 101802.

Ren, X., Li, Y., Wen, F., & Lu, Z. (2022). The interrelationship between the carbon market and the green bonds market: Evidence from wavelet quantile-on-quantile method. *Technological Forecasting and Social Change*, *179*, 121611.

Rukundo, F. (2024). *Sustainable Finance*.

Syed, A. A., Ahmed, F., Kamal, M. A., Ullah, A., & Ramos-Requena, J. P. (2022). Is there an asymmetric relationship between economic policy uncertainty, cryptocurrencies, and global green bonds? Evidence from the United States of America. *Mathematics*, *10*(5), 720.

Yousaf, I., Riaz, Y., & Goodell, J. W. (2023). Integration between asset management tokens, asset management stock, and other financial markets: Evidence from TVP-VAR modeling. *Finance Research Letters*, *57*, 104276.