Risk spillovers between SP500, green bond, real estate, oil markets and dollar index

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Abstract

In the finance world, one of the fundamental concept is portfolio optimization and diversification. Usually, Investors apply the risk and return approach to diversify their portfolio, but risk spillovers and connectedness between different markets should be incorporated in investment decision-making as well, especially during crisis periods. This study measures risk spillovers and connectedness between S&P500 index, green bond, real estate, oil markets and dollar index in the USA using the TVP-VAR- Diebold- Yilmaz (2012) model from 2016 to November of 2022. TVP-VAR model is considered as time varying model, which can incorporate political and economy events and conditions, therefore, investors can make an insightful decisions regarding their portfolios. The results show that the S&P500 index and real estate market are two main drivers of volatility in the system compared to other markets. Not only do they transmit more volatility, but they also receive more of it in comparison to others. After 2020, the level of the S&P500 index and real estate market volatility increases significantly, possibly due to the Covid-19 pandemic. Furthermore, as expected, the green bond market receives spillovers from others, however, it does not transmit.

Key Words: Risk spillovers, S&P500 index, green bond, real estate, oil, dollar index

JEL codes: G01, G11, G17, G32

Introduction:

One of the important issues related to decision-making for investment in uncertain conditions is how to allocate assets in investors' portfolios. In fact, major of the types of important financial assets are stocks, bonds, real estate, oil and currency, which should be decided in relation to their weight in the portfolio of investors. In the meantime, what is of great importance is that the risk of investing in each of these assets can affect the yield volatilities of other assets, and in this way, it can be claimed that the price fluctuations of these assets, is affected by the risk that is being transferred between them. Considering the importance of this issue, this article discusses the effectiveness and impact of investment risk in each of these assets in the United States of America.

In fact, asset portfolio risk management is one of the basic actions of investors so that they can ultimately prevent their financial loss by reducing risk or eliminating the risk of uncertainty. This mechanism can work in the form of identifying the effectiveness of risk among different assets in the investor's portfolio. Typically, stocks, bonds, and major currencies are among the most important assets in an investor's portfolio. In the meantime, it should be mentioned that investing in green bonds and real estate is very important in the major economies of the world, but despite their importance, in previous studies, the relationship between the risk of these two assets and other types of assets has not been paid.

Actually, since the emergence of green bonds in 2007, the expected value of this type of asset has increased from $807.2 million to $1.5 trillion in 2022 (Chopra and Mehta, 2023). Based on the previous studies, green bonds can be considered as a suitable risk hedge against the major stocks of the world. Because these types of assets (which are among fixed income assets) have hedging and safe haven benefits in equities (Chopra and Mehta, 2023). Also, the green bonds have sizeable diversification benefits when they are included in low-carbon investment portfolios (Reboredo, et al., 2022). In connection to this subject, the Climate Bonds Market Intelligence shows that the green bond market value achieved over half a trillion (USD517.4bn) in 2021. In other words, investing in eco-friendly financial instruments is becoming more and more important as pollution increases (Kim, Park, and Ryu, 2017).

Green bonds are regarded as stable and sustainable investment vehicles for funding long-term social projects. On the other hand, green bonds are investments that can provide long-term income for investors. Nevertheless, it still has a small share of the total fixed income market, which shows the high potential of this security instrument. On the other hand, the United States is one of the leading countries in issuing green bonds (Jones, 2022), which can increase the importance of paying attention to this type of asset in the investment portfolio of investors.

Regard to the importance of paying attention to the share of green bonds in investors' portfolios, this article, unlike previous studies, also paid attention to the risk of investing in the real estate sector. In fact, housing is one type of financial asset that is affected by the risk of investing in other types of assets, including green bonds (Chopra and Mehta, 2023). Housing is one of the types of real assets that have investment risk as well as high returns. However, its share in the investment portfolio of individuals depends on the risk involved in investing in other forms of assets. Recent crises, particularly the global financial crisis (GFC) sparked by the subprime mortgage market meltdown in 2007, showed that the real estate market is an indisputable part of an economy, and its relatedness to other economic factors should be considered. In other words, real estate can provide diversification benefits. However, diversification benefits can be reduced by spillovers effects, especially during a crisis period.

In fact, due to the increasing number of markets and financial instruments in recent years, the risk imposed on the financial system has also increased (Baur and Lucey, 2010). This makes it more important to study the extent to which various types of financial assets are affected by the risk that exists in this system, especially after the financial crisis of 2008 and the recent Covid-19 pandemic. It should be noted that the importance of paying attention to the connectedness and spillover between types of financial assets has also been noted in previous studies (Reboredo and Ugolini, 2020; Ferrer, et al., 2021; Guo and Zhou, 2021; Heq et al., 2021; Reboredo, et al., 2022; Christiansen, 2010; Cappiello, Engle, and Sheppard, 2006; Chuliá and Torro, 2008; Dean, Faff, and Loudon, 2010; Fleming, Kirby, and Ostdiek, 1998; Steeley, 2006). In fact, analyzing the connectedness between the green bond, real estate and other asset markets could help investors optimize their portfolios more efficiently. However, paying attention to the relationship between green bonds, real estate, S & P, oil price and Dollar index have been ignored in previous studies.

Therefore, identifying the spillover between green bonds and other markets such as the stock market, commodities, and others is invaluable.

Numerous studies used different models to define and identify the spillover and connectedness between markets, such as ARMA, ARIMA, ARCH-LM and GARCH, EGARCH, and multivariate GARCH. The mentioned models can hardly gauge quantification spillovers in a detailed manner (Asadi et al., 2022; Bouri et al., 2021). In this study, to achieve more accurate estimation, we apply Diebold and Yilmaz's (2012) (DY) approach, which uses the Time-Varying Parameter Vector Autoregressions (TVP-VAR). Different from the DY based on the VAR system, which is influenced by the window size. Other distinction between the DY based on VAR system and the DY based on TVP-VAR is that the rolling window method does not enable us to achieve the outcomes in the first window, which would bring about the loss of observations, particularly as the window size is not insignificant in the VAR approach. Besides, there is a sensitivity in the outlier of rolling window, and an adverse consequence is that findings are less likely to be corroborative as the window first includes or not accepts an outlier in the VAR system. The latest benefit from the TVP-VAR is to provide a possibility to calculate adjust efficient to parameter changes (Bouri et al., 2021). In a nutshell, main aim of this study is to explain and model the connectedness and spillover between S&P500 index, bonds market, real estate market, oil market and dollar index by estimating the DY based on TVP-VAR. The following contributions will be inserted into the current literature.

1. Examination of connectedness and spillover between the S&P500 index, bonds market, real estate market, oil market, and the dollar index, which is not considered in previous studies;
2. Applying the TVP-VAR model helps to overcome the shortfall of other approaches.
3. Financial institutions, investors, and policymakers will be able to arrive at a decision to manage their portfolio's risks and returns and optimize their portfolio diversification more efficiently, specifically during a crisis, because the approach measures volatility spillovers between different markets.
4. Financial models of diversification, like the most used model of Mean-Variance, are not time-varying, in contrast to the TVP-Var model. It means that political and

economic conditions and events which occur day by day can be incorporated into portfolio selection and diversification.

5. By defining spillovers and connectedness between markets, the results of this study, policymakers can understand those relationships and increase their supervision if needed to minimize the effect of the volatility spillover between markets, especially during crisis periods.

According to the net system of connectedness which is the ultimate result of this study, S&P500 risk spillover diffuses to all markets. Real estate receives risk spillover from the S&P500 market and transmits it to the dollar index and green bonds. The oil market receives risk spillover from the S&P500 market and transfers it to green bonds only. The green bond market is the only one that receives volatility from other markets. It is worth mentioning that the intensity of risk spillover between the S&P500 to dollar index and real estate to dollar index are high compared to the others. On the contrary, the oil market's volatility spillover intensity to green bonds is not as strong as others.

Sections 2 and 3 mention the literature review, data gathering, processing, and descriptive statistics, respectively—sections 4 and 5 are devoted to methodology and the results. Finally, in section 6 conclusion is rendered.

Literature review:

Extensive empirical studies have addressed that there are relationships and connectedness between various markets. For example, using TVP-VAR, Zhang, Chen et al. (2021) demonstrate that in the COVID-19 pandemic, there were dynamic spillovers between energy and stock markets. Wen, Zhang et al. (2019) examine the dynamic effects of financial factors on oil price based on a TVP-VAR model and show that the USA dollar index affects oil price. Sarwar, Tiwari et al. (2020) analyze the spillover between oil and Asian stock markets using the bivariate BEKK-GARCH model in their study and accept this spillover from oil to stock markets and vice versa. Furthermore, they find that the global financial crisis does not affect the mentioned market relationships. The acceptance and transmission of the volatility between the oil and U.S. stock markets are tested in Wen, Wang et al. (2019). They use a multivariate quantile model called the VAR for VaR approach. They also analyzed the spillover of oil and the U.S. stock market before

and after the 2008 global financial crisis and concluded that the spillover was significantly higher after this event. Shahzad, Mensi et al. (2018) analyze the connectedness between oil and Islamic stock markets and find asymmetric down- and up-side risk spillovers from oil to the Islamic stock markets and vice versa. Besides, this spillover mentioned above is stronger after the financial crisis. Khalfaoui, Sarwar et al. (2019) split the oil importing and oil exporting countries and suggest that there would be a difference in the volatility of spillover of oil importing and oil exporting countries. The evidence shows that oil importing countries' stock markets are more affected by lagged oil price shocks. This article used symmetric and asymmetric versions of DCC and cDCC models.

Xu, Ma et al. (2019) test the relationship between the volatility of stock markets such as the S&P 500 index and the Shanghai stock market composite index and the oil market. They accepted the relationship of negative volatility between oil and stock markets using the asymmetric generalized dynamic conditional correlation (AG-DCC) model. Rao, Gupta et al. (2022) test the connectedness between the S&P500 stock market and oil and Green Bonds markets. Finding the connectedness between the markets uses TVP-VAR and Quantile regression model, and the results reveal a considerable degree of interconnectivity across assets from pre- to post-covid periods.

Xiao, Hu et al (2019) examine the relationship between the volatility of the oil market and the Chinese stock market using a quantile regression approach and find that the risk of the oil market influences the Chinese stock market. Pham and Nguyen (2022) study the effect of the volatility of stock and oil markets and policy uncertainty on green bonds. By defining three indexes of uncertainty, they conclude that, in low uncertainty, the relationship between uncertainty and the green bond is weaker when the uncertainty is low. Park, Park et al. (2020) is another research that examines the effect of stock and green bonds markets. They conclude that these two markets have spillover between each other, but they have no response to negative shocks. Elsayed, Naifar et al. (2022) examine the relationship between green bonds and financial markets using a multivariate wavelet approach and dynamic connectedness by combining Ensemble Empirical Mode Decomposition (EEMD) with Diebold and Yilmaz's (2012) spillover framework. The evidence shows that investing in multi markets can have the advantages of diversification in the short run. The results of the static connectedness framework explain that the green bond market

receives more and transmits less volatility. Chopra and Mehta (2023) document the connectedness between green bonds and eleven stock sectors by using dynamic conditional correlation approach in the USA. Arif et al. (2022) investigate the co-movement of green bonds, equities, commodities, forex and fixed income indices as well as oil Brent and gold by applying time varying lead lag association technique during 2011-2020. The results show that green bonds act as hedge for conventional financial assets such as equities, commodities, forex and fixed income. Reboredo et al. (2022) study the relationship between green bonds and low-carbon stocks across three regions during 2016-2020. Using Copula approach, their findings depict that green bonds have major benefits diversification of low carbon investment portfolios. Also, they show that there is a negative relationship between the return of green bonds and low-carbon stocks in the case of China and Europe. However, in the case U.S. there is a negligible effect from green bonds to low-carbon stock returns. Reboredo et al. (2020) identify the connectedness of green bonds and asset classes in Europe and the United States and conclude that treasury, green, and corporate bonds are strongly connected in the short and long run. Naeem, Conlon et al. (2022) examine the relationships between green bonds and traditional assets such as commodities, stocks, and bonds, from 2008 to 2020 using a quantile-connectedness approach and find higher total time-varying risk spillovers during extreme high volatility periods than those with average and low volatility.

Gabauer and Gupta (2020) test the uncertainties in real estate and macroeconomics using the TVP-VAR method and find that uncertainties are connected to the real estate market. Samitas, Papathanasiou et al. (2022) use the TVP-VAR model to investigate volatility spillover between multiple markets, oil, and real estate. They conclude that oil diffuses volatilities to the real estate markets. Tiwari, André et al. (2020) study the strength and time variation of spillovers between returns on residential real estate, real estate investment trusts (REITs), stocks, and bonds in the United States, using the Diebold Yilmaz (DY) (2012) approach in the time domain and the Baruník-Křehlík (2018) methodology in the frequency domain. They concluded that Spillovers in both directions are much stronger between REITs and stocks than between REITs and housing. Nazlioglu, Gormus et al. (2016) examine the relationship and spillover of oil market volatility and six REIT groups. They use a model that augments the Toda-Yamamoto method with a Fourier approximation. Also, they find that their test shows bi-directional volatility transmission between the oil market and all REITs.

Zhang, Fan et al. (2008), and Lizardo and Mollick (2010) use the monetary approach to test the relationship between the us dollar and oil price. Uddin, Tiwari et al. (2013) investigate the relationship between oil and exchange rate using wavelet analysis within the time-frequency space. Adekoya and Oliyide (2021) examine the effect of the COVID-19 pandemic on the interconnectedness between markets. They use TVP-VAR in the commodity market and find that the US dollar is one of the markets that receive shocks from others.

Data

This study uses daily data of S&P500, Green Bonds, Dollar Index, Real Estate Index and WTI Oil markets from 2016 to November of 2022. This sample covers major economic and political events (USA contractionary policy, trading war between USA and China, harsh sanctions on energy producers including Iran and Venezuela, COVID-19, Ukraine- Russia war, Energy resource uncertainties after the war between Ukraine and Russia). The data are fetched from https://fred.stlouisfed.org/. Using this data set is valuable since they are the study's input which yields important results about connectedness between the S&P500 index, Green Bonds, Dollar Index, Real Estate Index, and WTI Oil market. This data could be influenced by political and economic aspects of commodity and financial markets like fluctuations in energy markets, the USA and China trading war, and the war between Ukraine-Russia.

To perform data analysis and graphical representations, we compute the returns series (r_t) by differencing data with the first differences for each series with a natural logarithm.

$$r_t=100*[\Delta \log(P_t)] \quad (1)$$

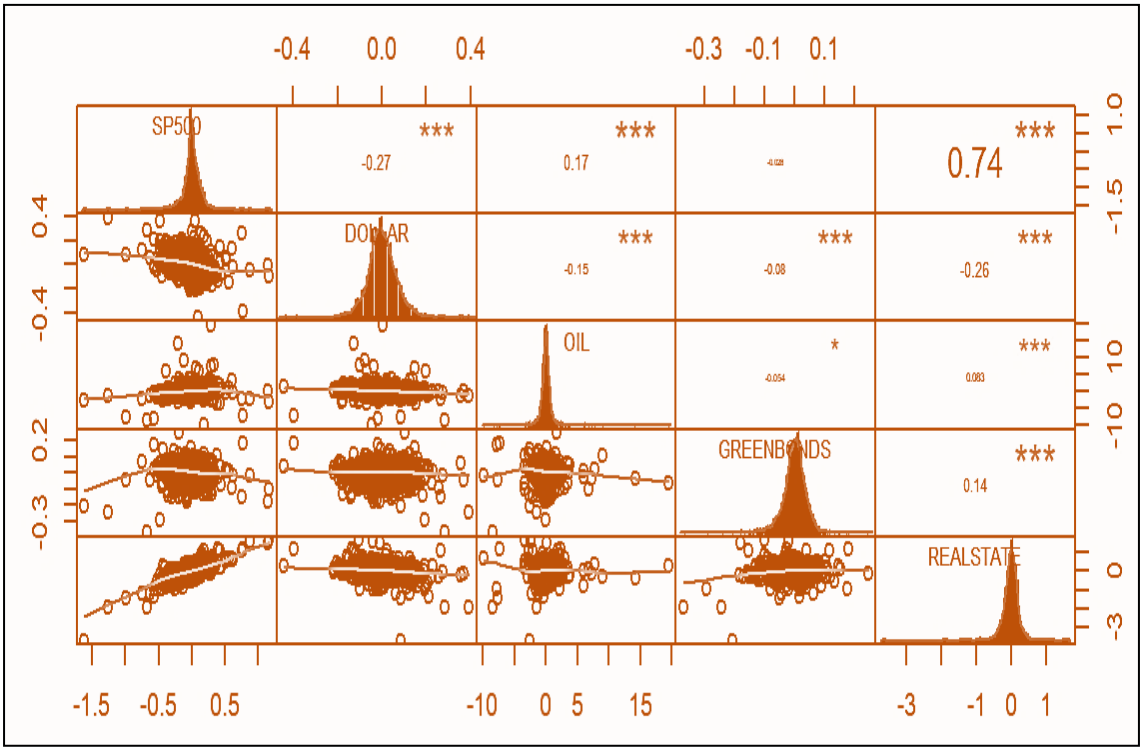
Exhibit 1, shows the descriptive statistics and unit root tests for all return series. As it is illustrated, all of the markets have a positive or zero means of return. Considering the volatility, Oil Market has the highest, and green bonds have the lowest volatility. Furthermore, analyzing skewness shows that all of the variables are asymmetrical. The kurtosis values indicate that all returns follow a leptokurtic distribution and have fat tails. The Jarque-Bera (JB) test shows that all returns series exhibit non-normality distribution.

Since series of returns have the leptokurtic distribution, along with jumps and structural breaks, utilizing the Elliott, Rothenberg, and Stock (ERS) unit root test is useful.

Exhibit 1: Descriptive statistics of return series					
	SP500	**DOLLAR**	**OIL**	**GREENBONDS**	**REALESTATE**
Mean	0.005	0.002	0.033	0.000	0.001
X	(0.175)	(0.266)	(0.183)	(0.903)	(0.842)
Variance	0.022***	0.005***	1.127***	0.002***	0.064***
Skewness	-0.925***	0.165***	4.277***	-1.057***	-2.014***
X.1	(0.000)	(0.004)	(0.000)	(0.000)	(0.000)
Kurtosis	18.506***	3.497***	93.385***	8.365***	31.866***
X.2	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
JB	26805.709***	955.979***	681257.182***	5768.344***	79954.130***
X.3	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
ERS	-17.625***	-17.188***	-17.859***	-15.230***	-17.977***
X.4	(0.0000)	(0.000)	(0.0000)	(0.000)	(0.000)
Q.20.	273.294***	19.596***	120.665***	77.056***	117.473***
X.5	(0.000)	(0.021)	(0.000)	(0.000)	(0.000)
Q2.20.	2244.499***	167.271***	543.100***	769.366***	1044.937***
X.6	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
kendall	SP500	DOLLAR	OIL	GREENBONDS	REALESTATE
SP500	1.000***	-0.156***	0.162***	-0.101***	0.414***
DOLLAR	-0.156***	1.000***	-0.167***	0.000	-0.131***
OIL	0.162***	-0.167***	1.000***	-0.082***	0.049***
GREENBONDS	-0.101***	0.000	-0.082***	1.000***	0.049***
REALESTATE	0.414***	-0.131***	0.049***	0.049***	1.000***
Source: Results of study					

Exhibit 2 represents the results of the pairwise correlations. According to this graph, none of the indictors are normally distributed. According to that, a significant and high correlation (0.74) between S&P500 and the real estate exists. Furthermore, there is a weak negative correlation between S&P500 and oil.

Exhibit 2: Pairwise correlations of the return series



Source: Results of study

Methodology

There are several models for specifying the connectedness between factors in a variety of markets. DY model presents a new approach for calculating the relationships among markets. The main reason this approach has been chosen is that in a dynamic condition where the factors of markets vary over time, this approach shows a better index for connectedness between markets.

The advantage of this model is as follows:

1) Not affected by outlier data.
2) There is no necessity for arbitrarily choosing the size of the rolling window.
3) There is no missing data

4) Data collection, which does not include high frequency, is also usable via this method.

For creating an index for measuring the connectedness between the markets, the non-dynamic approach of the TVP-VAR based on the Bayesian Information Criterion (BIC) has been applied.

$$V_t = \beta_t V_{t-1} + \gamma_t , \qquad \gamma_t \sim \mathrm{N}(0, D_t) \tag{2}$$

$$\mathrm{vec}(B_t) = \mathrm{vec}(B_{t-1}) + \mu_t , \mu_t \sim \mathrm{N}(0, P_t) \tag{3}$$

In the above equations, Vectors of V_t, V_(t-1), together with γ_t, are K×1 dimensional. Other elements are β_t and D_t, which are typical of K×K dimensional matrices in Eq. (2). Next equation is the equation (3), vec (B_t) and μ_t depict vectors, which are k^2×1 dimensions; yet, P_t is a matrix with a distinguishing characteristic of k^2×k^2 dimension.

After the aforementioned stages, we measure the H-step ahead (scaled) Generalized Forecast Error Variance Decomposition (GFEVD), which shows invariability of the variable ordering, the exact opposite of orthogonal Forecast Error Variance Decomposition. The cornerstone of this version is the Wold representation theorem, transferring the calculated TVP-VAR approach to a TVP-VMA process via the below equality, and it can be described as follows:

$$V_t = \sum_{i=1}^{p} B_{it}\ v_{t-i} + \gamma_t = \sum_{j=0}^{\infty} S_{jt}\ \gamma_{t-j} \tag{4}$$

Then, using (scaled) GFEVD is necessary so that we can obtain a degree of unity in every row. To do this, we should normalize the (unscaled) GFEVD, together with σ_(ij,t)^f. To clarify, σ_(ij,t)^f (H) gives us information regarding how much asset *j* is subject to i in terms of its forecast error variance share. In doing so, utilizing the pairwise directional connectedness from *j* to *i* is crucial. The desired equation is:

$$\sigma_{ij,t}^{f}(\mathrm{H}) = \frac{D_{ii,t}^{-1} \sum_{t=1}^{H-1} (l' S_t l_j)^2}{\sum_{j=1}^{k} \sum_{t=1}^{H-1} l_i D_t S_t' l_i} \tag{5}$$

$$\sigma_{ij,t}^{f'}(\mathrm{H}) = \frac{\sigma_{ij,t}^{f}(H)}{\sum_{j=1}^{k}\sigma_{ij,t}^{f}(H)} \quad (6)$$

There will be a close correspondence of a chosen vector with unity on the ith position and zero otherwise, provided that $\sum_{j=1}^{k}\sigma_{ij,t}^{f'}(H) = 1$, $\sum_{i,j=1}^{k}\sigma_{ij,t}^{f'}(H)$ k, together with l_i.

In accordance with the GFEVD, extracting spillovers calculations via the DY is straightforward, along with this equation is identifiable as follows:

$$TO_{jt} = \sum_{i=1,i\neq j}^{k}\sigma_{ij,t}^{f'}(H) \quad (7)$$

$$FROM_{jt} = \sum_{i=1,i\neq j}^{k}\sigma_{ji,t}^{f'}(H) \quad (8)$$

$$NET_{jt} = TO_{jt} - FROM_{jt} \quad (9)$$

$$TCI_t = k^{-1}\sum_{j=1}^{k}TO_{jt} = k^{-1}\sum_{j=1}^{k}FROM_{jt} \quad (10)$$

$$NPDC_{ij,t} = \sigma_{ij,t}^{f'}(H) - \sigma_{ji,t}^{f'}(H) \quad (11)$$

Eq. (7) primarily enables us to realize total directional connectedness to others using the aggregated effect of a shock by variable j on the whole of other variables. Next, Eq. (8) interprets the aggregated impact of total alternative assets upon variable j. From Eq. (9), we are able to gain a clearer perception of whether a variable is a net receiver, a net giver, or not. The Eq. (10) is used to uncover whether interconnections in a system, together with the market risk, are high or not. On the contrary, if this index is low, most variables are not contingent on each other. Consequently, a shock in a variable is not subject to other variables to bring about low market risk. In the end, Eq. (11) provides net pairwise directional connectedness, making a signal as to how much variable i impact on variable j, and vice versa. From this index, thus, we can inform that variable j affects asset i, providing NPDC is non-negative, and the effects of i on j are reverse.

Results and discussions

Exhibit 3, provides information regarding spillovers between the S&P500 index, bonds market (green bonds), real estate market, oil market, and dollar index. The results show that S&P500 and real estates with 42.52% and 34.6%, respectively, are the two main transmitters and drivers in this system. The dollar index, Oil, and green bonds are placed next as a transmitter. For more illustration, 19.04% of shocks are given to this system by Dollar index, whereas 13.42% by oil. These results are the same as Balcilar, Ozdemir et al. (2021). They confirm that S&P500 and oil market transmit volatility to other markets.

Based on the "from" column in the exhibit, it can be concluded that the S&P500 index has the highest sensitivity among the variables, which is 35.63%. This is followed by the real estate's market, receiving 32.48% shocks from others. To analyze the spillovers between the variables, the S&P500 index receives 8.53% of its volatility shocks from the Dollar index, 6.01% from oil, 4.05% from green bonds, and 23.93% from the real estate market. These results are the same as the following studies. The volatility spillover between S&P500 and the oil market is confirmed in Xu, Ma et al. (2019). The spillover between the S&P500 stock market and Green Bonds markets are accepted in Park, Park et al. (2020). The spillover between Real Estate and stock markets like the S&P500 stock market has been tested and accepted in Tiwari, André et al. (2020).

Furthermore, the Total Connectedness Index (TCI) yielded a high percentage, which implies contemporaneity of losses in the S&P500 index, bonds market, real estate market, oil market and dollar index appears probable.

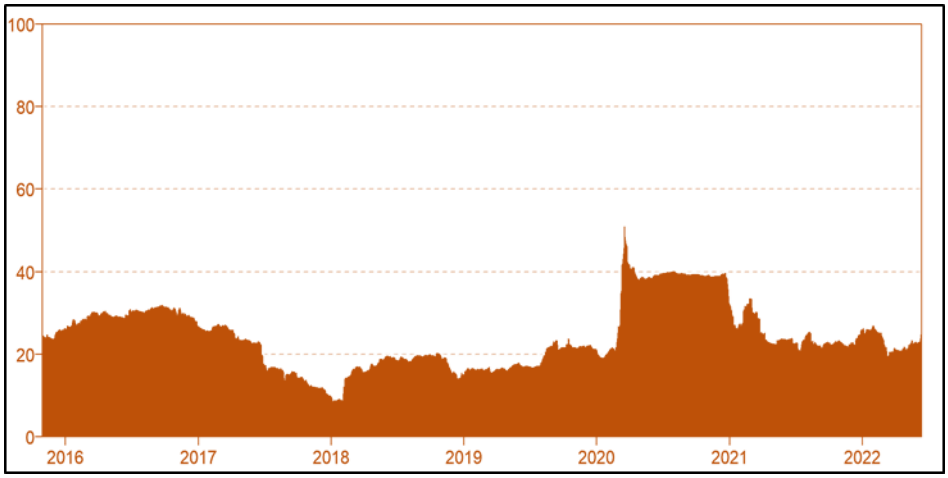
Ehhibit 3: Estimates of spillovers between the S&P500 index, bonds market, real estate market, oil market, and the dollar index						
	SP500	**DOLLAR**	**OIL**	**GREENBONDS**	**REAL ESTATE**	**FROM**
SP500	63.37	5.97	4.57	2.69	22.4	35.63
DOLLAR	8.53	77.5	4.5	3.24	6.22	22.5
OIL	6.01	4.25	85.58	1.99	2.17	14.42
GREENBONDS	4.05	4.58	2.66	84.92	3.8	15.08
REAL ESTATE	23.93	4.25	1.69	2.61	67.52	32.48
TO	42.52	19.04	13.42	10.54	34.6	120.12
NET	6.89	-3.47	-1	-4.54	2.12	TCI = 24.02
Source: Results of study						

Notes: Results are based on a TVP-VAR model with lag length of order one (BIC) and a 20-step-ahead generalized forecast error variance decomposition

From Exhibit 4, which shows dynamic total connectedness, it can be inferred that changes in economic, political, and even health conditions can affect dynamic total connectedness. According to this exhibit, the index varies between approximately 10% and 50%. It is evident that chaotic conditions amplify concerns, and therefore the index experiences some hump and trough. From 2016 to 2017, the index experienced a steady growth concurrent with the Brexit referendum. On the other hand, oil prices, as the leading energy market, fell to $26.19 per barrel early in 2016. After this year, the index experienced a downward slope due to the US's implementation of a contractionary monetary policy. After 2018, the index experienced a soar, concurrent with important events like the trade war between China and the US, imposing sanctions on energy exporting countries, including Iran and Venezuela, and a plummet in energy prices. In 2019, uncertainty increased in financial and commodity markets because of the Covid-19 pandemic. Zhang and Mao (2022). They show that in 2020 and the context of covid 19, the volatility of Chinese stock markets spillover to USA stock markets, which could be one of the reasons why the S&P500 market received so much volatility in 2020.

After vaccination, the world was optimistic about the world economy, but in 2022, the war between Ukraine and Russia increased uncertainties again. The US imposed harsh sanctions against Russia, negatively influencing the energy and food markets.

Exhibit 4: Dynamic total spillover based on the DY-TVP-VAR

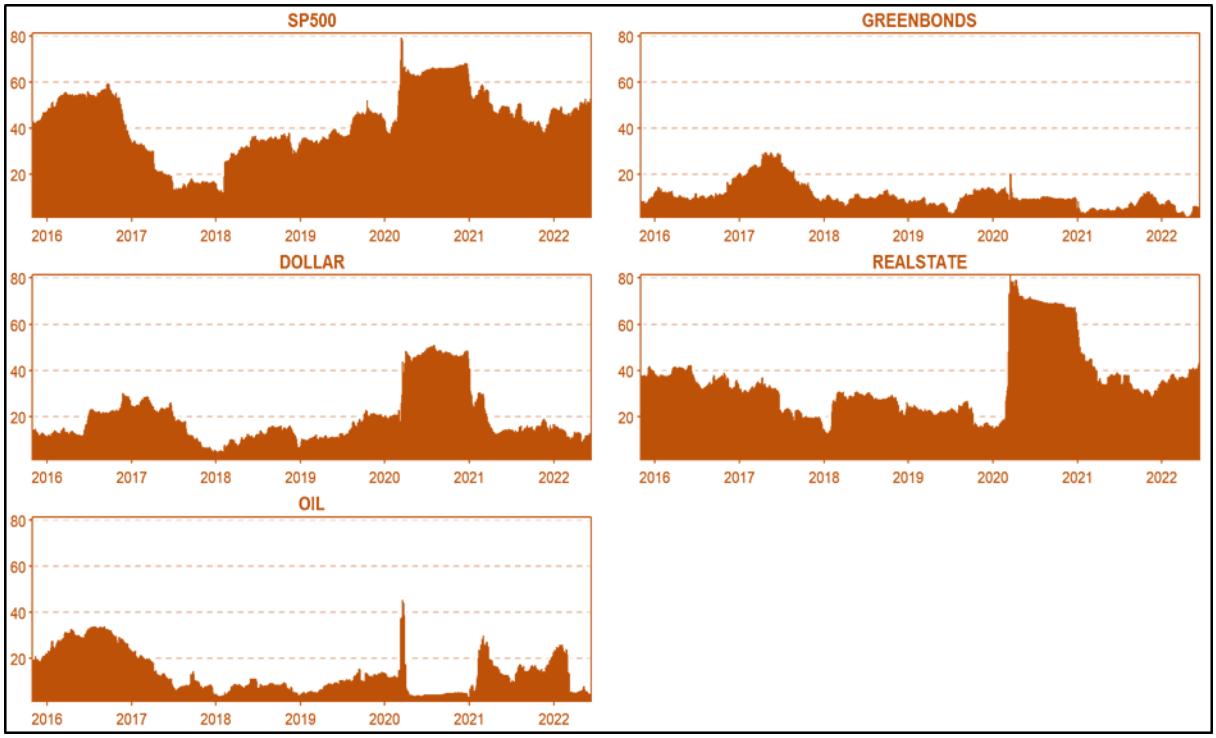


Source: Results of study

The exhibit 5, provides a more detailed illustration about volatility spillovers amid a market to S&P500, Green Bonds, Dollar Index, Real Estate market, and WTI Oil market. It can be inferred from exhibit that S&P500 gives the enormous volatility shocks to others.

After that, the real estate is by most the important transmitter in this network. The real estate greatly affects volatility shocks to other markets after 2020, which is also true about S&P500. Considering S&P500, its shocks experienced a decrease after 2017 but reversed to the highest values. The US trade policies and President Trump's trade rhetoric are concurrent with these ups and downs. The highest S&P500 and real estate level appears during the Covid-19 pandemic crisis. The Covid -19 crisis significantly impacted the real estate market in 2020. Health concerns and stay-at-home orders led to fewer buyers looking for homes and fewer sellers willing to list their properties or allow strangers to enter their homes during a pandemic. Furthermore, it can be understood that the green bonds have a lower spillover of volatility in the network, which confirms the least transmission of Green Bonds volatility to other markets because of their low risk compared to other markets. The Covid -19 pandemic decimated global oil demand, which plummeted in the second quarter of 2020 at an astonishing rate as lockdowns and other pandemic-related restrictions came into force. Whole countries abruptly stopped driving and flying.

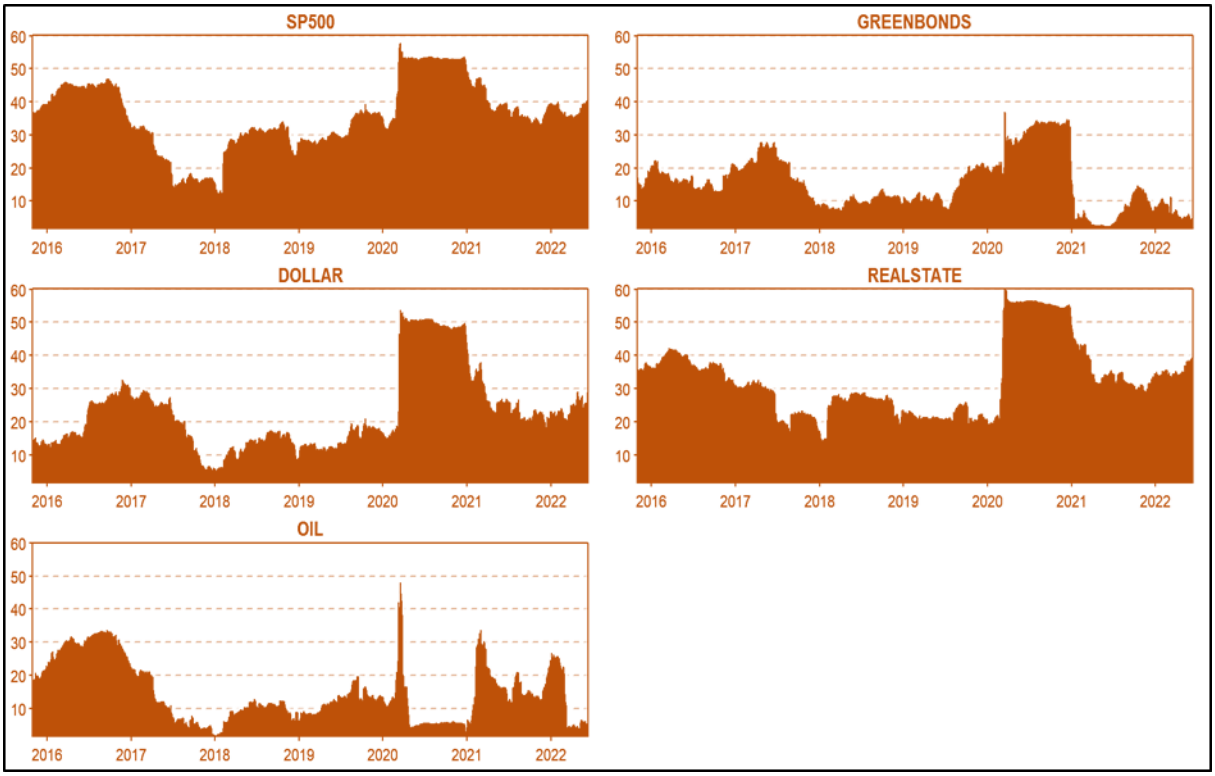
Exhibit 5: Time-variations of volatility spillovers amid a market S&P500, Green Bonds, Dollar Index, Real Estate Index, and WTI Oil markets



Source: Results of study

Considering exhibit 6, S&P500 is the most consequential volatility receiver from other markets, particularly amidst turmoil conditions. This matter suggests the dependence of S&P500 to other markets. It implies that authorities should scrutinize this market due to its significance for US economy, especially during crisis. It is worth mentioning that, although the green bond market gives the low volatility to the network, it received a high level of that from other markets. Between, 2020 and 2021, each market, except for oil, received high level of volatilities from other markets. After 2021, the level of risk-taking in each market decreased but for bond market this decrease is significant. The oil market showed a different trend in comparison to other markets. It received low volatility from the market between 2020 and 2021, but it experienced a surge after that.

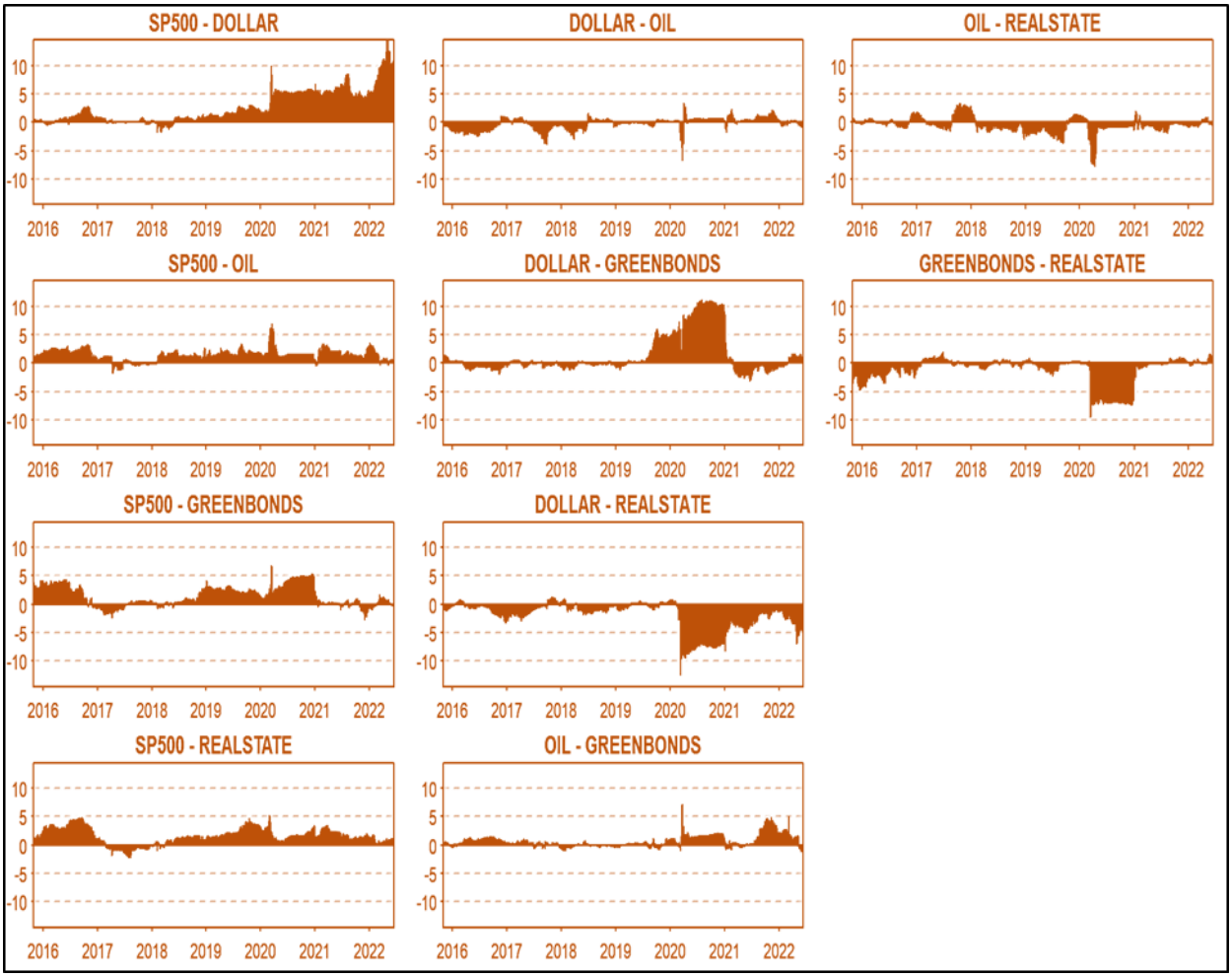
Exhibit 6: volatility spillovers from a market to S&P500, Green Bonds, Dollar Index, Real Estate Index, and WTI Oil markets



Source: Results of study

In order to compare pairwise spillovers among S&P500, Green Bonds, Dollar Index, Real Estate market, and WTI Oil markets, this study performs a close analysis resulting in exhibit 7. According to this exhibit, the pairs of S&P500 and dollar index have high intensity after 2020. By contrast, the relation between two pairs of the Dollar index and oil market and the oil market and real estate is weak and negative. Generally, pairs of (S&P-Oil), (S&P-Green bonds), (S&P - real estate), and (Oil-Green bonds) have low but positive ties with one another. During 2020 and 2021, pairs of (Dollar-Green Bonds), (Green bonds-real estate), and (Dollar index-real estate) have high positive, negative, and negative relationships together, respectively. However, their intensity decreased after 2021.

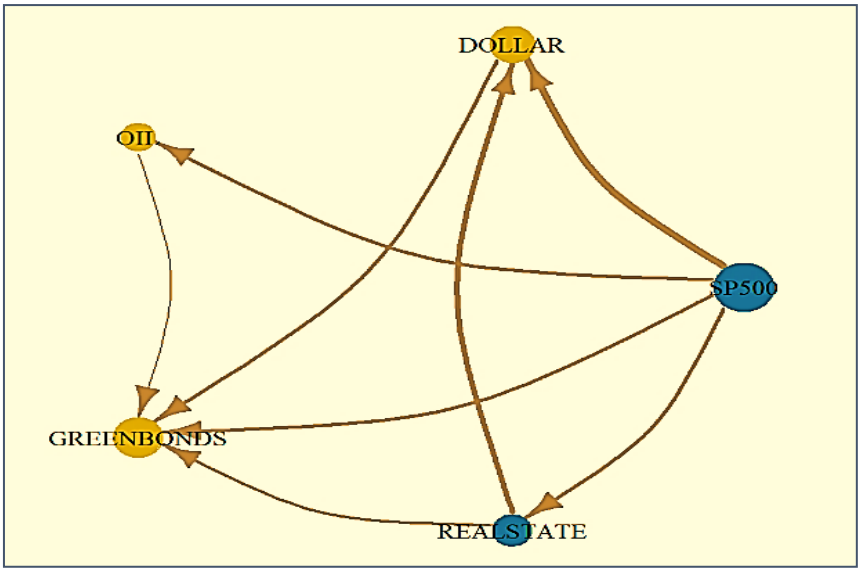
Exhibit 7: Pairwise spillovers based on the DY-TVP-VAR model



Source: Results of study

In a nutshell, exhibit 8 shows the System network connectedness among S&P500, Green Bonds, Dollar Index, Real Estate, and WTI Oil market. The bold arrows show the intensity of volatility spillovers between markets. According to this exhibit, S&P500 is a volatility transmitter, whereas the green bonds market is just a receiver. Other markets are both transmitters and receivers of volatility spillover.

Exhibit 8: System network connectedness among S&P500, Green Bonds, Dollar Index, Real Estate Index and WTI Oil market



Source: Results of study

Conclusions and policy implications

The relationship between the risk of different types of assets, including green bonds as a fixed income asset, is one of the important issues not only for optimal allocation in investors' portfolios, but also for policymakers' decision-making. This issue is especially important in the United States, as one of the leading countries in issuing green bonds. Considering the importance of this issue, the main aim of this study is to investigate the spillover risk between S & P 500, real estate, oil market, dollar index and green bonds.

In fact, Investors apply risk and return approach to diversify their portfolio, but, risk spill overs and connectedness between different markets should be incorporated in investment decision making, especially during crisis periods, which are not considered in portfolio optimization models like Mean-VaR. This study measured risk spillovers and connectedness between the S&P500 index, bond market, real estate market, oil market and dollar index using the TVP-VAR model from 2016 to July 2022. The results show that the S&P500 index and real estate market are two main drivers of volatility in the system compared to other markets. Not

only do they transmit more volatility, but they also receive more of it in comparison to others. After 2020, the level of the S&P500 index and real estate market volatility increases significantly, which could be due to the Covid-19 pandemic.

According to the net system of connectedness, S&P500 risk spillover diffuses to all markets, and real estate receives risk spillover from S&P500 and transmits it to the dollar index and green bonds. The oil market receives risk spillover from S&P500 and transmits it to green bonds only. The green bond market is the only one that receives volatility from other markets. It is worth mentioning that the intensity of risk spillover between the S&P500 to dollar index and real estate to dollar index are high compared to others. On the contrary, volatility spillover intensity from the oil market to green bond are not as strong as others.

The findings of this study can provide valuable insight for market participants. From an investor perspective, they can manage their portfolio risk more efficiently due to the holistic view yielded from the spillover and connectedness approach in contrast to the Mean-Variance model, which is used frequently.

Since there are pronounced links between S&P500 and the real estate market, investors should not include both in their portfolios. Furthermore, green bonds can be added to the portfolio as hedging means. The results show volatility spillovers of S&P500 and real estate market experienced a rise after 2020, and thus it is necessary for investors who analyze markets to consider this factor. Under this condition, financial participants ought to not only quantize non-static as well as other portfolios but also continually adapt their strategies to political and economic conditions. Therefore, portfolio managers and investors in different markets should formulate dynamic and alternative portfolios and regularly rebalance their portfolios according to the market circumstances and volatility spillovers. Also, financial actors should broaden their knowledge about market interaction to comprehend major volatility drivers. Investors should monitor S&P500 fluctuations due to its importance in the spillover network. They, as a result, ought to capture these index changes for making decisions in an investment scheme in financial markets.

From policy makers' perspective, USA policymakers should not neglect an in-depth analysis of the S&P500 index and its effects on other markets such as real estate and the dollar index, especially during a crisis. To illustrate, for example, monitoring real estate market is an

essential step towards reducing adverse effects of high shock diffusion to the system, which is analyzed in this study, specifically during the crisis. Adjusting economic strategies to react against health crises, including Coronavirus, bringing about real estate market and S&P500 represent high oscillations.

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