Determining the recipients and transmitters of asymmetric volatility spillover for green bond indices & agricultural commodity markets: Evidence from TVP-VAR method

[1]Wajid Shakeel Ahmed, [2]Aneeza Ismail, [3]Malik Jawad Saboor, [4]Adil Tahir Paracha, [5]Ijaz Gul

[1] Associate Professor, Department of Management Sciences, COMSATS University, Islamabad, Pakistan, wajid_shakeel@comsats.edu.pk.
[2] PhD scholar, Department of Management Sciences, COMSATS University, Islamabad, Pakistan, aneezakhan2010@hotmail.com
[3] Assistant Professor, Department of Management Sciences, COMSATS University, Islamabad, Pakistan, jawad_saboor@comsats.edu.pk
[4] Assistant Professor, Department of Management Sciences, COMSATS University, Islamabad, Pakistan, adil_paracha@comsats.edu.pk.
[5]Manager ORIC, Department of ORIC, COMSATS University, Islamabad, Pakistan, ijaz.gul@comsats.edu.pk.

ABSTRACT

The primary aim of this research study is to determine recipients and transmitter of asymmetric volatility spillover for green bonds global/regional indices and agricultural commodity markets. The study uses daily data in order to study the asymmetry and volatility spillovers in agriculture commodity market and green bonds market by incorporating TVP-VAR approach. Our conclusions indicate that the highest transmission and reception of spillovers arises between sunflower oil, coconut oil, wheat, and corn respectively. This study adds to the growing body knowledge pertaining to green bonds by investigating the asymmetric spillover impact among green bonds and agricultural commodities that are progressively financialized. For policymakers the spillover volatility effect received by agricultural commodities from the green bonds market indicates mainly because of their effect on price inflation. Finally, for investors it will be beneficial to know which agricultural commodities carry higher and lower risks and this will aid them in accurately assessing financial resources allocation and investment strategy.

Keywords: *Asymmetric volatility spillover; dynamic connectedness; green bond indices; agricultural commodities; TVP-VAR*

INTRODUCTION

In turbulent and unstable markets, there is a rapid change in the investment policies and the idea of corporate environmental responsibility (CER), and sustainable growth emerge out. There is a growing trend of investing seen in social, environmental and governance factors. CER is an crucial role in sustainability of firms and, is also a subset of CSR (Kim et al., 2017). Indeed, it is important for governmental institutions and environmental scientists to attain a low-carbon or climate-resilient economy. Moreover, green bonds are debt securities which are aimed at raising funds in order to invest in sustainability projects and climate change mitigation. As stated by Ferrer et al. (2021), the first time a green bond was introduced was in 2007 as climate awareness bond.

Since then, numerous green bonds have been issued, making up the total volume approximately USD 800 billion between 2008 and 2019. In January 2014, to enhance the integrity and transparency regarding green bonds, the International Capital Markets Association (ICMA) released Green Bond Principles (GBP).

According to Gianfrate and Peri (2019) , it is suggested that the green bonds are fixed-income securities which are launched by financial organizations responsible for the green project's developments. It is quite noteworthy here that their aim is to aid with the sustainable development of society and also address the development of a national ecological civilization. Many corporations are contributing immensely in environmental degradation by releasing toxic chemical emissions. Griffin and Heede (2017) demonstrated the facts that according to carbon majors report, since 1988, just 100 corporations are the major source of approximately 70% of emission of greenhouse gases (GHG) on earth.

Another research by Agrawal et. al., (2024) suggests a novel approach by introducing framework based on Green Finance and innovation that provides sustainable strategies that bridge financial imperatives with environmental innovation. Furthermore, it provides valuable insight for businesses to unlock new venues through practicing green financing techniques while contributing to broader societal and environmental benefits.

Green bonds help in raising capital and to finance green technologies and low-carbon projects. Keeping in view of the imperfection of markets and information, it is insufficient for investors to judge an organization's commitment towards the environment. To establish the link and interconnectedness among different markets, JIANG and ZHANG (2017) proclaimed that the global climate deterioration is endangering the everyday lives of all humanity and for the usage of green finance is paramount to protect the environment.

As far as commodity markets are concerned the volume of trade can vary significantly depending on the specific commodity, the region, and the year. For instance – global wheat exports are estimated around 200-210 million metric tons per year, corns (maize) are around 180-200 million metric tons with largest exporters are USA, Brazil, Argentina and Ukraine. Rice is another important commodity with exports around 45-50 million metric tons and the major exporters are India, Pakistan, Thailand, Vietnam and USA, Coffee and cotton global exports are roughly around 10 and 9 million metric tons respectively. The demand for agricultural commodities is rising globally, fueled by population growth, particularly in Asia and Africa. Sustainability concerns are also shaping trade, with more emphasis on organic and eco-friendly products.

This study uses research analysis by utilizing a directional spillover index by using TVP-VAR on the data of daily frequency price covering the period from 12/31/2010, to 12/31/2020. The research questions that we have directed are subsequent.: Among which commodities in agriculture show the largest transmission and reception of spillover effects? Which agriculture commodities experienced the largest spillovers by global and regional green bonds markets?

Which agricultural commodities are the largest (smallest) risk contribution to total portfolio risk? Which agricultural commodities are viewed as the most lucrative investment options?

First, we model the volatility transmission between green bond and agricultural commodities indices, which represent the green bonds market. The factors influencing agricultural commodity prices are defined by the balance of demand and supply in the commodity markets. In retrospective way, our findings led to the evidence that an asymmetric relationship exists between agricultural commodities and green bonds. The study also shed light on the asymmetric information spillover dynamic relationship between ten Agricultural Products (Cocoa, soybean oil, cotton, sugar cane, wheat, sugar beets, corn, lumber, coffee, soybeans) and green bonds through following propositions.

P1: Between which agricultural commodities do the largest reception (transmission) of spillover and thus contribute largest (smallest) portfolio risk.

P2: Between which greens bonds indices and agricultural commodities experience the dynamic asymmetric spillover connectedness and thus most desirable for the investment opportunities.

In this study we proposed that the volatility spillovers demonstrate varying degrees to which agricultural commodities may transmit positive or negative shocks returns. Our motivation for inculcating the global green bond indices in the spillover evaluation is to explore how and to what extent of influence do changes in the green bonds market have on agricultural commodity prices This is a crucial aspect regarding our Study, as primary Agricultural commodities currently examined are manufactured, purchased and traded at various tiers worldwide, thus affecting the green bond market in a totally different way. Based on this argumentative dimension, agricultural commodity markets from various regions globally show a greater (less robust) Impacting economy and financial markets. Our prospect is the fluctuations in green bonds market indices exert a fluctuating influence on the international agricultural prices of commodities and vice versa.

This study contributes in relation to examine the dynamic asymmetric spillover effect among global, regional greens bonds and agricultural commodities is worth mentioning. First, no other research has examined regional and global green bonds markets and their influence on agricultural commodity markets in this context. Our reason for choosing these agricultural commodities is because they include majorly globally traded commodities, which present an accurate depiction of the agricultural commodity market.

Second, we address asymmetric connectedness by separating the return series into gains and losses of each asset. Predominantly, the comprehensive findings on asymmetric spillovers suggest that the positive spillover occur within a short timeframe, whereas negative spillover maintains substantially across both time frames and the risk involved in other commodity markets the green bonds market act as succor. A key development in this research is that we calculated directional spillover indices for apparently unrelated green bonds and agricultural commodity markets.

Third, the dynamic connectedness is measured by the spillover framework initially proposed by Diebold and Yilmaz (2012) with TVP-VAR technique. Explicitly, Antonakakis and Gabauer (2017) declared that TVP-VAR is superior in measuring connectedness estimates, using exchange rate market as a point of evidence. This notion has been rooted by research done by Naeem et al. (2021) creating asymmetric spillover dynamics between commodities and green bonds.

Fourth, it allows for presenting new evidence with regards to regional and global green bonds indices and their dynamic pairwise connectedness with agricultural commodities prices. For the policymakers, green bonds resilience to shocks in in different financial assets across various forecast horizon is utmost important because of the significant interest in building a robust financial system which can improve the sustainable projects required for decarbonization of global economy as well as the efficacy of government climate related policies via funding (Ferrer et al., 2021).

The following sections of the study are structured as detailed below: Section 2 examines the literature. followed by Section 3 methodology; Section 4 contains preliminary data analysis followed by the results and interpretations, which is section 5. Lastly, Section 6 examines the implication and conclusion of the study.

LITERATURE REVIEW

There is a potential contagion effect which is found between agricultural commodities and oil because of higher spillover transmissions during crisis period and this might result in substantial losses to agricultural commodity producers, investors, and merchants. Nazlioglu et al. (2013) analyze the volatility transmission among agricultural commodity and oil prices (sugar, soybeans, wheat, and corn) by incorporating a recently formulated causality in Variance Lagrange Multiplier (CV-LM). The findings suggested that no causality-in-variance is found from oil to agricultural commodities during pre-food crisis timeframe (2006-2008) but there is presence of bidirectional and unidirectional causality-in-variance between few of agricultural commodities and oil. Du et al. (2011) studied the association among agricultural markets and prices of crude oil along with potential transmission of volatility during the period from Nov-1998 to Jan-2009.

The association of green bonds with commodities is comparatively new and there are limited research which examined connection between commodities and green bonds. Hammoudeh et al. (2020) established the connection among green bonds, and the environment and other financial assets, Typically, the financial assets comprise US-conventional bonds and Wilder Hill clean energy (equity) index, whereas CO_2 pollutants depict the Ecosystem. Data is analyzed through time- varying Granger causality test which suggests that Substantial causal links originating from USA ten years to green bonds from treasury bond index. However, there is substantial effect of CO_2 pollutant allowances to green bonds and low effect to green bonds from clean energy index.

Lyon and Montgomery (2015) proposed that in order to mitigate the information asymmetry problem, the signaling theory came into effect, in which information senders take costly actions to signal to the information receivers about the underlying intentions. If the signaling theory is applied in the green finance field, it is observed that when companies issue green bonds, it automatically sends signal in the market about their commitment and intentions in improving the carbon footprint (Ferrer et al., 2021, Lyon and Maxwell, 2008, Lyon and Montgomery, 2015). The financialization of agricultural commodity markets and the growing curiosity in the production of bioenergy has encouraged major financial institutions to invest in them, so they can enhance liquidity and speculative opportunities. The characteristics of agricultural commodities are relatively distinct from alternative commodities and there has never been a time like now when there is intense interest in agricultural commodities as financial assets.

According to Zapata et al. (2012) agricultural commodities are characterized as defensive investments i.e., less volatile during financial turmoil which is turning them into lucrative for constructing equity portfolios and hedging against market downturns. Investors consider commodity markets as alternate investment options which help in the diversification of the portfolios Due to the positive risk premium and Minimal correlations In relation to different asset classes (Gorton and Rouwenhorst, 2006). Studies related to portfolio risk and volatility spillovers transmission is a major issue of producers of agricultural commodities and investors of green bond markets because new findings can be detrimental for forecasting the green bonds and agricultural commodity prices as well as optimal hedging across the markets.

The study by Creti et al. (2013) suggest that the policymakers are interested in fluctuations (volatility) in commodity prices and the spillover they acquire from alternative markets due to their capability to cause price inflation. Kanamura (2020) focused on association between energy commodities and green bonds which resulted in different results when the green bond indices were considered. This research reveals that there is an affirmative Association involving Bloomberg Barclays MSCI In relation to crude oil and S&P prices of green bond, whereas an inverse relationship exists among selective green bonds and crude oil respectively.

Another 2023 study by khamis et. al., (2023) examined the dynamic correlations between economic policy uncertainty, commodities and green bonds. It found that green bonds tend to mitigate shocks transmitted by commodities like oil during uncertain economic periods, acting as a hedge in portfolios exposed to commodity price risks.

Moreover, previous research studies focus on the interaction among energy commodities and green bonds (Naeem et al., 2020, Reboredo, 2018, Reboredo and Ugolini, 2020, Reboredo et al., 2021). Tiwari et al. (2020) analyzed the co-movement between energy markets and agricultural commodities considering the impact of geopolitical risks (GPRs) by using a copula-based technique.

Evidence indicates that the agricultural commodities, especially oats, corn and we can hedge wheat associated oil returns which result from geopolitical unrest. Additionally, agricultural commodities like oats, corn, and wheat have demonstrated a capacity to hedge against oil market volatility. These commodities, while affected by geopolitical unrest, often move independently of energy markets, providing investors with a diversified risk management strategy (Micallef, et. al., (2023).

Another study by Jain, K., Gangopadhyay, M., & Mukhopadhyay, K. (2024) emphasizes that the development of deeper capital markets, similar to those in developed countries, would enhance the ability to attract both domestic and international investors, while supporting global efforts to address climate change.

With the continuous expansion of the green bond market, the research focus is now tilted towards the integrity of the 'green' label. Scant empirical evidence is present regarding the volatility spillover dynamics of green bonds and commodity markets. Therefore, this research strives to fill the research gap in pertinent literature initially via analyzing spillovers among global, regional green bonds and agricultural commodities and subsequently via examining risk transmission and allocation of resources traits of a portfolio consisting of agricultural commodities.

METHODOLOGY

This section outlines the theoretical framework. underneath the specific hypothesis and methodology which is employed to estimate the asymmetric spillover effect in green bonds and agricultural commodity markets. To explore the Dynamic connectivity among green bonds market and agricultural commodity market, we followed TVP-VAR a methodology combined with the one proposed earlier by Diebold and Yilmaz (2012).

Consider Y_t as a (Nx1) vector of N return prices. The TVP-VAR model can be represented as detailed below with these set of equations:

$$Y_t = \phi_t Y_{t-1} + u_t; u_t \backslash \Omega_{t-1} N \sim (0, S_t) \qquad \text{Eq.1}$$

$$\phi t = \phi_{t_-1} + j_t; j_t \backslash \Omega_{t-1} N \sim (0, R_t) \qquad \text{Eq.2}$$

Where Ω_{t-1} indicates the set of information which is accessible at t-1. Y_{t-1} is a (N_p x 1) as a dependent variable's lagged vector. ϕt is a matrix when coefficients are time varying. u_t and j_t are the vectors for error terms. St and Rt reflects time-dependent variance-covariance matrices of the error terms $u_t \, and \, j_t$.

Furthermore, we implemented connectedness measurement methodology developed originally by Diebold and Yilmaz (2012), using a comprehensive framework of vector autoregressive. Particularly, the time-varying spillover approach of Diebold and Yilmaz (2012) in evaluating total volatility negative and positive from volatility spillover index and is built upon the pattern of generalized vector autoregressive (VAR) model. Previous index of spillover presented by Diebold and Yilmaz (2009) was built on the variance decomposition of the forecast errors (FEVD) in a vector autoregressive model (VAR). Diebold and Yilmaz (2012) has several advantages compared to earlier spillover methods. Initially, although findings aren't reliant on variable's order as it does not incorporate Cholesky Variable recognition of VAR model. Secondly, it encourages them monitoring connectivity across various tiers including Both in pairs and on a system wide scale which is mainly logical and mutually reinforcing. Finally, it inculcates time variation because it is a dynamic spillover model as Relative to alternative static model. For initiate it with VAR(p) process and FEVD by considering time t=1……t, the structural VAR(p) demonstrate the n-variate process $x_{t,1}......x_{t,n}$ as follows:

$$\varphi(L)x_t = \epsilon_t \qquad \text{Eq. 3}$$

Where $\varphi(L) = \Sigma_h \varphi_h L^h$ represents an n * n coefficient matrix t with lag polynomial running into infinity. Accordingly, FEVD in accordance with Diebold and Yilmaz (2012) is given as:

$$(\theta_H)_{j,k} = \frac{\sigma_{jj}^{-1} \sum_{h=0}^{H} \psi_n \Sigma(\psi_h \Sigma)(\psi A \, \Sigma) jk \,)2}{\sum_{h=0}^{H} (\psi \Sigma \psi_h') jj} \qquad \text{Eq. 4}$$

Where $\sigma_{jj} = (\Sigma)_{j,j}, and\ \psi_h$ illustrates an n x n coefficient matrix having lag h$h \cdot (\theta_H)j,k$ shocks are explained which are Given by $k - th$ variable impacting forecast error variance of another variable, j. However, by computation the Sum for each separate row of $(\theta_H)j,k$ is not equivalent to unity. Therefore, to utilize the data provided by variance decomposition matrix during computation of spillover index, every component of variance decomposition matrix can be normalized using sum of row as follows.

$$(\bar{\theta}H)_{j,k} = \frac{(\theta_H)_{j,k}}{\Sigma_{k=1}^{H} (\theta_H) j,k} \qquad \text{Eq. 5}$$

With $\Sigma_{k=1}^{H} (\theta_H) j,k$ = 1 and $\Sigma_{kj,k=1}^{n} (\bar{\theta}H)_{j,k}$ = N (i.e., "The total forecast error variance is used to normalize the contributions of spillovers from volatility shocks. (Barunik et al.2016). Diebold and Yilmaz (2012) demonstrate that the spillover measure represents a fraction of the cumulative elements in off-diagonal of the complete summed matrix, as depicted.

$$\frac{C_H = \sum j \neq k (\bar{\theta}_H) j,k}{\Sigma_{(\bar{\theta}H) j,k}} \times 100 = \left(1 - \frac{\mathrm{Tr}\{\bar{\theta}H\}}{\Sigma(\bar{\theta}H)}\right) 100 \qquad \text{Eq. 6}$$

Where C_H reflects the aggregate spillover within the network and is defined as the proportional contribution of the remaining series in network to forecast variances. the trace operator is represented by $\mathrm{Tr}\{.\}$.

A more detailed measure of spillover for the spillovers directed by a particular variable, j, to other variables, k, found in network, such as., from spillover (to spillover) Is assessed as:

$$(C_H)_{j\rightarrow} = 100 \times \frac{1}{n} \sum_{j \neq k,k} (\bar{\theta}H)_{j,k} \qquad \text{Eq. 7}$$

$$(C_H)_{j\leftarrow} = 100 \times \frac{1}{n} \sum_{j \neq k,k} (\bar{\theta}H)_{j,k} \qquad \text{Eq. 8}$$

Whereas $(C_H)_{j\rightarrow}$ and $(C_H)_{j\leftarrow}$ explicitly indicate ‘To spillover’ and ‘From spillover’ respectively.

Once the directional spillovers have been obtained, it is imperative to lead towards net spillovers are then measured as Variation in total volatility shocks which Are transferred to and acquired from every other markets. Regarding variable j, cumulative spillover is derived as the 'to spillover' subtracting 'from spillover' as depicted as:

$$(C_H)_{j,net} = (C_H)_{j\rightarrow} - (C_H)_{j\leftarrow} \qquad \text{Eq. 9}$$

We can imply by positive magnitude of the net spillover $(C_H)_{j,net}$ That variable j serves as a net transmitter of shocks. If value of total spillover is negative, it suggests that the variable j is a net receiver of shocks.

ANALYSIS AND RESULTS

Preliminary data analysis

In our analysis, for this study we use daily data for volatility spillovers and asymmetry in the agriculture commodity market and green bonds market, and how the green bonds market's volatility is transmitted to the agriculture commodity market. This study selects the four main green indices including S&P Selected index, S&P USD index, S&P US Municipal Index and S&P Index. In agriculture commodities, we selected three different commodity groups- agricultural oils, livestock, and grains.

Table 1: Descriptive statistics analysis for selective global and regional green bonds indices and agricultural commodities.

Indices	Mean	Variance	Skewness	Ex kurtosis	JB	ERS	Q (10)	Q2(10)
COCO.oil	1167.45	112447.99	0.356***	-0.729***	73.58***	-1.46	8980.15***	8754.27***
palm.oil	985.16	79325.05	0.644***	-0.119	118.31***	-1.33	9056.33***	9025.04***
Soybean.oil	721.69	6467.86	0.970***	2.192***	606.74***	-0.82	8292.65***	8119.02***
Sunflower.oil	764.59	8202.83	1.607***	3.994***	1860.04***	-0.46	8593.06***	8481.70***
corn	172.28	297.20	1.064***	2.084***	627.97***	-1.30	8249.24***	8191.46***
wheat	223.67	1060.52	0.827***	1.702***	398.86***	-0.10	8633.19***	8395.31***
fishmeal	1554.85	35869.85	1.627***	3.555***	1643.72***	-0.81	9097.83***	9090.61***
S&P.SI	119.63	23.96	0.791***	0.238*	181.36***	-0.79	8734.79***	8726.74***
S&P.USD	104.73	15.92	0.165***	0.257**	12.34***	2.45**	8790.80***	8782.45***
S&P.US.MUN	99.48	6.27	0.097	0.019	2.68	2.32**	8702.11***	8724.10***
S&P. Index	103.55	15.15	0.916***	0.649***	267.39***	-0.63	8738.04***	8731.88***

Notes: The table represents the descriptive analysis for selective 4 greens bonds with symbols S&P.SI = Greens bonds Selected Index; S&P.USD = Greens Bonds USD index; S&P.US.MUN = Greens bonds Municipal index; S&P.Index = Greens bonds Index and 7 agricultural commodities namely COCO.oil = Coconut oil/MT*; palm.oil = Palm oil/MT; soyabean.oil = Soyabean oil/MT; sunflower.oil = Sun flower seeds oil/MT; corn = Corn oil; wheat = Wheat/MT and fishmeal = Fish meal/MT respectively. The statistical measures include central tendency, Ex kurtosis = Excess kurtosis; Jarque-Bera = JB; ERS = Point Optimal test and Q, Q2 are the quartiles. *** = level of significance @ 1% confidence interval.

The data for green bonds indices and agricultural commodities spans from 12/31/2010 to 12/31/2020. The data was obtained from Thomas Reuters Eikon database which ranks as a leading source of historical data from stocks, commodities, and financial markets.

In accordance with the generalized practices in financial literature, we start with the properties of the underlying analysis, including descriptive, distribution, and connectedness aspects as it is quite paramount for the selection of empirical methods and techniques

In this dynamics, Table 1 provides the Descriptive statistics for green bonds indices and agricultural commodities. Fishmeal, coconut oil, palm kernel oil, sunflower oil and soybean oil are the commodities with the highest mean values respectively.

Generally, in finance it is usually accepted that low returns are associated with low risks, while high returns are linked with high risks, while. This assumption is not valid for the asset classes considered in the table. For instance, fishmeal is a commodity with high mean value as compared to coconut oil. But in terms of risk factor, coconut oil has the highest risk (palm kernel ranking second, fishmeal ranking third) regarding risk factor evaluated by their variances.

However, green bond indices exhibit the lowest volatility and thus considered the safest bonds. Each series listed in Table 1 are observed to exhibit substantial and positive skewness coefficients, apart from for S&P Price index which is negatively skewed. In addition, it is quite evident that S&P green bonds index is leptokurtic and others like S&P Select index, S&P US Municipal bonds, S&P USD green bonds are all significantly mesokurtic.

In the case of commodities fishmeal, sunflower oil are leptokurtic and remaining series are all significantly platykurtically distributed. Finally, the test for data normality by Jarque-Bera (1980) demonstrates that S&P US Municipal green bonds index is the only index which is normally distributed. The stationarity levels of this study are measured using Dickey-Fuller GLS (ERS) i.e., ERS Point Optimal test. According to the DF-GLS test, the null hypothesis is that the series has a unit root.

In table 1, only two series (S&P price index and S&P US Municipal index) show stationarity and their ERS is significant. The weighted Ljung-Box statistics of Fisher and Gallagher (2012) indicate that all series are statistically significant, auto-correlated and show ARCH/GARCH errors. Suggesting using TVP-VAR model with time-varying variances appears to be a suitable option.

Model Analysis

Directional asymmetric volatility spillovers

This study additionally explores the directional asymmetric volatility spillover to evaluate the contribution and receipt of volatility spillover to (from) agricultural commodities and green bonds indices.

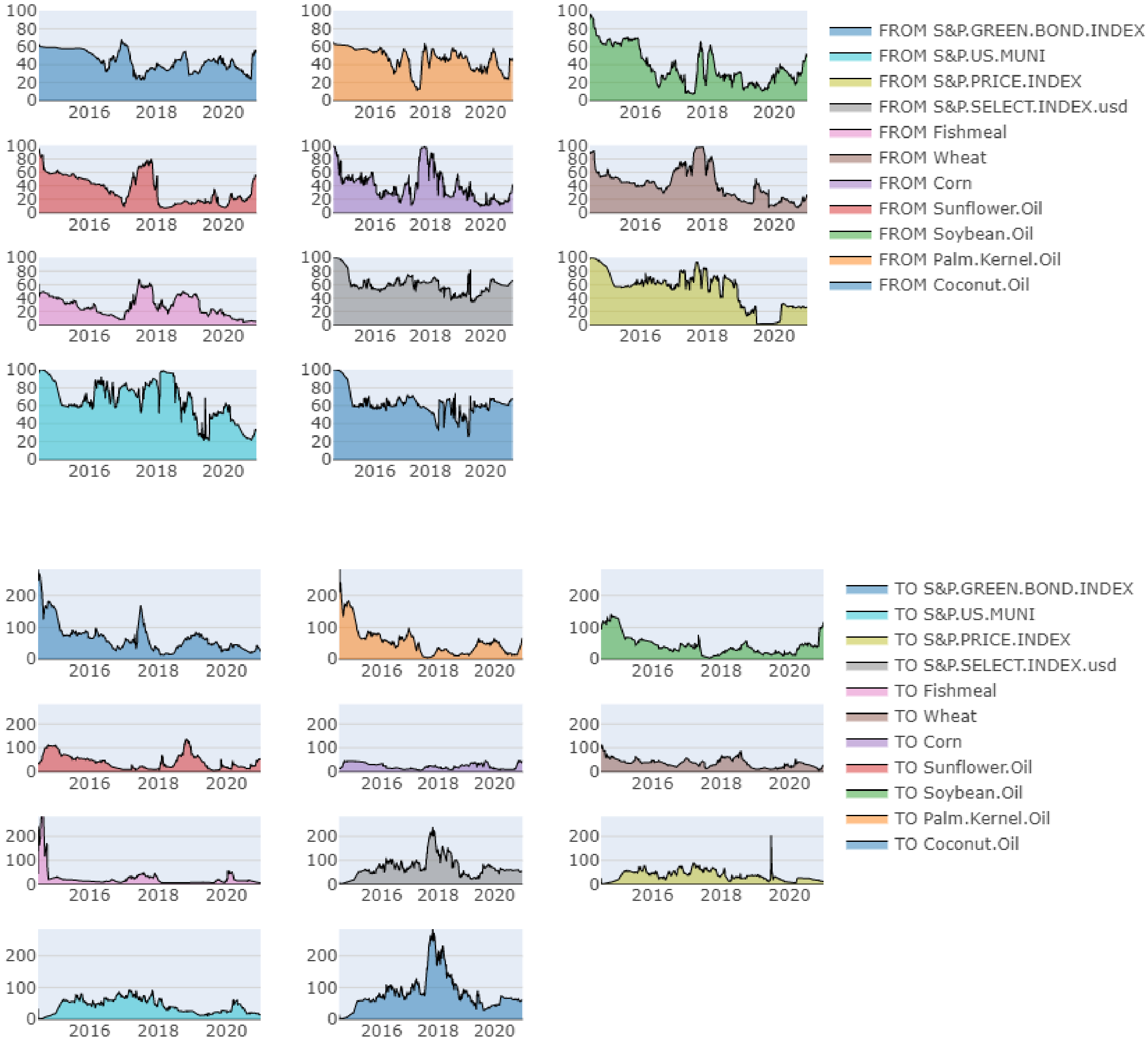

Figure 1(a-b): Net Pairwise directional connectedness.

Results were built on TVP-VAR model with lag length of order one (BIC) and a 10 step ahead forecast error variance decomposition. Expression "To others" represents degree of directional connectedness that a specific variable i conveys Its impact on all other variables j. The terminology "From others" represents directional connectedness measure that a specific variable i obtains by shocks from every other variable, j. "Net spillovers" Signifies distinction among two directional connectedness measures. Figure 1(a) and (b) plot the directional spillover asymmetry measure and depicts the transmission of volatility spillover to (from) one asset class to another.

By comparing these two plots, we can remark about the spillover transmission and recipients among them. Fig 1(a) demonstrates that S&P green bond index, S&P Select index, coconut oil and palm kernel oil are the ones which transmit high spillover to others. Similarly, in Fig 1(b) S&P US Municipal bonds, S&P Green bonds, S&P Price index, coconut oil, palm kernel oil, wheat receive high spillovers from others.

Network connectedness

In order to explore volatility spillovers among these markets, we further constructed a risk based network connectedness. Fig 2 show the pairwise directional connectedness between agricultural commodities and green bonds indices. System under consideration comprises, S&P US Municipal, S&P Price index, S&P Select index, S&P soyabean oil, fishmeal, palm kernel oil, corn, sunflower oil, coconut oil, wheat.

The magnitude of node is proportional to the size of contribution of spillover, while the node's border color indicate the direction of spillovers. Thick blue lines demonstrate higher directio

nal connectedness, The connectedness network provide details regarding the transmitters and receivers As well as the intensity of the connectedness. The colur of node indicate market's nature, such as, blue colour nodes illustrate major transmitter and yellow colour nodes indicate the most significant receiver of shocks. Magnitude is shown by size of nodes.

We note that commodities as corn, wheat, fishmeal, S&P US Municipal, S&P Price index remain net recipients while, S&P Select index, S&P green bond index, coconut oil, palm kernel oil, soyabean oil, sunflower oil are net transmitters. S&P Green bond index has the strongest connectedness (indicated by the dark edge arrow and its thickness) to corn and wheat commodities.

Average dynamic connectedness

Table 2 shows a summary of average dynamic connectedness estimates for each agricultural commodity. and green bond index analyzed, produced by the TVP-VAR model.

Conclusion drawn from Table 2 is that it presents net spillovers for every agricultural commodity and green bond index and shows that S&P US Municipal index, S&P Price index, Corn, Wheat, Fishmeal were net recipients of spillover from others.

On the other hand, the remaining entities were net transmitters for all others. We observed that the own agricultural commodities and green bonds spillovers described the maximum values of forecast error variance due to the diagonal elements receiving maximum values as relative to off-diagonal elements.

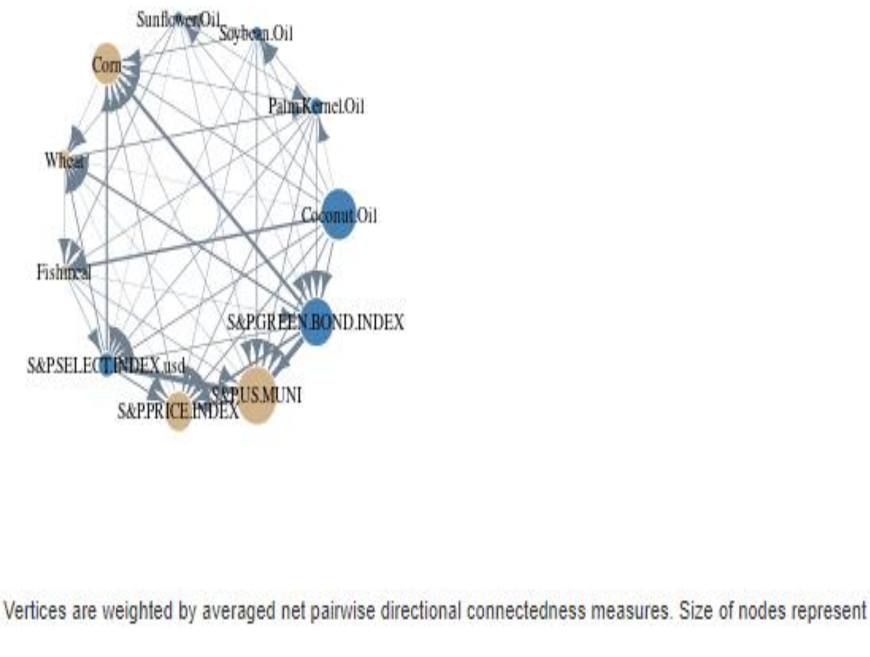

Figure 2: Network diagram of pairwise directional connectedness.

Moreover, net connectedness index (TCI) calculated the average influence including all corresponding Variables affect a single variable's forecast error variance over time. Here, the TCI across all markets is at 46.74% as displayed in Table 2. Suggesting that the agricultural commodities markets and green bonds were dependent on one another; the average effect is approximately 47%. This value pertains to the notion that the transmission of spillover in markets serves as a major contributor to agricultural commodities market fluctuation. Findings suggest that the S&P green bond index influenced forecast error variance of remaining indexes and commodity markets via transmitting leading index of 82.64%, subsequent to S&P Select index 70.26%, Coconut oil 66.16%, and Palm Kernel oil 53.86%.

However, the green bonds index shows that that the highest spillover received from others: S&P Municipal 65.66%, S&P Green bond index 62.29%, S& P Select index 60.07% and in agricultural commodities the highest spillover received is considerably lower than green bonds. The contributions of agricultural commodities (coconut oil, palm kernel oil, soyabean oil, sunflower oil, wheat to others were highest, with 66.16%, 53.86%, 43.45%, 39.84%, 35.86%, respectively. Additionally, Coconut oil, palm kernel oil, wheat, corn, soyabean oil, and sunflower oil received more spillovers than they transmitted, with 44.69%, 46.33%, 42.74% 39,68%, 37.75%, 35.05%.

Table 2: Dynamic asymmetric connectedness table.

Indices	Coconut Oil	Palm Kernel Oil	Soybean Oil	Sunflower Oil	Corn	Wheat	Fishmeal	S&P (Select)	S&P (Price)	S&P (Mun.)	S&P (Green)	FROM others
Coconut Oil	55.31	21.55	6.13	4.5	1.86	6.48	1.83	0.81	0.3	0.32	0.91	44.69
Palm Kernel Oil	22.34	53.67	6.87	3.63	1.35	8.49	1.21	0.84	0.19	0.23	1.17	46.33
Soybean Oil	7.61	8.45	62.25	8.83	3.44	3.39	2.03	1.44	0.47	0.39	1.72	37.75
Sunflower Oil	6.07	2.31	10.38	64.95	4.7	4.06	4.61	0.91	0.63	0.5	0.88	35.05
Corn	3.78	2.84	5.48	4.48	60.32	3.92	2.68	4.89	2.19	1.98	7.46	39.68
Wheat	7.07	5.94	2.96	5.67	4.9	57.26	3.81	3.9	1.42	1.86	5.23	42.74
Fishmeal	6.89	2.71	2.01	6.57	2.86	4.88	72.06	0.59	0.22	0.3	0.92	27.94
S&P(Select)	3.13	2.64	2.51	1.59	0.82	1.4	2.05	39.93	7.13	7.1	31.7	60.07
S&P(Price)	2.8	2.15	1.8	1.06	0.48	0.79	1.81	10.17	48.03	18.7	12.2	51.97
S&P(Mun.)	2.82	2.3	2.6	1.69	0.65	0.98	1.86	17.01	15.28	34.34	20.46	65.66
S&P(Green)	3.65	2.98	2.72	1.81	0.95	1.48	1.68	29.71	7.35	9.96	37.71	62.29
To others	66.16	53.86	43.45	39.84	22	35.86	23.56	70.26	35.19	41.34	82.64	514.16
Inc.own	121.46	107.53	105.7	104.8	82.32	93.12	95.62	110.19	83.22	75.68	120.35	TCI
NET	21.46	7.53	5.7	4.8	-17.68	-6.88	-4.38	10.19	-16.78	-24.32	20.35	46.74
NPDC	0	3	4	3	7	5	5	8	8	7	5	

Note: This table illustrates the variance decomposition for the calculated TVP-VAR model by focusing on different green bond indices and agricultural commodities. Variance decomposition is based on 10-step-ahead forecast horizon and a TVP-VAR lag length of order 1. The phrase "To others" indicates the measure of the directional connectedness which variable i transmits its shock to each other variables j. The phrase "From others" shows directional connectedness measure which certain variable i takes in as shocks from every other variable j. "Net spillovers" refers to the variation among two directional connectedness. TCI denotes the overall connectedness.

Dynamic total connectedness

To determine whether mean connectedness among green bonds index and agricultural commodities varied over time. Figure 3 suggests the timeframe for dynamic total connectedness index (TCI). Significant differences were noted throughout the entire sample timeframe. Furthermore, total connectedness was consistently high during the entire duration. Before 2015, there is a downward slump which reached 55%. This dynamic reflects certain events which occurred during these years, such as the European sovereign debt crisis. Also, between 06-2014 and 02-2015, global commodity prices decreased by 38%. In the middle of 2018 and initial three months of 2019, the TCI attained its minimum value, with approximately 30%. The spillover during these times could be attributed to the worldwide economy's recovery originating from the 2008 till 2010 credit crunch, which resulted in the worldwide financial crisis.

After the crisis period, it is quite noteworthy here that oil prices are a key factor in creating a bubble. However, the spillover has taken a declining trend from 2018 to early 2020, corresponding with the natural gas and oil crashes mainly resulting from supply factors like the US oil glut and geopolitical crises. Endorsing results of our study, Arif et al. (2020) and Adekoya and Oliyide (2020b) likewise confirms this period also demonstrates significant connectedness between financial markets.

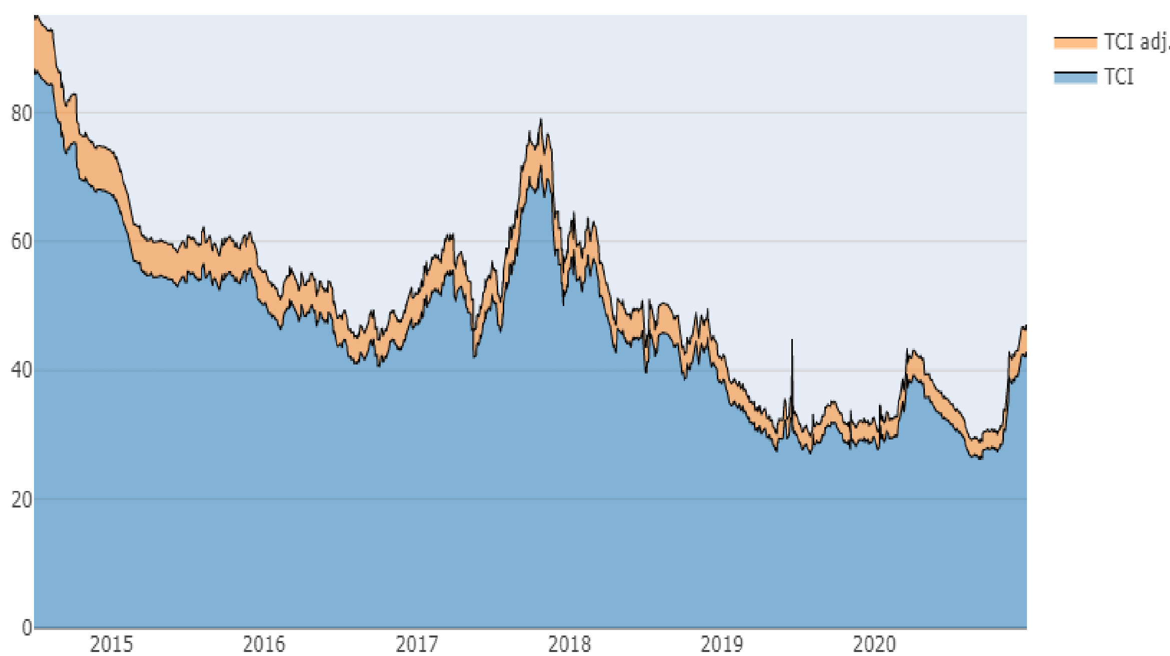

Figure 3: Dynamic total connectedness. Notes: Results are based on a TVP-VAR model with lag length of order one (BIC) and a 10 step ahead forecast error variance decomposition.

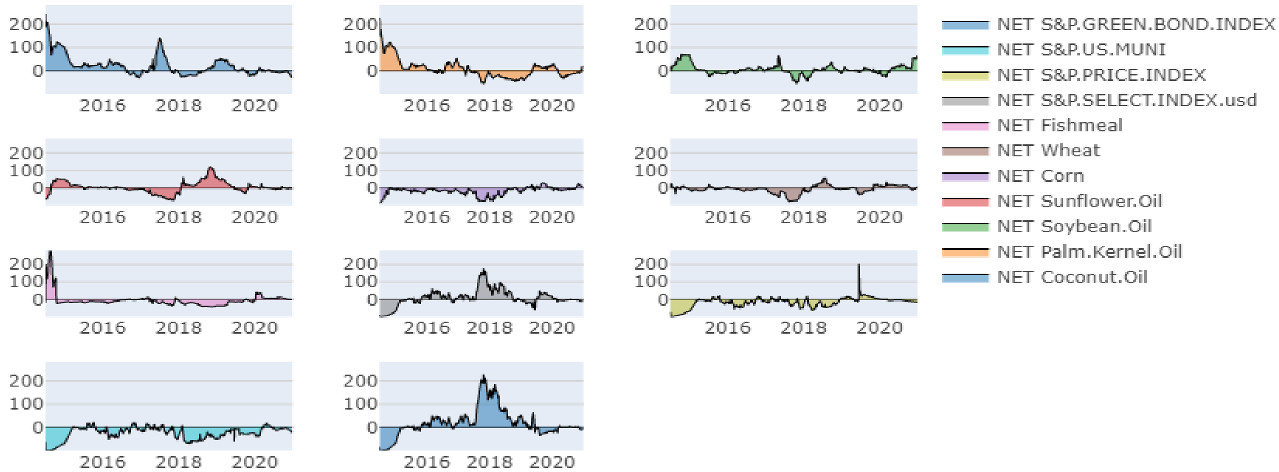

Figure 4: Rolling window plots of net spillover index in green bonds index and agricultural commodities.

Net-total directional connectedness

This segment illustrates a comprehensive view of the spillover risk among the agricultural commodities and green bonds indices via the network of net-total directional connectedness. Figure 4 depicts the fascinating insights regarding changing trends which indicate every asset's net position with respect to spillover it transmits or receives. The index for every asset is produced by subtracting directional 'from others' spillover from directional spillover "To others". It is paramount that value of spillover effects positive(negative) on an asset suggests that it is a net transmitter(receiver) regarding the spillover between various assets. Figure 4 suggests that corn, wheat, fishmeal, S&P Price index, S&P Municipal are net receivers while coconut oil, palm kernel oil, sunflower oil, soyabean oil, S&P green bond index, S&P Select index are the net transmitters.

According to (Mensi et al. 2018) cross-market linkages or spillovers are intensified by financial crisis which result in the persistent co-movement of stock volatility and correlations. Corroborating with the findings of Klotz et al, (2014), In comparison, commodity markets show reduced volatility spillover with the equity markets. Also, Diebold and Yilmaz (2012) illustrate that spillover from commodity market affects the equity market increases over the period of increased interest in metal and oil demand from China was surprising for investors. Accordingly, the time from 2011- 2014 is the era of worldwide economic improvements and heightened commodities demands. Similarly, 2014-2018 is the time frame during which commodity markets and oil encountered a worldwide downturn. Therefore, it is a primary reason due to the regular fluctuations in agricultural commodities net position as a shock-transmitter to a shock-receiver throughout sample period.

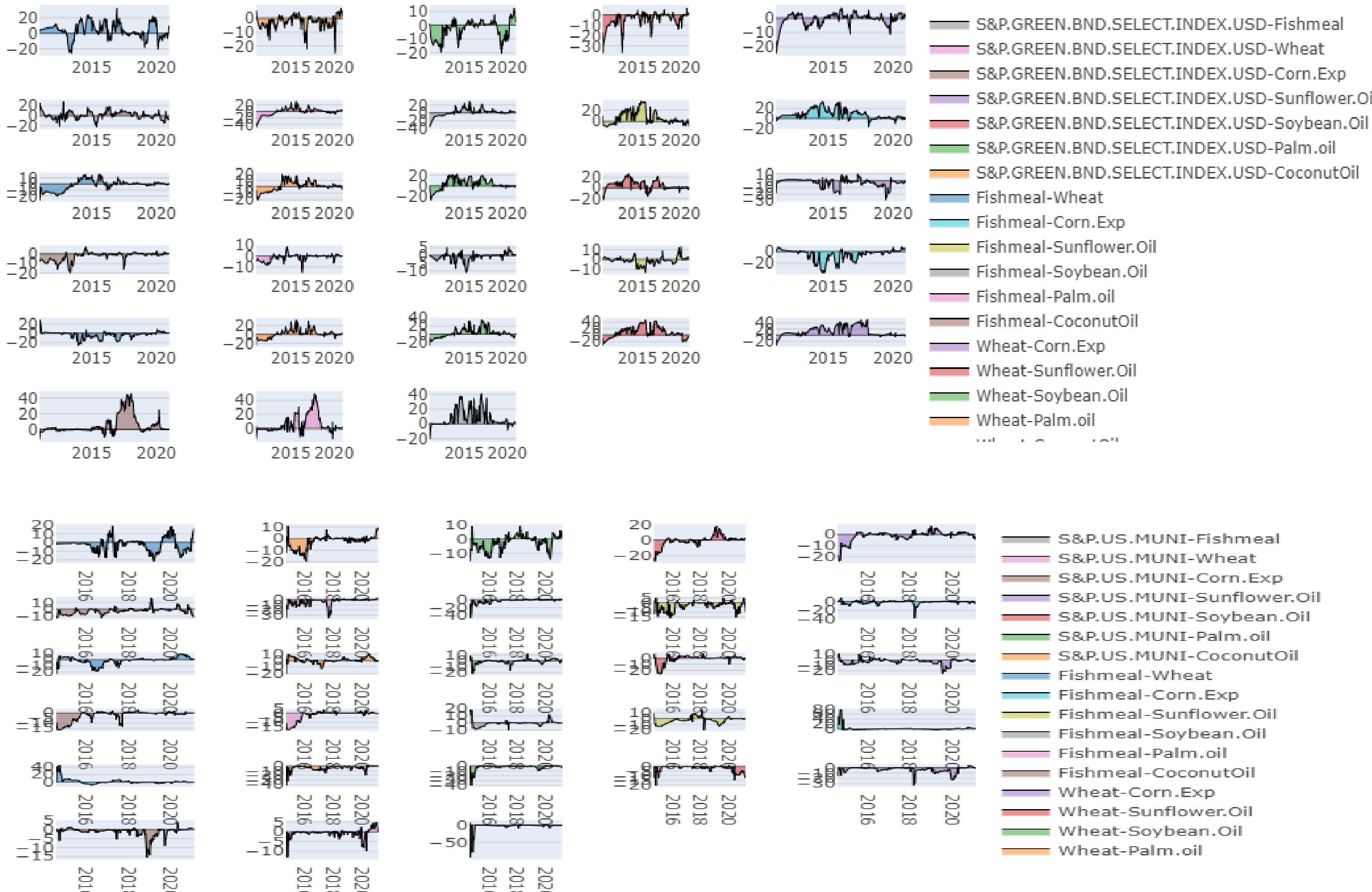

Figure 5 (a-b): Net pairwise directional connectedness of S&P Select and Municipal index with agricultural commodities over time.

Corroborating with the findings of Klotz et al, (2014), less volatility spillover is present in commodity markets compared to others with the equity markets. Also, Diebold and Yilmaz (2012) illustrate that equity market is impacted by spillover of commodity market increases at the time of China's requirement for metals and oil was surprising for stakeholders. Accordingly, during 2011-2014 is the time of increased commodities' demand and worldwide economic resurgence. Similarly, during 2014-2018 worldwide collapse of commodities market and oil. Hence, it is a key factor contributing to regular fluctuations in the agricultural commodities' net position as a shock-transmitter to a shock-receiver throughout the sample duration.

Net pairwise connectedness

Though the net total approach can yield important information and challenging as well because total numbers undoubtedly hide intriguing narratives among specific variables in the system. It is worth mentioning here that the net total figures can clearly illustrate the variables of the network throughout the time period, However, it fails to take into account pairs of variables illustrate the associated dynamics. So, in this regard the bilateral results are displayed to explore the specific connections between the asset classes of interest.

Figure 5(a-b) represents net pairwise directional connectedness of S&P Select and Green index with agricultural commodities over time. Even though there are fluctuations over time, the S&P Select Index plays the role of net shock transmitter in their pairwise relation with all commodities. However, agricultural commodities pairwise connectedness indicates that fishmeal, wheat, corn, soybean oil acts as net receiver of most volatility shocks from every other commodity and coconut oil and sunflower oil act as a shock transmitter to other agricultural commodities.

The S&P US Municipal green bonds are primarily the net volatility receivers in their pairwise connectedness with agricultural commodities. Figure 6(a-b) represents the net pairwise directional connectedness of S&P green bond index with agricultural commodities over time. Even though there are fluctuations over time, the S&P Select Index plays the role of net shock transmitter in their pairwise relation with all commodities. However, agricultural commodities pairwise connectedness indicates that fishmeal, wheat, corn, soybean oil is net receiver of majority of volatility shocks by all every commodity and coconut oil and sunflower oil act as a shock transmitter to other agricultural commodities. Also, the S&P USD green bond index are primarily net volatility receivers in their pairwise connectedness with agricultural commodities.

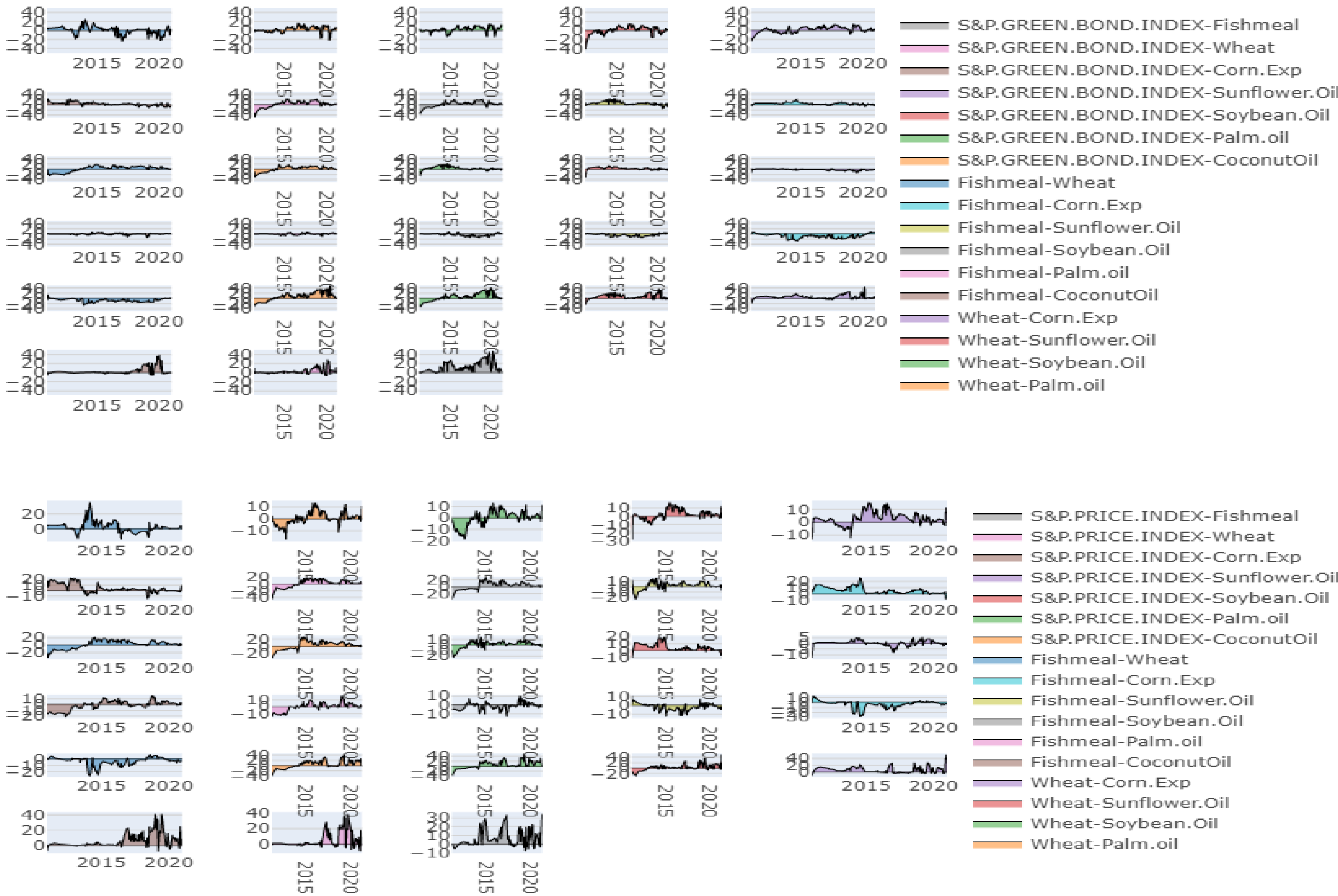

Figure 6(a-b): Net pairwise directional connectedness of S&P Green and Price index with agricultural commodities over time

The findings indicate that the green bond market traders can develop hedging strategies and risk management by monitoring the agricultural commodity market performance which strongly impacts the agricultural commodities' prices. Investors in financial portfolios and agricultural commodity growers can utilize our results to effectively hedge among bond and markets of agricultural commodities, as well as for predicting future prices including green bond and agricultural commodities. For regulatory authorities, volatility spillover effect experienced by agricultural commodities from the green bonds market indices matters mainly because of their effect on price inflation. Reboredo et al. (2020) suggests Even though green bonds possess comparable traits to conventional corporate bonds, they generate their returns through environmental sustainability and friendly projects. Furthermore, green bonds lead towards the improvement of the environmental performance as well as financial performance by enhancing long term green investments and green innovations (Flammer, 2021). Finally, for investors it will be beneficial to know what agricultural commodities carry higher risks and those that are lower risk and this will help in accurately managing investment strategies and financial resources.

CONCLUSION

In this study, our main goal is understanding risk transmission among green bonds and agricultural commodities (sugar beets, cocoa, corn, soybean oil, cotton, wheat, sugar cane, coffee, lumber, soybeans). Research findings show that there is an interrelationship between international markets. Such interrelationship led towards this notion that investors seek to combine various asset classes within their portfolios for the purposes of diversification and hedging. Green bonds have introduced new opportunities and challenges to the conventional bond market and as a result, it is worth studying to analyze the relationship among innovative bond markets and other financial markets. Recently, Green bonds have gained popularity as they are seen as a suitable financial instrument for transitioning to a low carbon economy(Monasterolo and Raberto, 2018).

Our findings suggest that the most significant transmission and reception of spillover is observed among sunflower oil, coconut oil, wheat, and corn respectively. The green bond indices are mostly to have large spillover effect by sunflower oil, wheat, and soya bean oil. Additionally, the major green bond indices are largely spillover by coconut oil, sunflower oil and wheat, while the S&P Municipal green bonds are spillover by fishmeal. The comprehensive result of the study is informative and suggests that agricultural commodities and green bonds can provide us with insights about diversification of portfolios, decisions to hedge and long-term sustainability for market of green bonds. The weak connection of green bonds with agricultural commodities pertains to the notion that green investments can act as a hedger to investors mitigating risks within the commodity markets.

In a nutshell, these resulted analysis consist spillovers volatility amoung the agricultural commodities prices and those of green bond indices is a relatively new and capable to attract the focus of researchers, policymakers and investors because green bond is considered as a favorable opportunity to hedge against risks.

REFERENCES

Agrawal, R., Agrawal, S., Samadhiya, A., Kumar, A., Luthra, S., & Jain, V. (2024). Adoption of green finance and green innovation for achieving circularity: An exploratory review and future directions. *Geoscience frontiers*, *15*(4), 101669.

CRETI, A., JOËTS, M. & MIGNON, V. (2013). On the links between stock and commodity markets' volatility. *Energy Economics*, 37**,** 16-28.

DIEBOLD, F. X. & YILMAZ, K. (2009). Measuring financial asset return and volatility spillovers, with application to global equity markets. *The Economic Journal,* 119**,** 158-171.

DIEBOLD, F. X. & YILMAZ, K. (2012). Better to give than to receive: Predictive directional measurement of volatility spillovers. *International Journal of forecasting,* 28**,** 57-66.

DU, X., CINDY, L. Y. & HAYES, D. J. (2011). Speculation and volatility spillover in the crude oil and agricultural commodity markets: A Bayesian analysis. *Energy Economics,* 33**,** 497-503.

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.

FLAMMER, C. (2021). Corporate green bonds. *Journal of Financial Economics*.

GIANFRATE, G. & PERI, M. (2019). The green advantage: Exploring the convenience of issuing green bonds. *Journal of cleaner production,* 219**,** 127-135.

GORTON, G. & ROUWENHORST, K. G. (2006). Facts and fantasies about commodity futures. *Financial Analysts Journal*, 62**,** 47-68.

GRIFFIN, P. & HEEDE, C. (2017). The carbon majors database. *CDP carbon majors report 2017,* 14.

HAMMOUDEH, S., AJMI, A. N. & MOKNI, K. 2020. Relationship between green bonds and financial and environmental variables: A novel time-varying causality. *Energy Economics,* 92**,** 104941.

Jain, K., Gangopadhyay, M., & Mukhopadhyay, K. (2024). Prospects and challenges of green bonds in renewable energy sector: case of selected Asian economies. *Journal of Sustainable Finance & Investment*, *14*(3), 708-731.

JIANG, X.-L. & ZHANG, Q.-B. (2017). Theory and practice review of green finance for developed country. *China Population, Resources and Environment***,** S1.

KANAMURA, T. (2020). Are green bonds environmentally friendly and good performing assets? *Energy Economics,* 88**,** 104767.

Khamis, Munir, and Dalal Aassouli. (2023). The Eligibility of Green Bonds as Safe Haven Assets: A Systematic Review. *Sustainability* 15, no. 8: 6841.

KIM, H., PARK, K. & RYU, D. (2017). Corporate environmental responsibility: A legal origins perspective. *Journal of Business Ethics,* 140**,** 381-402.

LYON, T. P. & MAXWELL, J. W. (2008). Corporate social responsibility and the environment: A theoretical perspective. *Review of environmental economics and policy,* 2**,** 240-260.

LYON, T. P. & MONTGOMERY, A. W. (2015). The means and end of greenwash. *Organization & Environment,* 28**,** 223-249.

Micallef, et. al., (2023). Assessing the Causality Relationship between the Geopolitical Risk Index and the Agricultural Commodity Markets. *Risks* 11, no. 5: 84.

MONASTEROLO, I. & RABERTO, M. (2018). The EIRIN flow-of-funds behavioural model of green fiscal policies and green sovereign bonds. *Ecological Economics,* 144**,** 228-243.

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***,** 101983.

NAEEM, M. A., PENG, Z., SULEMAN, M. T., NEPAL, R. & SHAHZAD, S. J. H. (2020). Time and frequency connectedness among oil shocks, electricity and clean energy markets. *Energy Economics,* 91**,** 104914.

NAZLIOGLU, S., ERDEM, C. & SOYTAS, U. (2013). Volatility spillover between oil and agricultural commodity markets. *Energy Economics,* 36**,** 658-665.

REBOREDO, J. C. (2018). Green bond and financial markets: Co-movement, diversification and price spillover effects. *Energy Economics,* 74**,** 38-50.

REBOREDO, J. C. & UGOLINI, A. (2020). Price connectedness between green bond and financial markets. *Economic Modelling,* 88**,** 25-38.

REBOREDO, J. C., UGOLINI, A. & AIUBE, F. A. L. (2020). Network connectedness of green bonds and asset classes. *Energy Economics,* 86**,** 104629.

REBOREDO, J. C., UGOLINI, A. & HERNANDEZ, J. A. (2021). Dynamic spillovers and network structure among commodity, currency, and stock markets. *Resources Policy,* 74**,** 102266.

TIWARI, A. K., NASREEN, S., SHAHBAZ, M. & HAMMOUDEH, S. (2020). Time-frequency causality and connectedness between international prices of energy, food, industry, agriculture and metals. *Energy Economics*, 85**,** 104529.

ZAPATA, H. O., DETRE, J. D. & HANABUCHI, T. (2012). Historical performance of commodity and stock markets. *Journal of agricultural and applied Economics,* 44**,** 339-357