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**GREEN BONDS AND OTHER FINANCIAL MARKETS; DIVERSIFICATION AND
VOLATILITY TRANSMISSION PATTERNS AMIDST COVID-19**

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PHD IN FINANCIAL ANALYSIS AND POLICY



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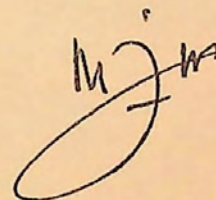
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ABSTRACT

The shift to a low-carbon economy and growing concern about the harmful impacts of climate change have heightened regulators' and investors' interest in environment-friendly financial products. As a result, green bonds have emerged as one of the most promising possibilities for assisting in the mobilisation of financial resources for clean and sustainable initiatives. Despite the tremendous demand for green bonds, very few studies analyse how the green bonds market offers portfolio opportunities to investors. Hence, the prime objective of the study is to examine the coherence between green bonds and other financial markets (stock, commodity, digital currency, bonds, and foreign exchange markets) in constructing an efficient portfolio. This study used global data ranging from November 2008 to March 2021. To achieve the objective of the study, various methods such as quantile on quantile regression (QQR), wavelets analysis, Diebold and Yilmaz (2014) spillover index, and dynamic conditional correlations (DCC) were applied. The QQR analysis confirmed asymmetric dependency between green bonds and other financial markets subject to changes in market conditions (normal, bearish, or bullish). However, during COVID-19, the green bonds market negatively correlate with other financial markets across the quantiles. Meanwhile, the findings from wavelet correlation and continuous wavelet transformation confirmed that coherence between green bonds and other financial markets is more evident up to the middle of the time frame of the study. In addition, the Diebold and Yilmaz (2014) spillover index findings showed that during the COVID-19 pandemic, green bonds transmit volatility spillovers to other pairs of markets. Finally, DCC findings confirmed that the green bonds market act as a safe haven against other financial markets during financial turbulence periods. Furthermore, this study has practical policy implications for individual investors, fund managers and policy makers.

Keywords: Green Finance, Green Bonds, Portfolio Diversification, Financial Markets

ABSTRAK

Peralihan kepada ekonomi rendah karbon serta kebimbangan yang semakin meningkat tentang kesan berbahaya perubahan iklim telah meningkatkan minat pengawal selia dan pelabur terhadap produk kewangan mesra alam. Hasilnya, bon hijau telah muncul sebagai salah satu kemungkinan yang paling menarik untuk membantu dalam penggemblengan sumber kewangan untuk inisiatif yang bersih dan mampan. Walaupun terdapat permintaan yang besar untuk bon hijau, kajian sangat terhad dalam menganalisis bagaimana pasaran bon hijau menawarkan peluang portfolio kepada pelabur. Oleh itu, objektif utama kajian adalah untuk mengkaji kepaduan antara bon hijau dan pasaran kewangan lain (saham, komoditi, mata wang digital, bon dan pasaran pertukaran asing) untuk membina portfolio yang cekap. Kajian ini menggunakan data global antara November 2008 hingga Mac 2021. Untuk mencapai objektif kajian, pelbagai kaedah seperti regresi kuantil pada kuantil (QQR), analisis wavelet, indeks limpahan Diebold dan Yilmaz (2014), dan korelasi bersyarat dinamik (DCC) telah digunakan. Analisis QQR mengesahkan pergantungan tidak seimbang antara bon hijau dan pasaran kewangan lain tertakluk kepada perubahan dalam keadaan pasaran (normal, menurun atau menaik). Walau bagaimanapun, ketika COVID-19, pasaran bon hijau berkorelasi secara negatif dengan pasaran kewangan lain di seluruh kuantil. Manakala penemuan berdasarkan korelasi wavelet dan transformasi wavelet berterusan mengesahkan bahawa kepaduan antara bon hijau dan pasaran kewangan lain lebih jelas sehingga pertengahan tempoh masa kajian. Selain itu, penemuan indeks limpahan Diebold dan Yilmaz (2014) menunjukkan bahawa ketika pandemik COVID-19, bon hijau memberikan limpahan turun naik kepada pasangan pasaran lain. Akhir sekali, penemuan DCC mengesahkan bahawa pasaran bon hijau bertindak sebagai tempat selamat terhadap pasaran kewangan lain semasa tempoh pergolakan kewangan. Tambahan pula, kajian ini mempunyai implikasi dasar praktikal untuk pelabur individu, pengurus dana dan pembuat dasar.

Kata kunci: Kewangan Hijau, Bon Hijau, Kepelbagaian Portfolio, Pasaran Kewangan

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**“Allah (SWT) does not burden a soul beyond that it can bear” | Surah
Baqarah (2:286)**

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ABBREVIATIONS

ESG	- Environmental, Social and Governance
SDGs	- Sustainable Development Goals
ICMA	- International Capital Market Association
EIB	- European Investment Bank
AFDB	- African Development Bank
CBI	- Climate Bonds Initiative
MPT	- Modern Portfolio Theory
APT	- Arbitrage Pricing Theory
EMH	- Efficient Market Hypothesis
S&P_GB	- S&P Green Bond
S&P_500	- S&P 500
DJ_IMWI	- Dow Jones Islamic Market World Index
S&P_GSCI	- S&P GSCI Index
CRIX	- Crypto Index
S&P_BD	- S&P 500 Bond
DJ_SUK	- Dow Jones Sukuk
FRX	- Foreign Exchange
QQR	- Quantile on Quantile
QR	- Quantile Regression
CWT	- Continuous Wavelet Transformation
MODWT	- Maximal Overlap Discrete Wavelet Transforms
DY	- Diebold and Yilmaz
DCC	- Dynamic Conditional Correlations

CHAPTER 1: INTRODUCTION AND BACKGROUND

1.1. Introduction

This first chapter discusses the background information on the relationship between green bonds and other financial markets and the impact of COVID-19 on these financial market's correlation. This chapter continues to discuss the problem statement followed by the research questions, objectives, significance and contribution, the scope of the study and finally the structure of the present study.

1.2. Background of the Study

The exponential growth of the global population, the depletion of resources and environmental challenges are the main factors in the transformation of the greener and healthier world that we are experiencing today. Climate change is a major problem that poses significant challenges to our environment and can harm our future generations. However, many agencies, organizations and academics have condemned the financial sector for this climate change.

Consideration of ethical standards and ethics has long been seen as a barrier to profitability in the business world. But, these views have recently shifted, and stakeholders from customers to creditors not only welcome them but demand more openness and commitment to ethical principles ([Glomsrød & Wei, 2018](#)). Environmental, social and governance (ESG) policies are growing significantly in this century when it comes to business decision-making and strategy formation. The finance industry, which has been heavily condemned for its ethical actions since the last financial crisis, gradually applies ESG and other sustainability principles to its investment decision-making mechanism. In today's business world, ethics "sells" and ethical violations are "punished" by public reputation damages and shareholder protests.

Due to the high importance of ESG, companies include environmental considerations in their policies ([Cao et al., 2019](#)). Recently, [Hart and Zingales \(2017\)](#) suggest maximizing shareholder welfare rather than stock returns. [Magill et al. \(2015\)](#) offer a stakeholder structure to show that a much more sustainable equilibrium is achieved when management increases the overall value of the company instead of the shareholders alone. Currently, worldwide, stakeholders are seeking responsible and sustainable business models ([EY, 2016](#)). However, heading towards a low or even carbon-neutral environment calls for green financial capital approaches from a business standpoint.

The Paris Agreement¹ of 2015, replacing the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol, is the first agreement to put together all countries, along with the United States, for collective action under the international public policy coalition and, at the same time, provides a forum for investors to fight against climate change. The prime goal of the Paris Agreement is to reshape all capital flows away from fossil fuels and headed for sustainable forms of production. The COP21 conference in Paris, which retains its pledge that global, warming, will stay far below 2 ° C relative to pre-industrial temperatures. Moreover, USD 100 billion will be mobilized annually by 2020 to reduce the impacts of climate change in developing countries, which has historically would be seen as a turning point. The UN also considers addressing climate change as one of its 17 sustainable development goals (SDGs).

¹ Over 195 countries worldwide (UNFCCC member nations) signed the Paris Climate Agreement (PCA) in 2015, a resolution that acknowledges the interdependence of mitigation, adaptation, and financing in order to successfully combat global warming and also its damaging consequences globally.

Overall, political support for resolving the environmental problem is gaining popularity and provides strong indications for potential investment trends ([Clapp et al., 2015](#)), following the U.S. government's change of attitude, the private sector feels the need to move on it. Green finance, in general, is therefore expected to play an essential role in the execution of these objectives. There is a substantial increase in institutional investors' preference for a financial asset that involves both the need for acceptable short-term portfolio risk and a diminishing risk of long-term climate change ([Climate Bonds Initiative 2017](#)).

Environmental finance or climate finance or green finance is, therefore, a new financial strategy aimed at merging ecological protection with economic development, with the focus on "green" and "financing." In recent years, the idea of "green bonds" has increasingly emerged in the mainstream as a modern green financial tool that tackles environmental concerns and has the essential features mentioned above. Green finance (especially green bonds) was implemented due to the current pressing issue of how ecosystems can flourish economically without affecting the environment.

1.3. Background of Green Bond Markets

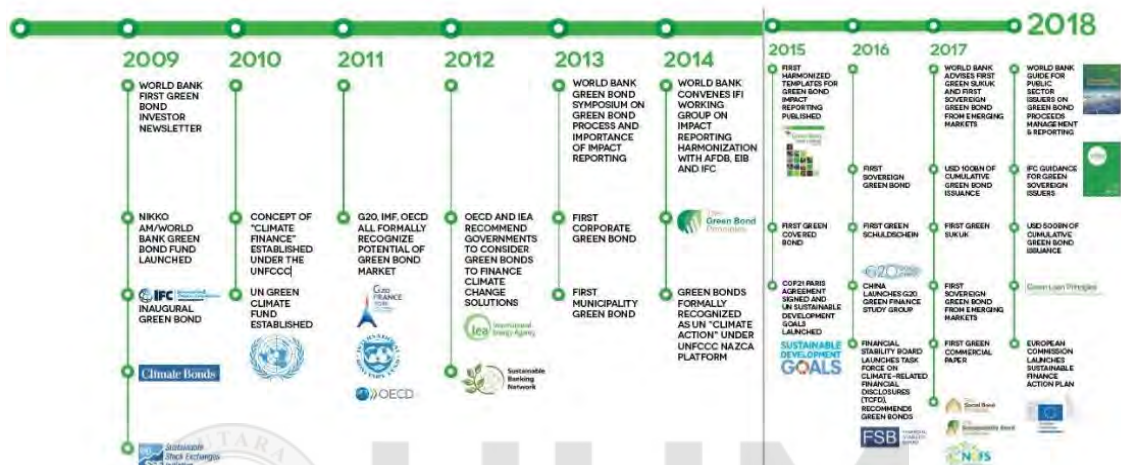
The World Bank describes a green bond, for example, “a debt security that is issued to raise capital specifically to support climate-related environmental projects” ([World Bank, 2015](#)). While the International Capital Market Association (ICMA) also defines green bonds as similar to World Bank “green bonds enable capital-raising and investment for new and existing projects with environmental benefits”. A green bond may be “labelled or ‘unlabelled’”. The labelled green bonds are publicly sold as “green” by the authority who issue these bonds, where issuers identify the kinds of environmental projects (initiatives) they expect to finance with funds raised by these bonds and report continuously to their investors. While corporations whose businesses

are inherently issued unlabeled or non-green marked bonds linked to environmental causes, e.g. wind energy or solar energy firm's bonds are known as unlabeled bonds. There are several projects, which are supported by the green bonds' proceed; however, two projects are prime, e.g. green energy and low carbon transport ([Shankleman, 2016](#)). In contrast to conventional bonds, a green bond is a promise to use funds collected purely for the financing or refinancing of green projects, assets or businesses activities. Green bonds, as debt instruments for long-term funding, launched in 2007 and has since undergone more than 50% compounded annual growth rate ([Kochetygova & Jauhari, 2014](#)). The European Investment Bank (EIB) issued the very first green bond, and the name of the bond was called a climate awareness bond. There are majorly four principles of green bonds "(i) Use of Proceeds (ii) Process for Project Evaluation and Selection (iii) Management of Proceeds and (iv) Reporting". Green bonds also deliver many advantages to investors, issuers, creditors, and policymakers. The green bonds suit for the issuers, because long-term investment maturities, reducing financial debt expenditures ([Curley, 2014](#)). Furthermore, green bonds improve environmental and financial efficiency at the corporate level ([Flammer, 2018](#)). Moreover, investors can effectively endorse their investment decisions with detailed information on sustainability policies of issuers ([Ng, 2018](#)) and improve access to less risky financial instruments ([Veys, 2010](#)), which appeal to both conventional profits gaining investors and to socially conscious

investors ([Chatzitheodorou et al., 2019](#)). The previous empirical studies have shown that green bonds highly affect environmental pollution reduction.

Fig 1.1 below shows the growth of green bonds within ten years after the launch of green bonds:

Figure 1.1: Growth of Green Bonds



Source: Green Bond Impact Report 2018

This drastic effect of green bonds on environmental pollution reduction is because most of the projects are funded through green bonds including “(1) renewable energy (2) energy efficiency (3) pollution prevention and control (4) environmentally sustainable management of living natural resources and land use (5) terrestrial and aquatic biodiversity conservation (6) clean transportation (7) sustainable water and wastewater management (8) climate change adaptation (9) eco-efficient and/or circular economy adapted products, production technologies and processes and (10) green buildings which meet national or internationally recognized standards or certifications” ([Tolliver et al., 2019](#)). Various studies confirm energy consumption is one of the major causes of environmental degradation and green bonds projects facilitate green energy projects that’s why green bond financing directly reduces ecological damages.

The following table 1.1 shows green bonds sectoral percentage contribution. The significant projects supported by green bonds are renewable energy (solar energy), energy efficiency, and clean transportation as of June 30, 2018. However, to achieve a sustainable environment an estimate of OECD² has shown that between 2012 and 2030, total funding in green infrastructure development of US\$ 36–42 tn is needed ([OECD, 2012](#)). The World Bank has successfully raised more than US\$ 10bn from green bonds since the inception of the green bonds market and has allocated its funds into 91 projects (25 completed) in 28 nations. There are various projects, which are already completed ([World Bank, 2017](#)), for example, Dominican Republic's energy and sanitation project, the hydropower plants project in India, the energy efficiency project in Tunisia, Turkey's green energy project. Since the inception of green bonds, the European Investment Bank (EIB) has collected almost EUR 20bn to support pollution-free projects. The projects, which support the environment, are mostly in Europe.

However, there are various projects, which are in developing economies as well. For example, two projected of wind power in Kenya and Mongolia that got EUR11.7m & EUR14.3m respectively from green bonds, in Peru Wayrawind farm and the Rubí solar PV plant projects got EUR84.4m green bond ([EIB, 2017](#)).

Table 1-1 Green Bonds Sectoral Contribution

Amounts in US\$ billion (may not add up due to rounding)	Committed			Allocated and Outstanding
	Mitigation	Adaption	Total	
Renewable Energy and Energy Efficiency	6.1	0.1	6.1	3.7
Clean Transportation	5.0	0.2	5.2	2.2
Water and Wastewater	0.1	1.2	1.3	0.8
Solid Waste Management	0.1	0	0.1	0.1
Agriculture, Land Use, Forests, and Ecological Resources	0.5	1.2	1.8	0.9

² Organization for Economic Cooperation and Development

Resilient Infrastructure, Built Environment and Other	0.3	0.7	0.9	0.7
Total	12.0	3.4	15.4	8.5
Percentage	78%	22%	100%	

Note: This table shows green bonds sectoral percentage contribution³

Green bonds are widely acknowledged not only domestically, but also internationally. Because of the exponential growth of the demand for green bonds⁴, Morgan Stanley described it as a “green bond boom” ([Stanley, 2017](#)) and the Financial Times ([Street, 2014](#)) has written, “green bonds are the answer to Africa’s investment need”. The African Development Bank (AfDB) in Africa has been involved in a green bond market and issued a triple-A grade investment of US\$ 500 million in 2013. Since 2013, the AfDB has released six green bonds, amounting to US\$ 1.5 billion that have been used to carry out 24 projects in 14 countries⁵.

Several members on the continent include IDC (USD 700 m) and Nedbank (USD 490 m) mainly in South Africa. Green bonds gained investors from traditional and local markets. For instance, socially responsible investors purchased 84% of the bonds in the case of the first AfDB issuance. Investors consisted of 43% fund managers, 28% insurance & pension funds, 28% central banks & government institutions, and 1%

³ Green Bond Impact Report 2018

⁴ In the previous five years, the green bonds market grows continuously, year after year, with US\$106 billion issued in 2017. This amount is anticipated to rise even higher, with a total of US\$1000 bn estimated to be achieved by the year 2020. A steady rise in the number of green bonds issuers is also observed; by the end of 2017, there were more than 550 issuers from 45 different nations and comprising 29 multiple currencies. Chinese issuance accounted for around 15% of the entire global issuance in 2017, making it the leading participant.

⁵ Some of the initiatives that have benefited from green bonds include: “Railway Infrastructure Reinforcement Project in Morocco”, for which the African Development Bank (AfDB) provided 28% of the funding, with Approximately USD 67.3 million generated from green bonds. (ii) “The Cabeólica Wind Power Project in Cabo Verde”, for which the AfDB provided 23% of the funding, with Approximately USD 12 million generated from green bonds. (iii) The installation of Itezhi Tezhi hydropower plant in Zambia, for which EIB provided EUR50 million and the AfDB provided 15% of the funding. (iv) “The Uganda Rural Electricity Access Project, the Buseruka Hydropower Project and the Farm Income Enhancement and Forest Conservation Program, designed within the context of the Government of Uganda’s National Development Plan and the long-run development strategy ‘Uganda Vision 2040’, all of which were financed by green bonds issued by the ([AfDB, 2017](#))”.

private banks, 39% in Europe, the Middle East and Africa, 52% in America, and 9% in Asia ([AfDB, 2016](#)).

Also, bond types are increasing, the Poland was the first government to launch a green sovereign bond in December 2016 and followed in January 2017 by France. The US government corporation Fannie Mae released the largest \$24.9 billion green mortgage-backed securities (MBS) up to date in 2017. While, Malaysia introduced green Islamic bonds, the first green bond world-widely “green Sukuk” in June 2017 to finance environmentally sustainable projects. However, the category of the issuer is now dramatically growing to include supranational organizations (for instance, World Bank, IFC), corporate (e.g., Bank of America), non - financial banking companies (i.e., REITs), companies (such as Apple, Inc. and Tesla) and development banks (for example, ADB, AfDB). The yearly issuance volume for green bonds, according to Thomson Reuters, amounts to 155.5 billion dollars in 2017, and 263 billion dollars by 2019, up 43% from 2018, and gained steam to achieve the 1 trillion dollars 2020 target. Furthermore, 963 bonds were issued in 35 countries in the first 3 quarters of 2018. The investment companies and businesses regularly use green bonds. Many governments, particularly in Asia, including Hong Kong and Singapore, provide massive support for this market expansion.

Some work has sought empirically to assess whether or not green financing (green bonds) substantially decreases environmental risks. The empirical results indicate that green finance (climate bonds) reduces ecological risks. For example, [Sachs \(2015\)](#) suggests that environmental sustainability can be achieved through green financial instruments. [Wang and Zhi \(2016\)](#) indicated that funding for solar energy might achieve ecological sustainability. While, [Li and Jia \(2017\)](#) have observed that environmental or green finance is the most successful way to reduce the deterioration

of the environment. Sustainable financing fosters investment in innovative technology and developments, including renewable or solar energy ([Böhringer et al., 2015](#)). According to a recent study by Meo and Karim (2021), green bonds can help to reduce pollution.

After studying, either green finance (green bonds) significantly reduce environmental risk another concern emerges from corporates or investors perspective. In the current time, the community is mainly concerned with environmental issues. Still, the investor or the company is concerned about environmental issues and the maximization of wealth as well. Because of the significant economic and ecological benefits of green bonds, it is crucial to know the dependency and volatility behaviour of green bonds relative to other traditional investments. The rapid development of the green bonds market generates a need to tackle its risk, return and diversification features to provide investors with useful understandings of the market.

Therefore, for the best interest of investors, a few studies find dependency and volatility spillovers between green bonds and other financial markets. Knowing how green bonds and other financial markets co-move is very important for investors, as it can explain the diversification opportunities of allocating green bonds to a portfolio and indicate whether financial markets price movements can influence green bond prices.

It is most essential to understand the dependency structure between financial markets for policymaking, asset pricing and most important for constructing an efficient portfolio. Investors see how different assets correlate because of the risk-return trade-off. [Bekaert et al. \(2014\)](#) find that correlation between financial assets is highly sensitive to the market condition such as bullish or bearish. Thus, it is essential to analyze how financial markets or financial assets are interlinked. This has implications

for managing risk, devising strategies for portfolio construction ([Mensah & Alagidede, 2017](#)).

After a careful literature review on green bonds and other financial markets comovement, we find very few studies, which examined comovement between green bonds and other financial markets. For instance, [Reboredo \(2018\)](#) conducted an empirical study to examine the comovement between green bonds and other financial markets. This study is cited in green bonds literature as a leading study, which empirically tested green bonds comovement with other financial markets. The results suggest that the green bonds market have minimal benefits for investors in corporate and treasury markets, while diversification benefits are significant for investors in equity and energy markets. This study also finds that from corporate and treasury fixed-income markets price spillover highly effect to green bonds market; however, volatility in energy and the stock market do not affect the prices of the green bonds market.

[Broadstock and Cheng \(2019\)](#) examine the correlation between green and conventional bond prices; they find that various factors affect correlation such as volatility, good-bad news and economic policy uncertainty. A recent study by [Reboredo and Ugolini \(2020\)](#) also confirm comovement between fixed-income, currency markets and green bonds receiving sizeable price spillovers from those markets and transmitting negligible reverse effects. [Reboredo et al. \(2020\)](#) have identified a strong short and long-term relationship between green, treasury and corporate bonds. They also find that the green bonds market received spillover effects from both financial markets in the EU and the USA. Additionally, green bonds have a weak correlation with high-yield corporate bonds, energy assets and stock over different time scale.

Moreover, the traditional econometrics method of correlation is unable to provide complete dependency between financial assets. For example, the negative return of an asset's (10th percentile) generally followed by the negative returns of the other asset's (10th percentile) cannot be addressed by using the traditional correlation method. Thus, a simple correlation method is unable to provide complete information ([Reboredo & Ugolini, 2016](#)). In addition, there are several reasons that create this non-linear relationship between variables, such as sudden policy changes, different financial crises and the recent emergence of the COVID-19 pandemic, and for all of these reasons, the simple correlation approach fails.

Therefore, traditional correlation approaches are not able to accommodate these structural breaks and provide misleading inference. Despite much research, this study did not find any research study, which examines the complete dependency structure between green bonds and other financial assets in bearish, mild bearish, mild bullish or bullish markets states. Therefore, it is most important to examine the complete dependency structure⁶ between green bonds and other financial markets (stock, commodity, digital currency, bonds and foreign exchange market etc.) in bearish, mild bearish, mild bullish or bullish market states to exploring the potential for diversification in the green bonds market.

There are various factors, which contribute to the performance of financial markets. For example, economic conditions, political stability, market volatility, financial crisis and pandemic uncertainty, among other factors. Currently, the whole world suffering from the COVID-19 epidemic, which affects almost all financial markets, other businesses and social life. Therefore, this study also examined the correlation between green bonds

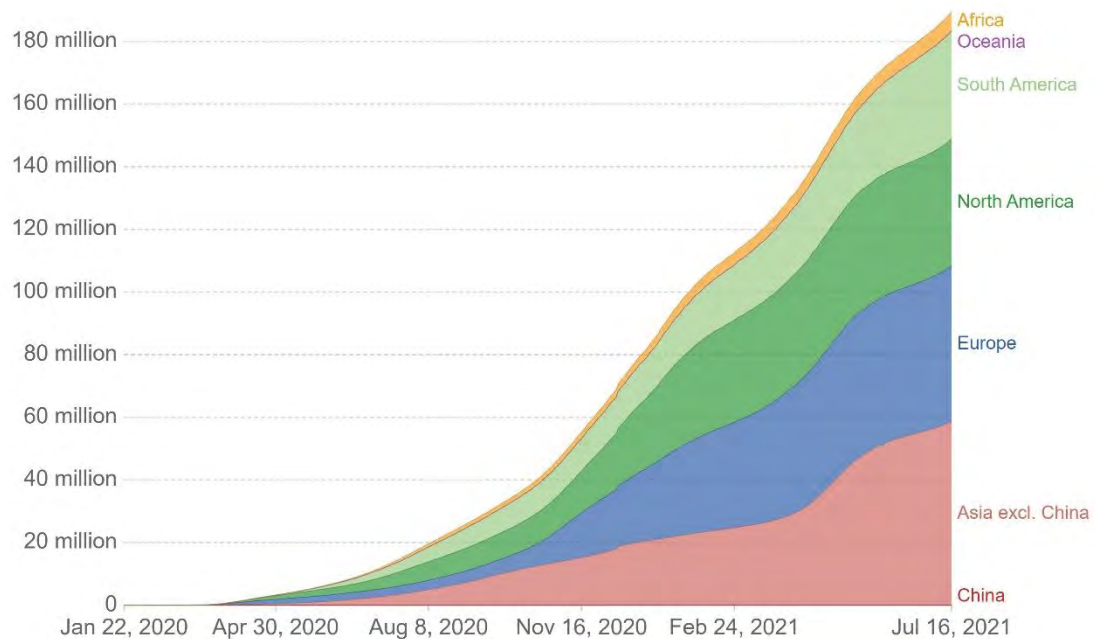
⁶ Complete dependency structure means, checking correlation between financial markets in all the situations like when markets are bullish, bearish, mild bullish or bearish.

and other financial markets considering the role of the COVID-19 outbreak. It is known that diversification advantages between financial assets have reduced in periods of extreme market volatility ([Campbell et al., 2002](#)). The new coronavirus (also known as COVID-19) outbreak was first identified in December in Wuhan, China. The dramatic threat of COVID-19 can be understood by looking at the total number of deaths and confirmed cases. The total number of fatalities exceed 4,093,043 and the total confirmed cases are 190,350,960 as of July 17, 2021.

Although new cases appear to have been resolved in China around March 2020, the total number of cases has risen exponentially in the rest of the World. The World Health Organization (WHO) formally announced on 11 March 2020 COVID-19 as a global pandemic. More than 170 countries suffered from COVID-19, with the most recorded cases (34,929,856) in the USA as of July 17, 2021. The COVID-19 epidemic had clear economic consequences. As several countries implement strict quarantine policies or smart lockdown in the short term, their business activities are substantially restricted. Rising unemployment with business failures could lead to the longer-term effects of this COVID-19 outbreak. Many countries have enforced stringent steps such as travel bans, social barriers, school and business closures, bars, restaurants ban to avoid the spread of the new virus.

The novel COVID-19 is not just about one area or nation but is a global issue; the following figure 1.2 shows the regionally confirmed number of cases.

Figure 1.2: Regional Confirmed Cases of COVID-19 Globally



Source: Johns Hopkins University CSSE COVID-19 Data

The empirical research on recession is extensive ([Bentolila et al., 2018](#); [Bezemer, 2011](#); [Gaiotti, 2013](#); [Mian & Sufi, 2010](#)). Nevertheless, the origin of the global recession in 2020 is fresh in modern history. COVID-19 initiated a new type of economic crisis, different from the previous causes of the recession.

For example, the 1997 Asian debt crisis had been attributed to the failure of the Thai baht that formed fear and confusion that triggered Asia's regional financial crisis and economic slump ([Radelet et al., 1998](#)). The prime reason for the 2008 financial crisis was the loss of monetary policy ([Allen & Carletti, 2010](#)). The collapse triggered Nigeria's 2016 crisis in crude oil prices, the balance of payments deficit, the implementation of the fixed-float exchange rates, and a rise in the pump price of petrol, pipeline vandals and infrastructure failures. The crisis in Greece in 2010 was due to the global financial crisis of 2008 because of the Greek weak economic framework ([Rady, 2012](#)). However, the 2020 economic recession or depression is triggered by COVID-

19, which is not the issue of a single nation, but has devastated world economies, and yet there is no indication of how long this pandemic will last. In a time of severe uncertainty or economic disaster, it is difficult to make financial or economic decisions because pandemics are unusual. The latest equivalent event is the 1918 Spanish Flu ([Trilla et al., 2008](#)), and epidemics may happen at once in each century. However, people have to take decisions such as buying and selling stocks, but all the decision during a pandemic depends on the pandemic severity.

Due to panic and confusion, companies' earnings lowered due to the effects of COVID-19, and global financial markets lost around \$6 trillion in equity in a week during the 24th -28th of February 2020. In the same week in the US, the S&P 500 index dropped about \$5 billion in revenue, as the S&P 500's top 10 firms suffered a cumulative loss of over \$1.4 trillion. It is observed that the world financial sector is highly affected due to COVID-19. Hence, it is most important to study green bonds and other financial markets comovement considering the role of COVID-19, to see whether this pandemic effect correlation or not between proposed financial markets.

Nowadays, the reaction of the financial markets and the outbreak of COVID-19 has attracted the attention of academics, policymakers and investors. There are few empirical studies, which find the impact of COVID-19 on financial markets such as [Zhan et al. \(2020\)](#) examined the impact of COVID-19 on stock market risk. They discovered that COVID-19 significantly increased global financial markets risk but based on the country-specific investigation, they find that each country stock markets effect as per the severity of country-specific COVID-19. [Ozili and Arun \(2020\)](#) found that the growing length of time of lock-down, monetary and overseas travel policy choices, significantly affected the performance of the economy and performance world largest stock indexes. A recent study also found that areas with high levels of the corona

various also made financial markets more volatile ([Albulescu, 2020](#)). Hence, it is important to study more deeply the effect of COVID-19 on various financial markets to understand comprehensively its effect.

Additionally, many empirical studies find that various investors have various investment horizons (short, medium and long-term) for example, the investment period of brokers varies from several minutes or hours to days, pension funds and sovereign wealth funds, which typically invest for multiple years ([Baruník et al., 2011](#)). Consequently, the comovement assessment must consider the fundamental difference between short-term and long-term investors ([Candelon et al., 2008](#)). A strong correlation between financial assets shows low diversification opportunity while no correlation or comovement show high diversification opportunity. Hence, an accurate estimation of comovement between assets is most important to mitigate the risk of the portfolio. However, comovement among the financial markets varies over time and frequency domain such as short, medium or long run. Thus, one must be capable of capturing this time-varying functionality as it indicates an evolving exposure to risk.

On the other side, the difference between short and long-term investors cannot be overlooked because the former is more involved in short-run fluctuations. While the latter is more interested in long-run movements. It means different types of investors risk preferences varies, and comovement across the financial markets or assets varies over the different frequencies. As per the best knowledge of the author, it is found that previous studies ignore such investigation between green bonds and other financial markets (stock, commodity, digital currency, bonds and foreign exchange markets). Therefore, it is most important to study comovement between the green bonds market and other financial markets based on time and frequency consideration to reduce portfolio risk.

Furthermore, over the last few years, there have been massive disruptions in the financial sector, leading to major international crises, including the Black Monday of October 1987, the Asian debt crisis of 1997, the European sovereign debt crisis of 2009, the global financial crisis of 2008-2009, the Greek crisis of 2010, the Nigerian crisis of 2016 and most recently COVID-19 pandemic outbreak. After these big incidents, researchers began studying volatility spillover effects between the financial markets. Volatility spillover is a process of information dissemination between various financial markets. Spillovers are found in returns and volatility, usually linked to risk ([Diebold & Yilmaz, 2014](#)). Realizing volatility spillover across markets is essential to risk managers, hedgers and policymakers particularly following the economic crisis or financial crisis.

The analysis of volatility spillover thus has a significant impact on improving portfolios, effective hedging, risk distribution and constructing policies to avoid damaging shock dissemination. Moreover, the enhanced globalization of financial markets over the last several years encouraged scholars and financial economists to study volatility spillover profoundly across financial markets, to avoid hazardous transmission of shocks, and to reduce the spread of financial crises or economic crises across borders. Even though the importance of volatility spillover effect between green bonds market and other financial markets, there are only a few studies, which empirically tested volatility spillover behaviour.

For example, [Reboredo \(2018\)](#) and [Pham \(2016\)](#) discovered that traditional bond market volatility have a significant impact on green bond markets. According to Reboredo (2018), huge price movements in the stock and energy markets have no effect on green bond prices. [Reboredo and Ugolini \(2020\)](#) further examine that shock in fixed income and currency market transmit to green bonds market. [Park et al. \(2020\)](#) also

finds overall scarce literature on volatility spillover effects between green bonds and other financial markets. Therefore, it is essential to expand the literature on the volatility spillover effect between green bonds and some other financial markets like (stock, commodity, digital currency, bonds and foreign exchange market etc.). The volatility effect between green bonds and other financial markets must also be studied in order to get insight into how to create optimal portfolios, efficient hedging, risk distribution, and developing regulations to prevent damaging shock transmission.

1.4. Problem Statement

Global warming is today's dominant theme, and we are at a turning point. Global warming is responsible for creating a series of problems such as failure of crops yield, rising sea level, desertification, in addition to that; it is forecasted that the temperature will increase to 1.1 – 6.4 °C in the 21st century (IPCC 2013⁷). Without decisive steps now, future adaptation to these effects will be much more complicated and expensive. Since environmental pollution and depletion of natural resources are becoming increasingly important issues, the Sustainable Development Goals (SDGs) have acted as a catalyst for new ideas like sustainable growth. There is a total of 17 SDGs and 8 (“Clean Water and Sanitation, Affordable and Clean Energy, Industry, Innovation and Infrastructure, Sustainable Cities and Communities, Responsible Consumption and Production, Climate Action, Life Below Water and Life on Land”) out of 17 purely focus on sustainability. Nowadays, it is acknowledged by various reports and studies that if needful steps have not been exercised to eliminate global warming, it could significantly decrease future economic growth and can lead to environmental disaster (DeCanio, 2009).

⁷ https://www.ipcc.ch/site/assets/uploads/2018/03/WG1AR5_SummaryVolume_FINAL.pdf

Currently, the financial sector is criticized for ignoring ecology. The financial sector affected the environment tremendously, therefore, the financial industry needs the knowledge to work effectively. Moreover, in their decision-making procedures, financial institutions scarcely care for the ecology. That has contributed to a rising number of environmental issues, including environmental degradation, pollution and depletion of resources. Despite its major role in the Anthropocene, finance has done relatively little to address ecological concerns (Scholtens, 2017). Finance is the company's bloodline and must be connected to environmental goals to promote corporate participation in sustainable practices.

Therefore, the financial sector took the initiative to fight against this world problem by introducing green finance (mainly green bonds) in response to financial sector negligence. According to a number of studies, green bonds have tempting properties in terms of their ability to redistribute the costs of minimizing the harmful effects of climate change over time ([Flaherty et al., 2017](#); [Orlov et al., 2017](#); [Sachs, 2014](#)), green bonds are also strongest financial investments to fund low-carbon growth ([Monasterolo & Raberto, 2018](#)). Moreover, [Li and Jia \(2017\)](#) and [Sachs \(2015\)](#) found that green financial instruments could achieve a green environment. Indeed, now a day's governments and international companies around the globe have made enormous efforts to encourage environmentally sustainable investments. However, to date, financing initiatives have proven unable to achieve a huge amount of funding planned to cope with climate change.

No doubt, currently investors care about the ecology like other stakeholders of the community. However, they want to invest their funds in those projects, which are eco-friendly (such as renewable energy projects, among others) but they also want to

maximize their wealth. Hence, investors want to achieve both objectives from their fund, (1) environmental sustainability and (2) wealth maximization.

Therefore, considering the potential of the green bonds market, it is necessary to study this market deeply from various perspectives (For, example diversification, co-movement, hedge or safe haven and volatility spillovers). All the individual investors, portfolio managers want to develop a profitable portfolio to increase their wealth or returns. However, to develop an optimal portfolio need to understand the interdependency and most important spillover effects between financial markets. The importance of such expertise is continually growing and essential to the development of optimal portfolios as there is a growing regulatory and fundamental convergence among financial markets pushing out the diversification opportunity for investors ([Aloui et al., 2011](#)).

There are few studies, which empirically tested the diversification benefits of the green bonds market. For example, [Reboredo \(2018\)](#) confirm that the corporate and treasury bonds market commove with the green bonds market, and it shows no diversification opportunity. While stock markets, energy commodity and green bonds markets do not commove, and it shows diversification opportunities. [Nguyen et al. \(2021\)](#) also discover that green bonds provide diversification benefits with the stock and commodity markets due to their low correlation. [Reboredo and Ugolini \(2020\)](#) didn't find any comovement among stock market, energy commodity market, high-yield corporate bond and green bonds market. [Reboredo et al. \(2020\)](#) revealed strong comovement among green bonds market, treasury and corporate bonds in the EU and the USA. Furthermore, they confirmed the absence of comovement between the green bonds market, high-yield corporate bonds, stock market and energy commodity market.

A depth literature review confirms that there are very few studies, which empirically analyzed diversification benefits of the green bonds market with other financial markets. The majority of prior research on green bond portfolio diversification has only looked at corporate debt and high-yield corporate debt, stocks, energy markets, and currency markets. Therefore, its dire need to explore more portfolio diversification benefits of green bonds with other financial markets such as (conventional stocks, Islamic stocks, commodity, digital currency, conventional bonds, Sukuk and foreign exchange markets etc.) in the global context, to acquire the trust of investors and raise funds through green bonds to safeguard the environment.

Furthermore, the green bond market has seen an increase in issuances from \$11 billion in 2013 to \$37 billion in 2014 since the first green bond was issued by the European Investment Bank in 2007. \$43bn 2015, \$81bn 2016, \$155.5bn 2017 and \$167.6bn 2018 ([Reboredo & Ugolini, 2020](#)), \$290bn in 2020 and 500bn in 2021 ([Garcia-Zarate, 2021](#)). This growth, although, is far lower than the investments expected by firms, supranational agents and governments. For instance, an estimation indicates that for the next 15 years, some USD 90tn is required to meet UN sustainability goals and climate commitments ([GFSG, 2016](#)). Nonetheless, given the massive popularity, inspiration and awareness of green bonds market is still like an infant in front of the traditional global bond sector. The global green bonds market is about 1% of global conventional bonds market and it shows a huge potential to grow ([Garcia-Zarate, 2021](#)). Because of this, it is vital to compare the green bond market to other financial markets from a diversification perspective in order to generate more funds and attract investors. Furthermore, recently world facing COVID-19 outbreak. The coronavirus epidemic (COVID-19) was formally announced as a global pandemic on 11 March 2020. The world economic implications of the COVID-19 are not obvious yet, but there have

already been drastic changes in the financial market response. The US stock market reached the circuit breaker mechanism 4 times in 10 days in March 2020. From the time when it was founded in 1987, it was only once triggered in 1997. The stock markets in Asia and Europe as well fell with the US collapse. FTSE, the UK's largest index, plummeted more than 10% on March 12, 2020, it was one of the worst days since 1987. Japan's stock market fell more than 20% from its highest point in December 2019. Financial institutions and governments reacted rapidly by advancing their policy instruments. As the epidemic has caused extreme volatility over how destructive it is, if and where we get an antidote, what impact policy measures would have, how society will adapt, etc. ([Wagner, 2020](#)), the response of investors is still confused with extreme uncertainty ([Baker, Bloom, Davis, & Terry, 2020](#)). The results of a thorough literature review revealed that few research studies are exploring how COVID-19 affects the diversification of green bond portfolios. A new study by [Naeem et al. \(2021\)](#) confirms that pandemic crises have a key influence on the diversification of green bond portfolios. Considering the critical situation of COVID-19, it is most important to find the benefits of whether COVID-19 change of portfolio diversification and to understand the patterns of systematic risk in financial markets.

Furthermore, in the portfolio diversification, or optimal portfolio selection correlation between selected security or assets play a vital role. Furthermore, the correlation between asset returns changes over time (nonlinear correlation or time-variant correlation) and increases dramatically in bearish market situations ([Forbes and Rigobon, 2002](#)). Due to the asymmetries, or nonlinearities and heterogeneity in assets relationship conventional estimation techniques for example simple regression may provide misleading results. For example, for large price shocks, the interdependence between financial assets may differ from that under low price shocks. Likewise,

Financial markets may have a heterogeneous or varying relationship or correlation, depending on market conditions (i.e. bearish or bullish). For this reason, it is imperative to investigate the relationship between green bonds and other financial markets to understand the correlations in various market conditions (bearish, normal or bull) to devise the best strategies for optimal portfolio construction.

In addition, different investors allocate their funds according to their requirements; some investors allocate funds for the short term (such as investment banks) and others allocate funds for the medium and long term (such as insurance companies, pension funds). Hence, investors' concern about portfolio returns vary, depending on their requirements; for example, long-term investors are concerned about low-frequency returns, while short-term and medium-term investors are concerned about high and medium frequencies. While, previous studies ignore such kind of investigation considering the green bonds market, which ultimately reduce scope of diversification in green bonds market. Hence, it is most important to find comovement between proposed financial assets considering investors requirements (i.e. long-term, short-term or medium) to provide diversification opportunities to short, medium and long-term investment holding investors.

Finally, the world is currently suffering from COVID-19, which has had a significant impact on financial markets and created anxiety among investors. In the wake of the pandemic, the volatilities in financial markets significantly soared, which led to enormous losses for market participants. In addition, during the periods of financial meltdown, policy makers and investors take keen interest in understanding the magnitude and direction of spillovers between different asset classes to restore financial stability and enhance portfolio decisions (Bouri et al., 2020). However, in the literature, there is a scarcity of studies, which find volatility spillovers between green bonds and

other financial markets. Hence, it is necessary to investigate the volatility spillovers between green bonds and other financial markets to determine whether green bonds serve as a safe haven during markets turbulences.

1.5. Research Questions of the Study

Several questions arise from the problem statement, which includes;

1. Does the dependency structure between green bonds and other financial markets vary under bearish, normal and bullish market states?
2. Does COVID-19 change the comovement pattern between green bonds and other financial markets?
3. Does the dependency structure of green bonds and other financial markets change over different investment horizons?
4. What is the net volatility spillovers transmitter and who is the receiver between green bonds and other financial markets?
5. Does the green bonds market act as a diversifier, a hedge or a safe haven against other financial markets?

1.6. Objectives of the Study

This research is related to the literature that focuses on the relationship between green bonds (green finance) and other financial markets (stock, commodity, digital currency, bonds and foreign exchange markets) with the following more specific objectives:

1. To analyze the dependency structure between green bonds and other financial markets under bearish, normal and bullish market states.
2. To examine whether COVID-19 changes dependency between green bonds and other financial markets.
3. To assess comovement between green bonds and other financial markets across various investment horizons.

4. To investigate net volatility transmitter and receiver between green bonds and other financial markets.
5. To examine whether green bonds market can act as a diversifier, a hedge or a safe haven against other financial markets.

1.7. Significance and Contributions of the Study

This research has theoretical and practical policy implications, for individuals, institutional investors, fund managers and policymakers. Policymakers can consider comovement and information transmission patterns between selected financial markets and develop policies, especially considering COVID-19 outbreak effects. This study has practical and theoretical significance because it examines the comovement of the green bonds market with other financial markets in the global context. Moreover, this seeks whether COVID-19 pandemic changes comovement of green bonds and other financial markets, which will help investors and policymakers for the best portfolio diversification.

This study contributes to financial markets literature from various perspectives. Firstly, many international investors seek alternative asset classes to diversify their portfolios. Therefore, this study advances financial markets literature by studying the green bonds market (known also as green finance or sustainable finance) as a new financial asset class. Consequently, this study checks the comovement of this new asset class (green bonds market) with other financial markets (stock, commodity, digital currency, bonds and foreign exchange market). The various studies find that correlation or comovement between financial markets highly depends on markets states (e.g., bearish, mild bearish, optimistic or bullish). Hence, it is most essential to understand the complete dependency structure between green bonds and other financial markets according to

market states because undervaluing the hedging and diversification potential of green bonds might lead to lesser diversification paybacks.

Moreover, the heterogeneous comovement between financial assets required policymakers and the portfolio manager's attention to minimize portfolio risk. At the same time, conventional correlation approaches provide an average correlation between selected assets. Therefore, traditional correlation approaches can provide misleading inferences due to heterogeneity in assets correlations due to different market states. Hence, to examine the complete dependency structure between green bonds and other financial markets, this study employs the QQR method. The intention of using the QQR approach is that as comovement between financial assets varies over the quantiles due to markets or economic conditions, which create a nonlinear correlation between financial assets, and QQR method can easily accommodate the market states varying comovement. Furthermore, QQR not only considers nonlinear relationship but perform well in the presence of structural breaks.

Second, most businesses suffered substantial decreases in market capitalization due to the unforeseen effects of market reaction to COVID-19. A few of these disruptions can be related to temporary causes and extreme market uncertainty, whereas others indicate long-lasting, or even irreversible, changes in the markets. COVID-19 has caused a stir or extreme volatility in the financial markets and upset investors. Hence, it is important to realize that maintaining uncorrelated assets in volatile markets is more beneficial than keeping uncorrelated assets in peaceful markets. It is important to note the correlation or comovement between financial assets changes during the financial market's turbulences due to volatility spillover effects and contagion. Since these correlations are essential aspects for portfolio investment management and risk management, therefore, it is most significant to monitor changes in the correlation of

assets. Therefore, this study is an attempt to examine the comovement between green bonds and other financial markets during the COVID-19 crisis. This study first examines comovement between financial markets before COVID-19 sample period and then during COVID-19. Based on the findings of this study, it can be understood either correlation between the green bonds market and other financial markets changed or not, and it will be helpful for the investors to opt for the best portfolio.

Third, different investors invest their funds as per their needs; some investors invest for the long term while some invest for the short and some for the medium term. Therefore, investors' concern about the portfolio returns based on their needs, for instance, long-term investors focus on low frequencies returns and short-term & medium-term investors care about high and medium frequencies ([Campbell et al., 2002](#)). Hence, the time and frequency aspect could be used to examine comovement between green bonds and other financial markets (stock, commodity, digital currency, bonds and foreign exchange market). The time and frequency domain consideration can be helpful for the policymakers and various inverters who invest their funds for the heterogeneous time horizon for design the best portfolio strategies ([Andrieş et al., 2014](#)). The depth literature on green bonds and other financial markets ignores short-term, medium-term and long-term comovement. Therefore, considering the importance of time and frequency correlation between financial markets is of immense importance. However, earlier econometrics approaches only focused on the time domain and ignored the frequency domain during green bonds and other financial markets analysis. This study employs wavelet methods to accommodate both time and frequency aspects. It is the beauty of the wavelet analysis to examine time and frequency comovement between the green bonds and other financial markets simultaneously.

Fourth, there were significant global financial crises over the last 30 years, such as the Black Monday of October 1987, the Asian debt crisis of 1997, the European sovereign debt crisis of 2009, the global financial turmoil of 2008 and 2009, Greece's 2010 recession and the Nigerian turmoil of 2016 and most recent COVID-19 pandemic etc. After suffering from these major crises, many researchers and policymakers' study how these shocks transmit across the borders or market to market. [Rigobon \(2016\)](#) find that volatility spillovers between financial markets are common in good and bad times (during markets turbulence). Therefore, individual investors, portfolio fund managers, risk managers and policymakers need to study financial markets' volatility spillovers effects to construct an efficient portfolio.

Early mentioned crisis insisted researchers to investigate volatility spillover effects between financial markets to formulate efficient policy regarding investment decisions in good and bad times. Therefore, this study extends financial literature by studying volatility spillover effects between green bonds and other financial markets (stock, commodity, digital currency, bonds and foreign exchange market) using [Diebold and Yilmaz \(2014\)](#) volatility spillovers index (including static connectedness analysis, dynamic connectedness analysis, directional volatility spillovers from, directional volatility spillovers to, net total directional connectedness, net pairwise directional connectedness).

Finally, the last (fifth) objective of this study is to verify whether green bonds can act as a hedge, diversifier or safe haven relative to other financial markets. If a portfolio is built, an investor attempts to mitigate his risk by having various assets that can respond differently to market changes. If the asset correlates or moves positively with the other financial asset, it is known as a diversifier. Diversification aims to alleviate un-systemic possible risks in a portfolio. The idea is that a perfect negative correlation between

financial assets or financial markets reduces financial risk. However, if an asset is negatively correlated or uncorrelated with another asset (base asset) is called a hedge. However, during a high volatility/economic downturn or economic or financial crisis if an asset negatively correlates with another asset is titled as a safe-haven asset. The inclusion of such assets /securities in the portfolio enables potential losses to be overcome both under standard market circumstances and in times of turbulence. To achieve this objective of the study DCC-GARCH model is being used.

In addition, the current study provides theoretical contributions as well. Previous finance theories are founded on traditional financial assets. Although the dynamics and tendencies of the present financial markets are fast changing. A few of these themes are the on-going digital revolution, the rise of FinTech firms, the expanding role of artificial intelligence (AI) and robotics, and re-thinking the concept of money. Furthermore, environmental sustainability is a significant shift in financial markets. As a result, taking into account the current dynamics in financial markets, this study adds to the literature on financial markets by examining the commovement and volatility spillovers between green bonds, stocks, commodities, digital currency, bonds, and foreign exchange markets.

The current study also contributes theoretically by examining MPT theory in light of nonlinear correlation between proposed financial markets.

1.8. Scope of the Study

This study examines dependency structure between green bonds and other financial markets from a global perspective. The other financial markets include stock, commodity, digital currency, bonds and foreign exchange markets. In this study, a global index for each financial market was used to examine the interdependency of the selected financial markets. The analysis includes daily data from November 28, 2008,

to March 21, 2021. Our analysis is divided into two sample periods. The first sample period is from November 28, 2008 to March 10, 2020 as a “before COVID-19”, while the second sample period is from March 11, 2021 to March 21, 2021 as “during COVID-19”. The WHO labeled the outbreak a pandemic on March 11, 2020, and this study selected "during the COVID-19" sample based on this statement.

1.9. Structure of the Study

This study consists of a total of 6 chapters. The following chapter 2 discusses the development and diversification nature of financial assets. Chapter 3 discusses underpinning theories and empirical findings. Chapter 4 presents data sources, theoretical and econometrics models applied to achieve the objective of the study. Chapter 5 discusses results obtained from econometrics models and discussion of obtained results. Finally, chapter 6 discusses policy recommendations and the conclusion.



CHAPTER 2: DEVELOPMENT AND DIVERSIFICATION NATURE OF FINANCIAL MARKETS

2.1. Introduction

This section discusses about selected financial markets, the origin of the markets, about the progress and diversification opportunities of these markets based on theoretical and empirical studies. First, we discuss the conventional bonds market, followed by the Sukuk market, and finally, the latest debt market, which is the primary focus of the study green bonds market. Following the market for green bonds, we discussed the history and nature of other selected financial markets.

2.2. Conventional Bond Markets

Most corporations and governments need funds to manage their operations. To continue operations, corporations and governments issue bonds to raise funds. Bonds are indeed the backbone of the global debt capital markets, and which in turn are the backbone of the global economy. A bond is a credit to a corporation or government that has a fixed rate of return and a maturity period. Bonds, also known as fixed income or credit instruments.

The first traditionally documented bond formed in 2400 B.C. a stone found in Nippur, Mesopotamia, currently known as Iraq. That specific bond assured the principal's payment of grain and promised repayment if the principal refused to render payment. In the 1100s, Venice started issuing sovereign bonds to finance presiti wars. During the 14th century, Venice citizens were free to buy and exchange government bonds, paying the owner a continuous annuity at a fixed rate. The Bank of England released the first government bond in 1693 to collect funds to support a war against France. Such first bonds combined lottery and annuity. A strong trend appears globally, with so many countries adopting England's example to finance wars by issuing government bonds.

There are four main bonds types offered in the markets (1) corporate bonds (2) municipal bonds (3) government bonds and (4) agency bonds.

The bond has a particular amount defined as face value, and bonds incur interest based on a set term known as maturity. At the time of bond maturity that is pre-defined, the borrower pays the actual amount or principal value to the bondholder. The interest rate, which is paid on bonds also known as coupon yield. Bonds are regarded as less risky assets as they have a fixed rate of return. There are different types of bonds based on maturity for example short term bonds typically mature in three years or less; medium-term bonds commonly mature in three to ten years and bonds that have more than ten-year maturity are called long-term bonds. Moreover, the longer the bond period (maturity time of bond), the greater the coupon rate. The prime reason for paying a high interest rate on long-term maturity bonds is to compensate lenders for the extra risk of loaning their funds for the long term.

The bonds are issued by companies, governments their agencies to support special projects. Interest and principal amount of the bonds shall be paid by the profits of the companies and the governments from the taxes and profits of the special projects. Compared to the preferred stock, the corporation pays interest on its debt, and the bondholders are compensated before the shareholders if they are bankrupt.

After the formation of the global bond markets, bonds are used frequently in portfolios for portfolio diversification. There are various reasons for including bonds in portfolio diversification, for example, it performs well as hedging in market turmoil's or economic slowdown, capital protection and capital appreciation. Bonds are known as safe securities since they are usually less risky than certain other asset classes, like currencies, stocks etc. Because of their nature of being less risky, many investors

include bonds in their portfolios to minimize the overall volatility of the portfolio. For example, government bonds continue to rise after a steep downturn in the stock market and act as a beneficial offset against these losses. Whereas a professional long-term investor may well handle the difficulties on the markets, a diversified portfolio can eliminate fluctuations in the road of accomplishment of a target objective.

There is a huge literature on bond market diversification, however, the findings are not definitive and reflect a diversity of opinions. A weak correlation of the bond market with other financial markets exist and this enables investors to diversify their portfolios ([Clare et al., 1995](#); [Levy & Lerman, 1988](#)). However, some noted strong correlations between bonds and other financial markets that restrict the advantages of portfolio diversification ([Smith, 2002](#); [Solnik et al., 1996](#)). Hence, mixed findings in the literature suggest studying more deeply the bonds market in terms of portfolio construction with other financial markets.

2.3. Sukuk (Islamic Bond) Markets

After the successful development of conventional bonds, a new type of bond was introduced known as Sukuk (Islamic debt instruments). The Sukuk was introduced based on religious concern. Sukuk is an Arabian word derived from ‘suk’ meaning certificate. Sukuk is indeed one of the main Islamic Sharia financial products/instruments that provide an alternate source of finance, particularly for huge firms and sovereign institutions compared to existing conventional bonds.

In addition, Sukuk is a revolutionary debt instrument close to traditional bonds in terms of cash flow and risk. It is necessary to note that Sukuk is Islamic debt instrument produced for medium and long-term funding due to certain constraints in the Islamic financial framework, resulting in the absence of traditional bonds. The Sukuk holders

have ownership in assets and a pledge against present or upcoming cash flows produced from these assets for a specified period. Moreover, all the risks or returns, which linked to these specific assets, are also given to the Sukuk holder. These assets, against the Sukuk, can be tangible or intangible.

Modern Sukuk, also called Islamic bonds, are best defined as Islamic investment bonds. Moreover, the conventional bondholders do not bother about the investments being financed through the issuance of the conventional bonds; the investment may involve the production of Haram products such as wine etc. The organizations with a high level of liquidity can refinance through the issuance of bonds, but such firms are not considered appropriate for Muslim investors. As a result, Sukuk has been created as an alternative to traditional bonds which are not suitable because they charge interest and business activities finance through conventional bonds are not sharia-compliant (alcohol, pork etc.) and many Muslim investors don't invest in conventional bonds due to these religion concerns.

Accounting and Auditing Organization for Islamic Financial Institutions (AAOIFI) describes sukuk as:

“Certificates of equal value representing undivided shares in the ownership of tangible assets, usufructs and services or (in the ownership of) the assets of particular projects or special investment activities⁸.”

The history or origin of Sukuk can be found in the classical Islamic era (700-1300AD), where the documents reflecting financial responsibilities resulting from trade and other

⁸ The AAOIFI Shari'ah Standard (17) on investment Sukuk.

commercial practices were released in compliance with the Quranic verses 2:282, which promotes contract setting in writing:

“When ye deal with each other, in transactions involving future obligations in a fixed period of time, reduce them to writing. It is more just in the sight of God, more suitable as evidence and more convenient to prevent doubts among yourselves”.

In ancient Islamic days (classic Islamic period) suk, which is singular of Sukuk, which means "deed" or "instrument" was used to define any paper that shows financial responsibility.

To confirm compliance of Sukuk to sharia law, three conditions must be met. First, Sukuk may reflect ownership of real assets or revenue-generating services; Second, payment /returns or dividend to investors derive from after-tax profit; and third, the value prepaid at maturity can represent the underlying asset's market price, not its original amount invested ([Aloui et al., 2018](#); [Godlewski et al., 2013](#)). There has lately been a controversy over whether Sukuk fully complies with Sharia or breaks the above laws. Researchers in the first category like [El Mosaid and Boutti \(2014\)](#) find little distinction between Sukuk and conventional bonds because they have a positive and significant correlation. However, other researchers claim that based on market perception, structure, risk and properties of conventional bonds and Sukuk ([Cakir & Raci, 2007](#); [Fathurahman & Fitriati, 2013](#)).

Most theory-based studies of Sukuk instruments are centred on understanding and developing Sukuk frameworks with a concentration on regulatory concerns ([Abdel-Khaleq & Richardson, 2006](#); [Tariq & Dar, 2007](#); [Vishwanath & Azmi, 2009](#)). In the literature, Sukuk is an important tool for resource mobilization as well as an important instrument for the growth of the Islamic financial market ([Wilson, 2008](#)). However,

few studies seek to compare the Sukuk frameworks with traditional bonds, there is quantitative research, which is just a few, to determine the risk, and return profiles between the two ([Ariff et al., 2012](#); [Godlewski et al., 2013](#); [Zin et al., 2011](#)).

From a diversification point of view, some researchers examine Islamic bonds (Sukuk) and other financial assets correlation ([Scip et al., 2016](#); [Shahzad et al., 2019](#)). These studies find diversification opportunities. While some studies find no diversification opportunities between Sukuk and stocks ([Ahmed & Elsayed, 2019](#); [Aloui et al., 2015](#)).

2.4. Green Bonds Market

Most international investors try alternate asset groups for portfolio diversification ([Boubaker & Jouini, 2014](#); [Saiti & Noordin, 2018](#)). From a Muslim investor's perspective, conventional bonds ignored the "Haram / Halal" concept of investment. Therefore, due to Muslim's religious concerns, Sukuk was introduced as a new asset class in the Islamic financial system.

However, conventional bonds and Sukuk both ignored environmental concerns of investment. In conventional bonds and Sukuk investment, the investor does not care either firms invest funds in the environmentally friendly project? However, nowadays environmental concerns have become a significant part of the corporate culture and cannot be overlooked – both customers and investors expect greater transparency from the businesses they purchase from and whose shares/stocks they own. It takes a lot of money to move toward a less polluted economy and to do that, we need to use the right financial tools⁹.

⁹The International Energy Agency forecasts that investment of USD 37 trillion would be expected only in the energy industry by 2035 (Schmidt, 2014).

Low-carbon finance, as per [Jiguang and Zhiqun \(2011\)](#), is a form of financial strategy, process, infrastructure, services and products designed to create a less-carbon economy. Therefore, to support the low-carbon economy, the financial sector has launched green bonds (GBs) as a creative financial instrument to raise capital for environment-friendly low-carbon projects ([World Bank, 2019](#)). The funds generated from green bonds, support development projects that reduce the threat of climate change; and funded projects can be public transport, renewable energy and clean drinking water etc. International Capital Market Association (ICMA) define green bonds.

“Green bonds enable capital-raising and investment for new and existing projects with environmental benefits”.

Therefore, based on environmental concerns of investors and consumers a new type of bond was introduced as a “green bond”. Conversely, green bonds, as a revolutionary investment tool, offer an incentive to tap into special pools of private funds to support environmentally friendly projects ([EY, 2016](#)). The term “green bonds” applies to bonds whose revenues are used to fund eco-friendly ventures such as low carbon transports, clean drinking water and clean energy ([Campiglio, 2016](#)).

Around the end of 2007, a team of Swedish pension funds decided to participate in climate-friendly ventures but probably didn't know how and where to seek such eco-friendly projects. However, they knew where they would go and the World Bank was invited to help. The World Bank launched its first green bond in less than one year and provide a way for connecting finance and climate projects¹⁰. In 2007, the first green

¹⁰ <https://www.worldbank.org/en/news/immersive-story/2019/03/18/10-years-of-green-bonds-creating-the-blueprint-for-sustainability-across-capital-markets>

bond was launched by European Investment Bank followed by green bonds from the World Bank¹¹.

Green bonds are a fixed income asset type that is comparable to conventional bonds that have a fixed interest rate and maturity term. However, the major difference between conventional bonds and green bonds is the use of funds raised by the green bonds, which are specifically used to support those projects, which are eco-friendly. Private organizations, governments and supranational entities issue green bonds. US dollar and Euro are the main currencies in which green bonds are majorly issued (about 80% of issuances) and the typical tenor is five to ten years ([Reboredo, 2018](#)). The investors get a fixed coupon rate or interest rate and issuers get funds to support eco-friendly projects. Upon maturity, the principal amount is returned unless the green bond issuer goes bankrupt.

In short, green bonds are the same as conventional bonds but green bonds are called “green” because funds received from green bonds are used in support of those projects, which are pollution-free such a renewable energy projects, clean transport projects or clean drinking water projects etc. ([Climate Bonds Initiative 2017](#)).

Green bonds have become an excellently established sustainable investment tool that has gained momentum not just between ecology-conscious investors, but also between those investors who are highly aware of the potentially important effect of climate change on government policy and climatic risks for companies. The green bond industry is projected to flourish by drawing attention from a variety of bonds issuers

¹¹ <https://www.climatebonds.net/files/files/Green%20Bond%20Labels%20and%20Standards%2010-06-2016.pdf>

and investors, for example including, individual investors, mutual funds, insurance companies, pension funds and small and medium institutions.

Most important the world largest stock exchanges have now established specific segment for the green bonds in those markets including Oslo, Shanghai, Shenzhen, Italy, Luxembourg, London and Mexico. In addition, Climate Bonds Initiative (CBI) 2017 report that more than 3,000 bonds have been released around seven environmental concerns “transport, energy, multisector, water, buildings and industry, waste and pollution, agriculture and forestry¹²”.

The established green bond literature mainly focuses on the advantages of bonds in terms of bond market premia ¹³. For instance, [Hachenberg and Schiereck \(2018\)](#), [Ehlers and Packer \(2017\)](#) and [Zerbib \(2019\)](#) noticed low bond price premiums for green bonds relative to traditional bonds. Moreover, recently [Zerbib \(2019\)](#) also notes that, on average, the yield for green bonds is two basis points lower than that for traditional bonds. Likewise, few other studies find that green bonds pay low returns as compare to traditional bonds ([Bachelet et al., 2019](#); [Hachenberg & Schiereck, 2018](#); [Kapraun et al., 2021](#)). In comparison, [Karpf and Mandel \(2017\)](#) contrasted green and traditional US municipal bond yield terms structure and noticed that green bonds had a higher yield average. Hence, a mixture of findings is available about the returns of green and conventional bonds.

Moreover, a few studies examine comovement between green bonds and other various financial markets to see diversification opportunities in the green bonds market. For example, [Broadstock and Cheng \(2019\)](#) examine the connection between green and

¹² <https://www.unpri.org/climate-change/low-carbon-investing-and-green-and-climate-aligned-bonds/3284.article>

¹³ The bond market premium applies to the lower return on green bond compared with a traditional bond.

black/conventional bond price indexes, noting that association is prone to financial market factors such as financial markets uncertainty, economic uncertainty and green bond sentiment. Similarly, [Febi et al. \(2018\)](#) note that market liquidity influences green bond yields. [Reboredo \(2018\)](#) reveals comovement between treasury and green bonds market and he find the absence of comovement between green bonds, energy and stock prices. Furthermore, [Reboredo and Ugolini \(2020\)](#) also focuses on co-movement between green bonds and other asset classes. All these studies argue that the green bonds market has diversification opportunities with some financial markets and some of the financial markets do not offer any diversification opportunities. There are presently four types of green bonds (1) standard green use of proceeds (2) green revenue (3) green project and (4) green securitized bonds.

2.5. Stock Markets

A stock (also characterized as the "equity" of a corporation) is a financial tool or instrument that reflects ownership in a business or organization, constitutes a proportionate right to its assets (as per the value of a share), and profits (what it earns in profits). A stock exchange or stock market is also known as a secondary market where shareholders can buy and sell their shares. It's important to remember that companies listed on stock exchanges may not always buy and sell their own securities. When someone purchases a share from the stock market it does not mean he is buying directly from the corporation but he or she purchases from existing shareholders. In the same way, you don't return your stock to the organization; rather, you sell it to another party.

There are two major stock markets first conventional stock markets and second Islamic stock markets. Both stock markets having a huge market capitalization and are the major source of investment globally. The first stock markets emerged in Europe in the

16th and 17th centuries, mostly in port cities or centers like Antwerp, Amsterdam and London.

2.6. Commodity Markets

Commodity trading is the oldest business in the world, with a longer history than the trading of stocks and bonds. The growth of various empires may be traced back to their capacity to develop sophisticated trade networks and facilitate the trade of commodities. The trading of commodities continues to take place in current times around the world. As per Bruce Babcock, a renowned commodities authority, the earliest known commodity futures exchanges took place in Japan in the seventeenth century, however, there is some proof that rice might be exchanged as far as back 6000 years earlier in China. A broad classification of commodities that are used in trading is divided into four broad categories. These are agricultural, metal, livestock, energy and meat.

2.7. Crypt-Currency Markets

In recent decades, the internet has generated a new idea and assets class in the financial sector. This new type is labelled with the generic name of crypto-currency. The cryptocurrency, often known as "virtual currency or digital currency" is a digital means of trade that employs cryptography to ensure its security. The word "crypto" comes from the ancient Greek word, "kryptós", which means hidden or private¹⁴. This digital currency is only used electronically based on the internet and outside the traditional banks. It is occasionally referred to as "money that circulates online but not through a bank". However, the status of legal money in any jurisdiction does not exist for any privately produced digital currency (Mullan, 2014).

¹⁴ <https://towardsdatascience.com/introduction-to-cryptocurrency-be9bd0c9545e>

Following [Nakamoto \(2008\)](#) suggestion in a paper called “Bitcoin: A Peer-to-Peer Electronic Cash System” bitcoin was launched on 3 January 2009 as an alternative payment mechanism independently without any central bank or authority and the first transaction was made on January 11, 2009. However, Polasik et al. (2015) said that bitcoin is a financial asset because its unit of value can be traded. Particularly, bitcoin integrates commodity attributes (i.e. gold) and sovereign currency and can therefore be viewed as synthetic commodity currency ([Selgin, 2015](#)).

For over three years, the interest in the very first cryptocurrency was minimal to its strict role in e-commerce. The cryptocurrency network soon continued to develop and attract mainstream support; by the end of 2012, the magnitude of the transactions continued to grow exponentially ([Ji et al., 2018](#)). Nakamoto subsequently created the very first blockchain (also recognized as the genesis block) on 3rd January 2009, announcing bitcoin's birth, and it was the first decentralized cryptocurrency. Bitcoin has since drawn growing interest from experts, academics, regulators, and journalists. For instance, in 2017 in Google's top search topics bitcoin (cryptocurrency) was ordered as second globally. The European Union, Japan and India all recently introduced the cryptocurrency regulation guidelines, which suggest that government officials paying more attention to the presence of bitcoin.

There are several kinds of cryptocurrencies; however, bitcoin is regarded as a primary crypto-currency, among the most widely recognized currencies. Bitcoin (BTC) is a virtual financial instrument, which is not supported by intangible or tangible assets. The BTC is sometimes known as “digital gold” and this might soon be branded as “digital bonds¹⁵”. Bitcoin is initially created as an electronic peer-to-peer payment mechanism

¹⁵ <https://cryptobriefing.com/bitcoins-correlation-bonds/>

where consumers may exchange individually without the need for an intermediary. It is a decentralized virtual currency that operates independently of the rules and regulations of any central authority, such as the state bank or banking system or government officials, and is sometimes seen as a solution to the inefficiency of traditional economic and financial frameworks ([Demir et al., 2018](#)). Bitcoin's main characteristics are that BTC has no tangible form, is not affiliated with any institution, and is developed using advanced mathematics and computational techniques.

Furthermore, the value of BTC is highly centered on the security of the algorithm as opposed to traditional currencies ([Platanakis & Urquhart, 2019](#)). Further, the supply of BTC remains the same because the actual number of BTC in markets are known ([Kristoufek, 2015](#)). In recent times, the adoption of bitcoin as a means of payment has significantly increased. BTC appears to be the most widely adopted digital currency and is the highest based on market value, the volume of regular transactions and overall capitalization of the digital currency industry ([Ciaian & Rajcaniova, 2018](#)).

In the financial literature, various researchers studied BTC in various fashions for example initial BTC literature theoretically reflects on whether bitcoin suits currency or asset criteria. Bitcoin, as per [Nakamoto \(2008\)](#), is primarily utilized alternative money. However, some significant stylized aspects of BTC are popular in financial assets like heteroscedasticity ([Gkillas & Katsiampa, 2018](#)), long memory ([Phillip et al., 2019](#)) and leptokurtosis ([Chan et al., 2017](#)). Nevertheless, bitcoin is considered a modern asset type, not a conventional currency, and its reputation as a financial instrument (asset) attracted many investors and speculators because of BTC extreme volatility and high returns ([Baek & Elbeck, 2015](#)).

A strand of literature studied BTC from the portfolio diversification (investment) perspective. The strong or low correlation between the BTC and other financial instruments could influence decision-making on effective portfolio management for global investors and governments in countries, which are likely to regard the BTC as the official virtue of digital currency. Because of bitcoin's increasing prominence, various studies explored the relationships among bitcoin and asset groups such as securities, bonds, currencies and illustrated bitcoin's hedging potential ([Bouri et al., 2017](#); [Dyhrberg, 2016](#)). Furthermore, [Baur et al. \(2016\)](#) found that BTC returns are fundamentally uncorrelated with other financial asset groups providing high diversification benefits.

[Baur et al. \(2015\)](#) found BTC as a significant diversifier because of its weak co-movement with the equity and bonds market. [Wu et al. \(2014\)](#) have noticed that bonds and BTC have a very weak association and having BTC can play a significant role in improving portfolio performance. [Baur et al. \(2018\)](#) find BTC returns mostly uncorrelated to all large asset groups in common and extreme volatility. Because of its relatively low correlation with other global financial assets, BTC is a highly useful resource for diversification and risk management ([Briere et al., 2015](#); [Giudici & Abu-Hashish, 2019](#); [Selmi et al., 2018](#)). While [Briere et al. \(2015\)](#) have shown that BTC provides substantial diversification advantages to indicate that only a limited percentage of BTC would significantly increase the risk-return trade-off of well-diversified portfolios.

2.8. Foreign Exchange Markets

Foreign Exchange also known as (forex or FX) is currency-to-currency trade. For instance, one can exchange the USD for the PKR. Forex is the world's growing, liquid market, with hundreds of billions of dollars transacted throughout the day. There is no fixed place, but the foreign exchange market is an online network of banks, individual trader's dealers and institutions.

The market decides the value, defined as the exchange rate, of many of these currencies. Trading currencies are specified in pairs like USD / CAD, USD / PKR or USD / JPY. Those are the U.S. dollar (USD) vs the Canadian dollar (CAD), U.S. dollar (USD) vs the PKR, and US currency vs the Japanese Yen (JPY). There would also be a value per pair, like 1.2569. If this value is correlated with the USD / CAD combination, it means purchasing one USD costs 1.2569 CAD.

The history of the exchange market is not new, evidence of currency exchange is found in 259 BC in Ancient Egypt. Throughout the late middle ages, currencies started dealing through the first network of international banks. Throughout the 15th century, the Medici family of Florence founded banks throughout foreign countries, to promote trade and exchange on the behalf of textile traders. The Bretton Woods Treaty ended in 1971 and the new foreign currency exchange was established.

Several studies have investigated the comovement of the foreign exchange market with other financial markets because of diversification opportunities in the forex market ([Ciner et al., 2013](#)). There are various studies that confirm that bonds and foreign currency excess returns are foreseeable ([Dai & Singleton, 2002](#)). However, a recent study by [Reboredo and Ugolini \(2020\)](#) also examined the correlation between green bonds and the currency market. They find that both markets move together.

CHAPTER 3: LITERATURE REVIEW

3.1. Introduction

The prime objective of this study is to examine co-movement between green bonds and other financial markets (including stock, commodity, digital currency, bonds and foreign exchange market). This chapter discusses previous theoretical and empirical research in the field of financial markets co-movement. Empirical research between different asset classes has attracted considerable interest among policymakers, economists, financial institutions, investors and academicians. Continuing shifts in the global financial environment due to the globalization of capital markets, the development of innovative financial instruments and the introduction of modern risk management methods have challenged stylized facts about cross-asset correlation.

The early studies (started before 1995) find a time-invariant correlation between financial assets (particularly, bonds and stocks). However, all the major studies starting from the late 1990s reject the hypothesis of time-invariant co-movement between financial markets. While latest strand of literature focusing on time-varying dependencies across different frequencies between financial assets. Now a day's time- and frequency domain correlation getting the attention of policymakers and fund managers. Moreover, as there is very limited literature on green bonds and other financial markets, therefore this study starts from the conventional bonds and other financial markets comovement literature to provide a comprehensive understanding of the relationship between proposed financial markets. This chapter contains major portfolio theories, empirical findings and research gaps about financial assets particularly green bonds and other financial markets.

3.2. Theoretical Background

Within this section, the present study addresses the various theories related to the financial market's co-movement and the various channels of co-movement between financial markets.

3.2.1. Modern Portfolio Theory (MPT)

[Markowitz \(1952\)](#), his first publication published in the essay "selection of the portfolio, introduced modern portfolio theory. Later, [Markowitz \(1959\)](#) extended his work in his book "Portfolio Selection: Efficient Diversification". Due to the importance of risk in the analysis of investments and portfolios as a key determinant, Markowitz's brilliant contribution is concerned with the revolutionary principle of diversification used in a variety of portfolio-based securities and their covariance relationships. Indeed, his work provided evidence that diversifying across securities can reduce a portfolio's total risk due to the removal of idiosyncratic risk.

3.2.1.1. Markowitz's Diversification

Markowitz's diversification's main idea is "not putting all your eggs in one basket or spreading your risks". The MPT theory works based on investing wealth in several assets, which are less correlated to lessen portfolio risk without sacrificing anticipated returns ([Francis & Kim, 2013](#)). The resulting portfolio would be the least risky due to the low or week correlation between the selected assets and no matter how risky portfolio assets are in isolation analysis. [Kristian et al. \(2006\)](#) called MPT "Magic Diversification" because of its practical implications.

[Markowitz \(1952, 89\)](#) put it this way:

"Not only does [portfolio analysis] imply diversification, it implies the 'right kind' of diversification for the 'right reason.'" The adequacy of diversification is not thought

by investors to depend on the number of different securities held. A portfolio with sixty different railway securities, for example, would not be as well diversified as the same size portfolio with some railroad, some public utility, mining, various sorts of manufacturing, etc. The reason is that it is generally more likely for firms within the same industry to do poorly at the same time than for firms in dissimilar industries. Similarly, in trying to make variance [of returns] small it is not enough to invest in many securities. It is necessary to avoid investing in securities with high covariances among themselves”.

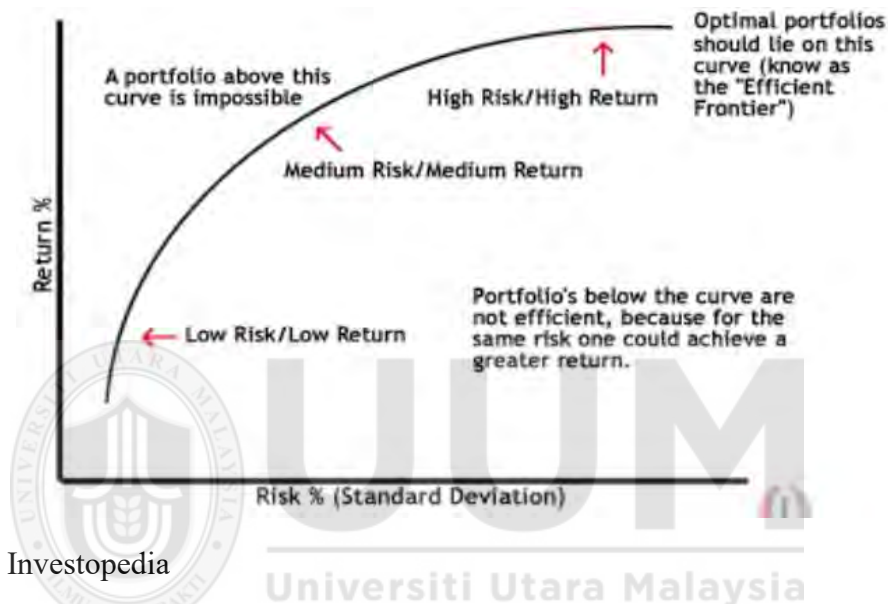
To prove MPT theory robustness, Markowitz first demolished the concept of keeping only high discounted expected return assets in portfolio management. He stated that investors that follow this rule keep only one high discounted expected return asset. After this, he argued about his mean-variance theory also known as MPT theory, that diversification can be achieved through investing in various securities, which are less correlated ([Constantinides & Malliaris, 1995](#)). Markowitz proved his MPT theory with the help of two basic rules (1) increasing expected returns, retaining constant variance and (2) reducing variance, maintaining constant expected returns ([Elton & Gruber, 1997](#)). On the basis of these two fundamental concepts, he established the concept of an efficient frontier. The efficient frontier is a “*graphical representation of a set of portfolios that maximize expected return for each level of portfolio risk*” ([Maritz, 2002](#)).

3.2.1.2. Efficient Frontier

[Markowitz \(1952\)](#) first described “Efficient Frontier” which is the main concept of MPT theory, which helps portfolio managers to find the best combination of portfolio which gives maximum return against the specific amount of risk. Markowitz plotted returns and risk of assets in the efficient frontier and found optimal portfolios. The following is the overview of different portfolios on the efficient frontier that does not

contain any risk-free assets; all the portfolios that exist on the efficient frontier provide maximum returns against the particular rate of risk. The portfolios which encompass the efficient frontier are known as the most diversified portfolio while all the portfolios which are close to the middle of the efficient frontier are known as less diversified portfolios.

Figure 3.1: Efficient Frontier



Source: Investopedia

Efficient frontier has two main elements, first, it helps to find the best portfolio, which provides a high return against a specific risk, and the second efficient frontier is curved, not straight. It is significant because it helps investors to understand how diversification let them improve their reward-to-risk ratio. The MPT theory is based on few market assumptions. However, few authors find that these assumptions are not true in practice.

Even though all the assumptions of MPT theory are not all time come true but yet modern portfolio theory play a major role in portfolio management. These are the assumptions (1) Market efficient (2) rational investors (3) security returns are normally distributed (4) no trading cost and tax (4) constant correlation of securities (5) single investors are unable to beat market prices (6) investors attempt to maximize returns

given their unique situation (7) unlimited amount can be borrowed at risk-free rate (8) all the investors have the same view about the expected returns.

As the prime objective of the study is to examine co-movement/correlation between the selected financial markets for the investors and policymakers to mitigate portfolio risk. Therefore, modern portfolio theory supports the hypothesis under examination.

3.2.1.3. Criticism on Modern Portfolio Theory

Before applying the theory to real market data and see how the theory performs, everyone must understand the theory limitations. A few years ago, a severe financial crisis hit the financial world and made big losses for everyone. The theory was very successful in the period from 2002 to 2007 but when the crisis happened, much of the blame went to the modern portfolio theory because even portfolios which considered safe by the theory, had significant losses. Theoretic premises such as the constant correlation exists between financial assets over time, while this assumption is not true in practical and in recession all stocks have downward fluctuations together, contribute to the failure of modern portfolio theory when it is most required.

Even though MPT has some flaws but it is a most famous theory which is used frequently in portfolio management. There are a number of studies that used MPT in portfolio construction for various financial assets such, ([Lee & Stevenson, 2005](#); [Pagliari et al., 1995](#); [Platanakis & Urquhart, 2020](#); [Širůček & Křen, 2017](#)).

3.2.2. Arbitrage Pricing Theory

In 1964, the capital market theory evolved when [Sharpe \(1964\)](#) introduced a capital asset pricing model (CAPM) for portfolio analysis. [Sharpe \(1964\)](#) expands [Markowitz \(1959\)](#) perspective by introducing assets that are expected to co-move with the market. The CAPM defines the association between systematic risk and expected return for securities. Although CAPM was considered the most famed model within the assets

pricing models, policymakers and academic researchers highly criticized CAPM. The standard CAPM model of [Sharpe \(1964\)](#), [Lintner \(1965\)](#), and [Black \(1972\)](#) suggest that an asset's expected return and its systematic risk positively correlate. This model justifies that market beta is the only factor that describes cross-sectional variances in returns.

However, [Röll \(1976\)](#) severely criticized the standard capital asset pricing model, which creates an ongoing debate on the validity of the CAPM approach. Roll completely negates accepting market beta as the only indicator of economic or systematic risk by suggesting that the stock index must contain all assets and wealth of people. Hence, the standard CAPM does not exemplify a market portfolio based on the market portfolio proxy used in the capital asset pricing model. Moreover, various studies find that other than market beta various anomalies' have a systematic effect on assets prices such as P/E anomaly ([Basu, 1977](#)), size ([Banz, 1981](#)), value anomaly ([Rosenberg et al., 1985](#)) among others. In summary major flow of the CAPM model is that it only considers market risk as a determinant of assets returns, however, there are many macroeconomic factors, which affect returns of assets directly.

Therefore, to understand the pricing mechanism or trend of assets arbitrage pricing theory (APT theory) was introduced. The APT theory introduced by [Ross \(1976\)](#) considers that various factors can affect asset return such as interest rate, uncertainty or commodity prices etc. Arbitrage pricing theory argued that cross-sectional variances in asset returns are not only due to dispersion in market return because it is the case of CAPM but cross-sectional variances in asset returns are also due to various macroeconomic factors such as interest rate, prices of other assets etc. each of these factors is then associated with a risk premium.

The APT theory is used in a substantial amount of literature to examine assets integration. The prime foundation of APT is that there are many macroeconomic factors/ sources of systematic risk that affect assets return other than market risk. Therefore, the arbitrage-pricing theory is a way of connecting economic variables /factors and the return of assets, where several risk factors may determine the return of assets. Following is the standardized form of APT theory:

$$E(R)_t = \beta_0 + \sum_{i=1}^n \beta_i F_i + \mu_i \quad \text{Eq (3.2)}$$

$E(R)_t$ = expected return of assets i

β_0 = a constant

$F_1 \dots F_n$ = values of factors from 1 to n

β_i = sensitivity of asset return to a particular factor

μ_i = error term

As the current study also includes the macro-economic variable effect, i.e. the pandemic uncertainty to see either, the comovement or correlation between selected assets effected due to pandemic uncertainty. Therefore, the APT theory also supports the hypothesis of the study. The financial markets cointegration/integration is being tested in the literature using APT theory ([Beaulieu et al., 2009](#); [Hung et al., 1996](#); [Koutoulas & Kryzanowski, 1994](#)).

3.2.3. Efficient Market Hypothesis

The efficient market hypothesis also known as EMH theory has been under the consideration for several decades in academicians and policymakers. EMH's broad work was motivated by several reasons. It is the fundamental assumption of EMH theory that assets prices reflect all the information related to a particular asset ([Fama, 1965](#); [Malkiel, 1962](#)). As a result, a financial market is considered more efficient as faster market-related information is embedded in asset prices. In efficient markets, past

information related to a particular asset should not affect its returns in the current period ([Fratzscher, 2002](#)).

In other words, the “efficient markets do not allow investors to earn more above-average returns without accepting above-average risks” ([Malkiel, 2003, p. 60](#)). The central premise of the efficient market theory is that assets prices completely represent all possible information regarding the assets. In his pioneering work, [Fama \(1965\)](#) claims, a market is efficient when “the price of a security accurately reflects all available information in the market”. This also supports the assumption that no particular investor can profit from the information because everybody has exposure to the same knowledge expressed in the market price. The concept of an efficient market is based on two main pillars: 1) relevant information has already been embedded in asset prices (2) investors cannot earn a risk-weighted excess return.

However, [Fama \(1970\)](#) suggest few conditions for the markets to be efficient. These are the few assumptions of EMH theory. First, no transaction costs of stock trading; subsequently, all information is readily accessible to every market player; lastly, there is consensus on the implications of current information for current prices and distribution on future prices of every asset. The EMH theory is categorized into three groups as per the term “all available information”, (1) weak-form efficient market (2) semi-strong form efficient market and (3) strong form efficient market hypothesis.

In the financial literature, there are various studies that consider EMH theory for example ([Lee et al., 2014; Phiri, 2015](#)) for stock markets, ([Hu et al., 2019; Le Tran and Leirvik, 2019](#)) for crypto-currencies and [Wickremasinghe \(2016\)](#) exchange rate. The prime claim of EMH theory is that prices cannot be forecast based on other factors, prices show random walk and nobody can predict prices of assets. However, there are many studies, which do not support this argument, by saying financial markets

commove with each other, therefore, change in one market can predict change in other markets. [Granger \(1986\)](#) finds that once two markets are integrated, one price may be used to estimate another that contradicts the efficient market theory.

In the late 1980s, several researchers like [Baillie and Bollerslev \(1989\)](#) and [Hakkio and Rush \(1989\)](#) continued this view. The findings of previous studies are mixed about the efficiency of financial markets; some researchers confirm the existence of EMH theory while some researchers reject EMH theory. The main objective of this study is to examine the comovement between green bonds and other financial markets (including stock, commodity, digital currency, bonds and currency markets), so our hypothesis is also related to the EMH theory, and the findings of the study can be supported based on this theory. If there is co-integration between the proposed financial markets, in this case, EMH cannot be supported by saying that the selected markets are efficient, but if the findings of the study confirm the lack of co-integration, this supports the view of EMH theory.

3.3. Empirical Findings on Nexus of Financial Markets

This section discusses empirical studies that debate the relationship between financial markets from a portfolio diversification perspective. Due to the lack of empirical studies on the relationship between green bonds and other financial markets, this study discusses the first studies which find the correlation between conventional bonds and stock, then Sukuk and stock and lastly green bonds and stock, and the same pattern of bonds correlation with other financial markets.

3.3.1. Bond and Stock Markets

It is the most important subject in financial economics to understand financial assets comovement. There are significant theoretical implications of financial assets comovement, for knowing price formation. Furthermore, it helps investors in portfolio

diversification and risk reduction. Practitioners and academics worldwide have been interested in the behaviour of financial assets amid unstable economic situations since the financial crisis of 2007. For portfolio diversification or assets allocation, there are three major elements including correlation among proposed assets, return and risk.

Following [Markowitz \(1952\)](#) foundational work, which explains the correlation between financial assets for portfolio diversification, asset correlation is the core subject of portfolio management. Bonds and stocks are fundamentally different in that bonds provide fixed income to investors after a set period of time, whereas stocks do not. However, the combination of bonds and stocks, as a result, allows the investor to maximize their return while also diversifying their risk. The correlation between financial assets is important in diversification; the lower the correlation between assets, the better for diversification. Hence, for risk management correlation is most important. Knowing the relationship between bonds and stock markets is important because of its particular implications for portfolio management. There are various reasons to examine the correlation between bonds and stocks (1) because bonds-stocks are the most important assets in portfolio allocation (2) bonds-stock correlation gaining huge attention of international investors due to diversification benefits. The pioneering work of [Markowitz \(1952\)](#) focused on the means-variance approach in assets allocation management. The investor or manager who invest in bonds-stocks not only should consider the forecast of returns of these assets but also correlation over time. The forecast of correlation among the assets has important implications from a diversification point of view. Although the correlation between assets over time matters a lot in portfolio diversification but still in the academic researchers mainly focused on contemporaneous variances in returns of assets (bonds-stocks) over time. However,

researches mainly focused on the correlation between bonds-stocks in the last ten year ([Jivraj, 2013](#)).

In the literature, early studies purely examined correlation existence and direction (negative or positive correlation). The researchers find a time-invariant correlation between bonds and stocks, they argue that correlation between these two assets does not vary over time. The primary studies, which found a time-invariant correlation, are ([Campbell & Ammer, 1993](#); [Keim & Stambaugh, 1986](#); [Shiller & Beltratti, 1992](#)). However, [Barsky \(1989\)](#) gives theoretical reasoning for bond prices and stock prices association. He says that comovement between bond and stock prices highly depends on the economic conditions. In general; he recognizes that declining productivity growth and growing market volatility have a negative effect on business income and real interest rates, causing equity (stock) and bond prices to move negatively. Moreover, the above-mentioned studies find and support a time-invariant correlation between assets (bonds and stocks) but in reality, due to policy changes, structural breaks like a financial crisis or economic conditions, the correlation between financial assets varies over time. Early literature, therefore, did not support this time-varying correlation and is a major drawback to early studies.

To test the time-varying correlation between financial assets various studies revisit correlation in different financial markets using different econometrics approaches. To explore the time-varying dynamics of bond-stock prices, several current pieces of research have studied bond-stock prices correlation based on the rolling-window approach ([Gulko, 2002](#); [Ilmanen, 2003](#)) or GARCH models ([Chiang et al., 2015](#); [Connolly et al., 2005](#)). Furthermore, the copula approach was used to describe the extreme dependency correlation between bonds and stock returns ([Chui & Yang, 2012](#); [Jammazi et al., 2015](#); [Wu & Liang, 2011](#)).

In other terms, investors are more risk-averse in periods of equity market volatility and change their portfolio strategies from volatile assets like stocks to stable investments like government long-run bonds ([Cappiello et al., 2006](#); [Durand et al., 2010](#); [Yang et al., 2010](#)). It might be important to keep in mind that exogenous activities like natural or anthropogenic hazards, social instability, political turmoil, violence and other destructive incidents such as violence and killing may also have an effect on the short-term stock-bond correlation ([Apergis et al., 2018](#); [Guidolin & La Ferrara, 2010](#); [Wisniewski, 2016](#)).

One common theory would be that the time-varying correlation relies on economic forces and that there is a “flight-to-safety” response during stock market turmoil whereby investors exit share markets and seek shelter in reasonably stable assets like government bonds. Many latest studies also confirm that the correlation between bonds and stocks varies over time (time-varying) and findings also varies from country to country and subject to economic or market condition ([Jammazi et al., 2015](#); [Selmi et al., 2019](#); [Selmi et al., 2017](#)). This strand of literature proved that correlation between financial assets is not time-invariant however, these studies failed to capture the time-varying dependency across different frequencies.

To capture the time-varying dependency through different frequencies, recently various studies are conducted and which used various methods to see either correlation between financial assets is time-varying dependent across different frequencies. For instance, [Bayraci et al. \(2018\)](#) argued that most of the studies only focused on time-varying structures but ignored the frequency domain. They also confirmed a positive co-movement between bonds and stocks but this positive co-movement vary over time and frequency. Many other studies also consider the time and frequency relationship ([Lin et al., 2018](#); [Tolikas, 2018](#)).

Finally, various studies discuss the direction of correlation between bonds and stocks. A substantial number of empirical researches have been undertaken over the previous years to identify the salient behaviour of the capital market's major assets i.e. bonds and stocks. For example, [Gulko \(2002\)](#), [Ilmanen \(2003\)](#), [Boyer et al. \(2006\)](#) and [Yang et al. \(2009\)](#) are several widely regarded studies focused on the fundamental correlation of assets returns. These studies find two conflicting correlation outcomes. First, bonds and equity returns are associated positively, owing to the presence of specific macroeconomic factors, like economic conditions, interest rate and inflation ([Gulko 2002](#)). While, a negative correlation exists between both markets at the time of markets turbulence or volatility ([Baele et al., 2010](#); [Campbell & Ammer, 1993](#); [Connolly et al., 2005](#)). During financial markets volatility, investors despise risks as a consequence of bond investments comes extremely favorable relative to stock or other riskier securities, and investors move money from the equity sector to bond market, interpreting bonds as risk-free assets, forming a “flight-to-safety or flight-to-quality” phenomenon ([Baur & Lucey, 2009](#)). In comparison, as stock market grow, in a condition investor feel safe and take the risk. Therefore, risky assets become highly appealing for investors and attract in stock markets also increase, which would help lead to “flight-from-quality” sensations ([Baur & Lucey, 2006](#)). Hence, economic conditions highly affect correlation behavior between financial assets.

3.4. Sukuk and Stock Markets

To examine diversification opportunities of Sukuk with other financial assets a group of researchers employed wavelet-based analysis and empirically find that the co-movement pattern of the Sukuk–shariah stocks vary over time and scale ([Aloui et al., 2015](#); [Nasreen et al., 2020](#)). According to the findings of these studies, the advantages of portfolio diversification are dependent on the time and frequency domain. [Naifar](#)

[\(2016\)](#) confirms the dependence between Sukuk yields and stock market volatility. [Shahzad et al. \(2019\)](#) found that Islamic bonds could be used in portfolio diversifications for the hedging/ safe haven purpose. [Aloui et al. \(2018\)](#) confirm the heterogeneous pattern of correlation between Islamic stocks and Islamic bonds over time and frequency.

A strand of literature on Islamic finance examines the volatility of Islamic and conventional assets. [Kim and Kang \(2012\)](#) utilizing the GARCH multivariate approach, find unidirectional spills of volatility from Islamic stock to Sukuk across financial subprime crises. [Sclip et al. \(2016\)](#) confirm strong correlations between Sukuk and US and EU equity markets. They also demonstrate that at the time of the financial crisis a volatility spillover effect exists between regional stocks indices and Sukuk. [Naifar \(2016\)](#) reported that the yields of Sukuk rely very heavily on market volatility. They also find that the dependency structure between Sukuk yields and stock market volatility remains the same of the various frequencies. Therefore, it can be concluded that Sukuk yields and stock market volatility in Saudi Arabia is symmetric rather than asymmetric.

3.4.1. Green Bond and Stock Markets

The prime objective of this research is to examine co-movement between green bonds and other financial markets (stock, commodity, digital currency, bonds and foreign exchange markets). Due to lack of sufficient literature this study first scrutiny all the possible studies which explore the correlation between conventional bonds, Sukuk (Islamic bonds) and stocks markets to understand the complete correlation between these markets. Green bonds fund supports an eco-friendly environment for environmental sustainability and are the fixed-income financial instrument. The biggest distinction between green and traditional bonds is their ecological design, expressed in

a bond financial statement supported by third-party sources. Green bonds have proven attractive in terms of green bonds potential to redistribute the cost of reducing the adverse impacts of climate change through generations ([Flaherty et al., 2017](#); [Orlov et al., 2017](#); [Sachs, 2014](#)), moreover, green bonds consider the safest strategic investment tool to fund low-carbon growth ([Monasterolo & Raberto, 2018](#)).

As green bonds are a new assets class, therefore, many investors and policy makers showed a lot of interest in green bonds from a portfolio perspective because most institutional investors try alternate asset groups for portfolio diversification. Considering portfolio opportunities, very few studies explored comovement between green bonds and other financial assets. Succeeding are few studies, which empirically explored the correlation between bonds, and various assets classes (particularly stocks). [Reboredo \(2018\)](#) examined the long-run association between green bonds and different financial markets. This study considered energy commodities, stocks and fixed income to check co-movement between green bonds. The outcomes of the study confirmed that the green bonds market commove with the fixed income and weekly commove with energy commodity and the stock market. This study also confirmed that the green bonds market has small diversification benefits to investors in the fixed income market, however, the green bonds market has significant diversification benefits to investors in stock and energy markets. Furthermore, this study also confirms that the green bonds market is highly affected by price spillover effects of fixed income markets while; stock and energy markets have minor spillover effects on the green bonds market.

[Reboredo and Ugolini \(2020\)](#) found that the green bonds market highly commoves with the currency market and fixed income markets. Receiving sizeable price spillovers from those markets and transmitting negligible reverse effects. The findings also reveal that

the green bonds market is weakly linked with the stock markets and energy commodity markets.

[Reboredo et al. \(2020\)](#) investigated network connectedness in the EU and US between green bonds and different asset classes. Based on wavelet coherence analysis they first checked the correlation between green bonds and other assets class price changes. They also decomposed time series into various frequencies and then checked price connectedness based on error variance decomposition of a multivariate vector autoregressive model. The findings reflect a strong comovement between green bonds and short- and long-term corporate bonds in the EU and US. Likewise, green bonds are weakly related to high-yield corporate bonds, energy and stock assets over varying time scales. Research affirms the importance of green bonds in portfolio allocation.

3.4.2. Bond and Commodity Markets

The use of alternate assets in conventional bond portfolios was examined with conflicting results in the literature. For example, [Gao and Nardari \(2018\)](#) and [Gorton and Rouwenhorst \(2006\)](#) consider that introducing commodities to the portfolio brings profit. However, [Daskalaki and Skiadopoulos \(2011\)](#) and [Platanakis and Urquhart \(2019\)](#), have found contrasting evidence. [Erb and Harvey \(2006\)](#) find that the commodity market does provide diversification benefits. However, a recent study by [Liu et al. \(2018\)](#) claims that few commodities provide diversification benefits and few do not provide diversification benefits.

[Suciningtias \(2019\)](#) showed that due to world gold prices shocks, the Indonesian Sukuk market was highly affected. However, in the short run, the Sukuk market effect is due to world oil price shocks. [Naifar \(2018\)](#) confirms the time-varying negatively comovement between the prices of Sukuk and commodities. [Widad and Hadjer \(2018\)](#)

accessed the relationship between Sukuk, oil prices and precious metals in Asia pacific. They find significant negative cointegration between Sukuk and the commodity market. They also found that Sukuk provides diversification benefits. [Kang et al. \(2014\)](#) find that a positive change in the oil market from the demand side bring negative change in bond returns. Which ultimately provide diversification opportunity.

A more recent study by [Reboredo \(2018\)](#) suggests that the green bonds market have minimal benefits for investors in corporate and treasury markets, while diversification benefits are significant for investors in equity and energy markets. [Reboredo et al. \(2020\)](#) have identified that green bonds have a weak correlation with energy assets over different time scales. Both studies that are based on green bonds and energy commodities confirm that green bonds and energy commodities are the two best assets that must be in a portfolio to diversify risk.

3.4.3. Green Bond, Conventional Bond and Sukuk Markets

Knowing how green bonds market and traditional bonds market co-move is important for investors to consider the diversifications of the allocation of green bonds within a portfolio and how price volatility in traditional bonds market impacts green bond prices. The examination of these impacts is of course also critical for improving environmentally sustainable investments and influencing private incentives for growth capital investments for the shift to an environmentally sustainable economy, as underlined by the 2015 Paris Climate Agreement ([Climate Bonds Initiative, 2015](#)). Academic research usually appears quiet on the subject of green bonds, with just a number of peer-reviewed papers, including few that provide a systematic market analysis.

Few notable examples include: [Pham \(2016\)](#) studied traditional and green bonds correlation patterns; [Reboredo \(2018\)](#) find spillover effects between green bonds market and other financial markets, while [Karpf and Mandel \(2018\)](#) studied US conventional and green bonds yield. [Nanayakkara and Colombage \(2019\)](#) investigated the difference in the prices of conventional bonds and green bonds of international markets. The findings of the study confirmed that green bonds markets could trade green bonds at a premium by offering opportunities of low risks to investors. Furthermore, issuers of green bonds can raise funds with low cost of capital. While, it is confirmed that green bonds are being traded globally at premium at least on 63 BPS. [Gianfrate and Peri \(2019\)](#) examined convenience of issuing green bonds considering interest of companies, entities or investors those want to invest in the environmentally friendly projects. The findings of the study confirmed that the of green bonds are more convenient as compared to traditional bonds.

Another strand of literature argued that macroeconomic factors affect the comovement between green bonds and conventional bonds. [Broadstock and Cheng \(2019\)](#) explored the connection between the green bonds market and black bond markets with respect to macroeconomic determents. They confirm that the relationship between the green bonds market and conventional bonds market is highly affected by macroeconomic factors such as stability of financial markets, positive and negative news about the green bond, daily economic activities, economic policy uncertainty and oil prices.

[Karpf and Mandel \(2018\)](#) confirmed that conventional bonds give a higher return as compared to green bonds. [Zerbib \(2019\)](#) also carried a study on the green bonds market using green bonds as an instrument to examine the impact of environmental preferences on green bonds market prices. The findings of the study confirmed that green bonds provide a low yield as compare to traditional bonds. The findings showed that investors

pro-environment preferences do not affect significantly green bonds prices, that why at this stage expansion of green bonds markets is not supported as distinctive for the investors.

[Reboredo \(2018\)](#) reported that green bonds comovement with corporate and treasury bonds. [VanEck \(2017\)](#) also observed a very close correlation between the price level of green and traditional bonds. Conversely, a new study by [Fender et al. \(2019\)](#) finds that including both green and traditional bonds in a portfolio can increase the efficacy of portfolio diversification.

3.4.4. Bond and Crypto-Currency Markets

Cryptocurrencies or digital currencies have become an interest of media, regulators and investors. Two of their important characteristics are blockchain technology and no central system (decentralization) allowing cryptocurrencies self governing and thus autonomous to the regulatory authority ([Corbet et al., 2019](#)). Since its invention in 2009 bitcoin has grown in value, bitcoin is indeed one of the renowned digital or crypto-currency. In addition, there has been increasing curiosity in bitcoin's economics and finance research.

Early work focuses including, prices discovery in the bitcoin market [Ciaian et al. \(2016\)](#) while, [Balcilar et al. \(2017\)](#) find bitcoin returns volatility, [Yermack \(2013\)](#) claims that bitcoin tends to be more of a speculative investment than a currency. [Gandal et al. \(2018\)](#) reporting bitcoin price manipulation, whereas [Foley et al. \(2019\)](#) confirm illegal acts by bitcoin.

The diversification nature of bitcoins with other financial assets is also studied by various studies. For example, [Makarov and Schoar \(2020\)](#) recently show the possibilities for arbitrage in the bitcoin market. Due to the highly volatile nature of

bitcoins, their use in a diversified portfolio is very profitable ([Eisl et al., 2015](#)). Despite the increasing concern for bitcoin as a virtual currency, there is currently a dearth of empirical evidence on the diversification, hedging, and safe haven features of green bonds in comparison to other markets.

[Bouri et al. \(2017\)](#) investigated the relationship between bitcoin and financial markets (including the bonds market). They find that bitcoins work as a good diversifier. [Baur et al. \(2018\)](#) claim a weak correlation of bitcoin with equities that indicate diversification in normal and market turbulence periods. While [Eisl et al. \(2015\)](#) studied bitcoin from a portfolio perspective and find that inclusion of bitcoin can diversify risk. [Wu et al. \(2014\)](#) and [Baur et al. \(2015\)](#) find bitcoin as a good diversifier in times of stability and in times of financial disturbance, because of the insignificant association between bitcoin and other financial markets. [Ji et al. \(2018\)](#) also find no correlation of bitcoin with other financial markets and find it as a good diversifier. [Ji et al. \(2018\)](#) find a time-variant association between bitcoin and other financial assets. [Dyhrberg \(2016\)](#) find that bitcoin has hedging properties and should be used in a portfolio to mitigate harmful impacts of potential risks. [Fang et al. \(2019\)](#) noticed a strong negative association between bitcoin and bonds and proposed that bitcoin might function as a hedge.

3.4.5. Bond and Foreign Exchange Markets

There are three main criteria that investors consider investing internationally, first changes in currency, second, cross-country correlation and third, market uncertainty or volatility ([Odier & Solnik, 1993](#)). The connection between capital market prices and exchange rates is significant as both variables serve a substantial economic role ([Tsai, 2012](#)). It has been well known that conventional macroeconomic variables do not describe exchange-rate movements well in the short to medium term. In the short and

medium term, [Gabaix and Maggiori \(2015\)](#) stress the significance of portfolio flows on the exchange rates, particularly where investment firms do not have adequate risk-bearing ability. Large outflows or inflows of capital might contribute to appreciate or depreciate currencies, contributing to enhanced exchange-rate uncertainty and greater difficulties in implementing macroeconomic policies. Due to the free movement of money, foreign portfolio flows influence the foreign exchange market while forex order flows are closely associated with exchange rate fluctuations ([Killeen et al., 2006](#)). [Gabaix and Maggiori \(2015\)](#) also conclude net equity inflows into an emerging market have a positive association with currency appreciation. As the emerging capital market rises, both the income of local investors and interest rates rise. The higher interest rate stimulates foreign investment, which in effect contributes to the appreciation of the currency ([Wong, 2017](#)).

Furthermore, investors invest in the currency market because of its nature of portfolio diversification and mitigation of portfolio risk, for example, [Cenedese et al. \(2016\)](#) find portfolio diversification opportunities in the currency market and find that equity returns and exchange rate has cointegration.

However, the above mentioned is the case where mixed results are about the correlation between stocks and currency markets. There are various views about bonds and the currency market also. [Ajand and Yung \(1997\)](#) confirm an inverse relationship between foreign currency futures and bonds returns. [Raza and Wu \(2018\)](#) find a weak comovement between currency and bond markets. The findings of the correlation between bonds and currency markets are mixed.

Bond and currency market associations vary under various cases. Usually, the bonds market may have a close positive association with respective currencies, since both follow interest rates. Currencies and bond yields appreciate as interest rates are

projected to increase. Bond yield changes are sometimes led by equivalent changes in local currency ¹⁶. Commonly, higher bond returns appreciate the currency. The higher bond yields attract foreign investors, which sell their local currency to buy the (specific currency) to purchase the bonds. This causes the (specific if currency) to appreciate against those currencies. Furthermore, it is not always the case that higher the bond returns, appreciation of the currency, a scenario where riskier bonds demand higher yields to encourage investors. This implies yields will grow as a nation's debt default chances increase. If this occurs, the related currency depreciates despite increasing yields.

Hence after study literature on bonds and currency market correlation this study finds mixed finding, some researcher supports the view that a positive correlation exists between bonds market and currency market and some say a negative correlation.

3.4.6. Financial Markets Comovement and Role of Macroeconomic Factors

Knowing financial assets comovement remains a central concern of the financial sector. This dilemma provides important theoretical significance for price formation knowledge and also has important practical implications in asset selection and risk management. The initial work on assets pricing i.e. CAPM assumes that assets return the only effect due to market beta however, in reality, this assumption does not come true. The arbitrage pricing theory is also known as (APT theory) was then suggested by [Ross \(1976\)](#) which suggests that market beta is not only a single factor that can affect the return of assets, but several factors can affect the return of a particular asset ([Kettell, 2001](#)).

Moreover, based on macroeconomics bases, an initial work provides a theoretical framework for stock market returns and macroeconomic variable's dynamic association

¹⁶ <https://www.forexsource.co/the-top-3-intermarket-influences-on-currencies/>

([Fama, 1981](#); [Geske & Roll, 1983](#); [Pearce & Roley, 1983](#)). Thus, under the APT paradigm, all investments have "expected returns" and are affected by economic and financial factors (the exact number of such factors are not identified in the underlying assumption). There are many latest studies that confirm the effect of macroeconomic variables on assets correlation ([Gokmenoglu & Hadood, 2019](#); [Kang et al., 2019](#)). APT begins with the presumption that assets returns are directly connected to unknown factors ([Iqbal & Haider, 2005](#)).

[Roll and Ross \(1980\)](#) reported four important factors "the unanticipated change in the inflation, risk premiums, the terms structure of interest rates and industrial production". It is important to note that the literature is silent on the exact number of factors affecting the return and comovement of financial assets. For example, [Hamburner and Kochin \(1972\)](#) find that monetary policy determines stock returns. [Gulko \(2002\)](#) observe a drastic change in financial assets comovement during financial crashes. [Rjoub et al. \(2009\)](#) find that unemployment, inflation, money supply and industrial production has affected weakly effect on stocks returns. While [Narayan and Gupta \(2015\)](#) confirm that oil prices, affect equity returns. There are few studies that find that market volatility affects assets correlation ([Andersson et al., 2008](#); [Lee et al., 2019](#)). A most recent study by [Sharif et al. \(2020\)](#) find the effect of pandemic uncertainty (COVID-19) on financial markets and finding confirm that COVID-19 significantly effect financial assets.

Time-varying comovement between financial assets has attracted a great deal of attention from policy makers, investors and fund managers to construct an efficient portfolio. Therefore, various studies find a time-varying correlations between bonds and stock using various macroeconomic variables see ([Gupta et al., 2018](#); [Lin et al., 2018](#)). They find that macroeconomic variables play a significant role in the time-varying correlation between bonds and stock.

Table 3-1: Review of Latest Studies on Green Bonds and other Financial Markets

Studies	Objective	Methodology	Other markets	Findings
Naeem et al. (2021)	To find how COVID-19 effect the connectedness between green bonds and other markets.	Diebold and Yilmaz (2012)	Bitcoin, gold, oil, bond etc.	COVID-19 plays a major role in financial markets connectedness.
Park et al. (2020)	Green bonds and equity volatility.	GARCH models	Equity market	Heterogeneous volatility is observed in green bonds.
Reboredo and Ugolini (2020)	Co-movement Of green bonds market with other financial markets.	Structural VAR model parameters	Corporate, treasury & high-yield corporate bonds, currency stock and energy commodity markets.	Green bonds commove with currency and bonds market and weak comovement with stock and energy commodity markets.
Reboredo et al. (2020)	Comovement between green bonds and other financial markets in EU and US.	Wavelet coherence	Stock, high-yield corporate, & treasury bonds and energy commodity market.	A high correlation between green bonds, treasury and corporate bonds and low correlation with high-yield corporate bond, stock and energy commodity market.
Tang and Zhang (2020)	Green bonds benefits to shareholders.	CAPM model	Stock and other conventional bonds markets.	Due to the issuance of green bonds, stock prices were positively effects.
Broadstock and Cheng (2019)	Time-varying correlation between green and black bonds.	DCC and DMA	Black bonds market.	The correlation between green and black bonds highly depends on macroeconomic factors.
Glavas (2018)	Stock prices response due to green bond issuance.	Regression and difference-in-differences analyses.	Stock prices	Green bonds issuance positive effect on stock prices.
Reboredo (2018)	Portfolio diversification opportunities of green bonds.	Non-parametric copula	Corporate & treasury bond, stock and energy commodity markets.	Portfolio risk can be lowered by mixing green bonds with equities and energy commodities; however, pairing green bonds with corporate and government bonds has little effect on portfolio risk.
Pham (2016)	Green bonds volatility analysis.	MGARCH	Conventional bond market	It is common for a shock in the traditional bond market to have an effect on the green bond market.

3.5. Research Gap of the Study

Green financing is essential as it facilitates, promotes and enables the movement of financial products and related services to build and enforce green business practices, industrial, financial, social and environmental ventures and policies. Since the financial industry plays a crucial role in the promotion of sustainable economic growth through its intermediate roles and risk management whereas guiding investment to the real economy, the interlinkage of these two is important.

A sustainable and low-carbon economy requires a huge amount of long-run financial resources and utilizing suitable financial tools for that reason. Green bonds are a financial fixed-income instruments, which is the response to investors appeal for a sustainable environment. Green bonds have proven their potential to redistribute the cost of reducing the adverse impact of climatic change over the decades ([Flaherty et al., 2017](#); [Orlov et al., 2017](#)). Moreover, [Monasterolo and Raberto \(2018\)](#) recognized green bonds as the strongest tool for low-carbon development. The demand aspect of green bonds demonstrates that investors' rising appetite for eco-friendly investment globally. Banking giant the “Development Bank of Singapore” (DBS) estimates that potential investments in ASEAN alone would need up to \$ 3 trillion in green project before 2030¹⁷.

The above discussion on green bonds shows the growing concern of researchers to explore this green finance instrument. The prevailing literature on green bonds mainly emphasises on green bonds in terms of bond market premia. For example, as compared to the traditional bonds market, the green bonds market has a small bond market premium. Green bonds provide lower yields as compare to traditional bonds

¹⁷ <https://indvstrvs.com/green-financing-set-for-agressive-growth-globally-in-2019/>

([Zerbib, 2019](#)). Similarly, there are some other studies, which find lower returns on green bonds as compare to traditional bonds ([Bachelet et al., 2019](#); [Hachenberg & Schiereck, 2018](#)). However, [Baker et al. \(2018\)](#) confirmed that as compared to traditional US municipal bonds, the green bonds are issued at a bond market premium.

However, there are very few studies that examine connectedness between green bonds and other financial assets ([Reboredo, 2018](#); [Reboredo & Ugolini, 2020](#); [Reboredo et al., 2020](#)), these studies find that green bonds diversification opportunity between green bonds and other financial assets varies across the financial assets. Furthermore, investors consider risk, return, volatility and spillover effect for the portfolio diversification however there is no sufficient literature to understand the volatility and spillover effect of green bonds. In addition, at the time of portfolio construction investment companies, portfolio managers or individual investors consider comovement between green bonds and other financial assets to avoid unsystematic risk considering diversification under the bullish and bearish market states.

Moreover, comovement between green bonds and other financial assets under the bullish and bearish market conditions is not studied sufficiently. Furthermore, comovement between green bonds and other financial markets also varies over the time-frequency domain, which highly effects investor's decision and portfolio formulation. The literature is scant on discussing this phenomenon regarding green bonds and other financial markets. In addition, pandemic uncertainty (particularly COVID-19) effect highly financial markets but there are still scant studies which explored either green bonds market effect financial markets. Furthermore, there are no studies which explain either this pandemic uncertainty (COVID-19) effect correlation between green bonds or other financial markets.

Therefore, this study fills the various missing areas of research between green bonds and other financial markets (stock, commodity, digital currency, bonds and foreign exchange market) comovement. Analyzing how the green bonds market commoves with other financial markets is most important for investors, fund managers and policy makers because comovement helps in policymaking and assets allocation for a portfolio. This study finds comovement between green bonds and other financial markets from a global perspective.

First, numerous studies show that the financial market's association strongly relies on various market conditions (e.g., bearish, mild bearish, optimistic or bullish). Therefore, it is most important to understand the full dependency structure between green bonds and o financial markets because underestimating the hedging and diversification potential of green bonds could lead to less diversification paybacks. Furthermore, the heterogeneous cointegration of financial assets (quantile variations) required policymakers and portfolio manager's attention to reduce portfolio risk. Whereas conventional approaches provide an average correlation between selected assets. Thus, conventional correlation approaches can provide misleading inferences due to heterogeneity in assets correlations due to different market states.

However, literature on the full dependency between green bonds and other financial markets (stock, commodity, digital currency, bonds and foreign exchange markets) is very rare which suggests to further study comovement between said financial markets in bearish, mild bearish, optimistic or bullish to provide a complete understanding of correlation to investors, fund managers and policy makers to reduce portfolio risk.

Second, presently whole world suffering from COVID-19 which has affect the world socially and economically. There are few studies, which are recently published; find that financial markets are highly affected by this world pandemic and based on literature it can be observed that pandemic or economic crisis highly affect comovement between financial markets. However, this study finds limited literature, which has explored either COVID-19 changes the correlation between green bonds and other financial markets. Hence, it is a dire need to conduct empirical research to examine either COVID-19 changes correlation between financial markets to device better policies regarding portfolio and reduce portfolio risk.

Third, different investors invest their funds according to their needs, e.g. brokers invest funds for a few minutes, hours or days, and there are different types of investors, some in the short, medium and long term. As a result, investor concerns about portfolio returns based on their needs, such as long-term investors focus on low-frequency returns, and short-and medium-term investors care about high and medium-frequency returns ([Campbell et al., 2002](#)). However, this study finds limited literature on time and frequency domain comovement between green bonds and other financial markets (stock, commodity, digital currency, bonds and foreign exchange markets). Therefore, this is the dire need to study the correlation between said financial markets considering time and frequency domain so that all types of investors can make a better decision about portfolio construction and policy maker can devise better policy based on the need of various types of investors to reduce portfolio risk.

Fourth, volatility spillovers models did not take into account dynamic correlations between green bonds and other financial markets (stock, commodity, digital currency, bonds and foreign exchange markets). Hence it is important to find net volatility transmitters and receivers between green bonds and other financial markets. Knowing

the systems through which financial markets transmit volatility to one another can be beneficial for portfolio managers, policymakers, and speculators in the development of exploitable trading strategies.

Finally, based on the literature review, it is observed that researchers ignored the role of the green bonds market against other financial markets (stock, commodity, digital currency, bonds and foreign exchange markets) in the context of green bonds being act as a hedge, diversifier or safe haven. Therefore, it needs to discuss the role of green bonds as a hedge, diversifier or safe haven against the stock, commodity, digital currency, bonds and currency markets. It will help policy makers, fund managers and investors to reduce portfolio risk.



CHAPTER 4: THEORETICAL FRAMEWORK AND RESEARCH METHODOLOGY

4.1. Introduction

This chapter discusses the theoretical framework, data and methodology to achieve the objectives of the study, as the current research have five primary objectives. The first two objectives are (1) to examine dependency between green bonds and other financial markets (including, stock, commodity, digital currency, bonds and foreign exchange markets) under bearish, normal and bullish market states; (2) to examine whether COVID-19 changes correlation between green bonds and other financial markets. The investment decision highly depends on the nature of the financial market's performance (e.g., bearish, mild bearish, optimistic or bullish market states), fund managers, individual investors and policymakers consider comovement/correlation between financial markets in different market situations to construct an efficient portfolio by investing in less correlated assets.

Hence, to find a complete dependency structure between financial markets (in bearish, mild bearish, optimistic or bullish markets states) this study employs quantile on quantile regression (QQR) approach. To achieve the second objective of the study either COVID-19 changes the correlation between green bonds and other financial markets. We split our sample period into two samples first as a before COVID-19 sample ranging from 11/28/2008 to 03/21/2021 and the second sample period that represents COVID-19 ranging from 03/11/2020 to 03/21/2021. We decided during the COVID-19 sample based on WHO announced the date as the coronavirus epidemic (COVID-19) was formally announced a global pandemic on 11 March 2020 by WHO.

Third, to explore the dependency between green bonds and other financial markets across various investment horizons because various investors may be very heterogeneous, based on how long they are involved in the green bonds market. Short-

term traders care most about equity gains on higher frequencies, intermediate frequencies are of considerable concern to medium-term investors, and low frequencies are of particular importance to long-term traders. Therefore, this study uses wavelets-based analysis to achieve this objective. Fourth, to find net volatility transmitter and receiver between green bonds and other financial markets.

Finally, to examining either the green bonds market can act as a diversifier, a hedge or a safe haven against other financial markets. To achieve these objectives, we applied [Diebold and Yilmaz \(2014\)](#) volatility spillovers index (including static connectedness analysis, dynamic connectedness analysis, directional volatility spillovers from, directional volatility spillovers to, net total directional connectedness, net pairwise directional connectedness) and DCC-GARCH model.

4.2. Theoretical Framework

In financial literature, diversification has considerable importance. Investors diversify their funds to reduce losses, earn profit and preserving capital. [Markowitz \(1952\)](#) established modern portfolio theory, also known as MPT theory that discusses portfolio diversification. Markowitz diversification's main idea is “not putting all your eggs in one basket or spreading your risks”. The MPT theory works based on investing wealth in several assets, which are less correlated to lessen portfolio risk without scarifying anticipated returns ([Francis & Kim, 2013](#)). The resulting portfolio would be the least risky due to the low or week correlation between the selected assets and no matter how risky portfolio assets are in isolation analysis. While, [Kristian, Carl & Jakob \(2006\)](#) called MPT "Magic Diversification" because of its practical implications.

In the financial literature, MPT theory always remains accessible, and various researchers find diversification opportunities based on MPT. For example, [Pagliari et](#)

[al. \(1995\)](#) and [Lee and Stevenson \(2005\)](#) used MPT in real estate portfolio, [Širuček and Křen \(2017\)](#) in the stock market and a most recent study by [Platanakis and Urquhart \(2020\)](#) for bitcoin. The prime objective of this study is to examine the comovement between green bonds and other financial markets (including stock, commodity, digital currency, bonds and foreign exchange markets). The current financial markets have changed significantly over time; many changes have emerged in financial markets, such as digitalization, internationalization, asymmetries, and many other revolutions. Currently, numerous financial markets are being introduced, such as green finance (particularly green bonds), digital currency (crypto currency), and so on. As a result, the financial market revolution created new opportunities for investors to diversify their investments. Therefore, MPT theory supports the hypothesis of the current study and based on MPT principles it can understand that either green bonds market against selected financial markets provides diversification opportunities that will help policymakers, fund managers and institutional investors or individual investors.

Furthermore, cointegration, correlation, or comovement between selected financial markets create information, which ultimately affects portfolio diversification decisions and can be helpful in profit earning. While as per the Efficient Market Hypothesis, also known as EMH theory “efficient markets do not allow investors to earn more above-average returns without accepting above-average risks”. This supports the assumption that no particular investor can profit from the information because everybody has exposure to the same knowledge expressed in the market price. Therefore, if cointegration exists between the green bonds market and other financial markets (including stock, commodity, digital currency, bonds and foreign exchange markets), it rejects the basic principle of EMH that future prices can’t be predicted based on current

or previous prices of the market. Hence selected markets that are efficient or not can support with the help of MH theory.

In the financial literature, there are various studies that consider EMH theory for example [Lee et al. \(2014\)](#) and [Phiri \(2015\)](#) for stock markets, [Hu et al. \(2019\)](#) and [Le Tran and Leirvik \(2019\)](#) for crypto-currencies, [Wickremasinghe \(2016\)](#) exchange rate among others. However, the findings of previous studies are mixed about the efficiency of financial markets; some researchers confirm the existence of EMH theory while some researchers reject EMH theory. Therefore, cointegration between green bonds and other financial markets can find the efficiency of selected markets.

4.3. Data Sources and Variables Description

This study examines the comovement between green bonds and other financial markets (including, stock, commodity, digital currency, bonds and foreign exchange markets). This study uses daily data ranging from 11/28/2008 to 03/21/2021¹⁸. All the financial markets, which are part of this research, are in a global context (e.g., global indices of financial markets). Data for the various financial markets are extracted from various sources (e.g., Refinitiv Datastream, Bloomberg, the CRIX and FRED).

¹⁸ This study chooses this dataset because of availability of the data, for the green bonds, there is a starting point of data from 11/28/2008 to present.

Table 4-1: Variables Descriptive

Variables	Abbreviations	Units of Measurement	Data Sources
Green bonds market	S&P_GB	S&P green bond index total return	Refinitiv Datastream
Stock markets	S&P_500 & DJ_IMWI	S&P 500 index (S&P_500) and Dow Jones Islamic market world index (DJ_IMWI)	Refinitiv Datastream
Commodity markets	S&P_GSCI	S&P GSCI index total return	Refinitiv Datastream
Digital currency markets	CRIX	Crypto index return	https://thecrix.de/
Bond markets	S&P_BD & DJ_SUK	S&P 500 bond index total return (S&P_BD) and Dow Jones sukuk index total return (DJ_SUK)	Refinitiv Datastream and Bloomberg
Foreign exchange market	FRX	TWEXB index	FRED

4.3.1. Green Bonds Market

It is the novelty of this research to study green bonds market comovement with other financial markets. Green bonds are newly introduced financial assets; therefore, it is imperative to understand their volatility spillover effects and comovement with other financial markets to devise diversification policies. Green bonds have characteristics identical to traditional fixed-income corporate bonds, while funds raised from issuing green bonds are specifically used to support sustainable projects. The green bonds market is getting recognition worldwide and various famous stock exchanges have recently opened a specific green bond segment such as those in Italy, Oslo, London, Mexico, Luxembourg, Shanghai and Shenzhen. Therefore, the green bonds market is a global market with a large, diverse set of issuers worldwide, including large enterprises, public bodies and supranational institutions and investors.

To follow the financial success of the global green bonds market, various green bond indexes were built to represent the price movements of the entire set of green bonds trading in the market. These indices help investors to equate green bond returns and volatility with traditional investments. There are currently four major green bond indexes, each of which has its own framework and requirements for the inclusion of bonds in the respective index components. However, [Reboredo \(2018\)](#) find that all these four indices show the same dynamics and show a near-one correlation coefficient. Conversely, this study uses the daily total return of the S&P Green Bond Index, which is based on a market value-weighted index designed to measure the performance of green-labelled bonds issued globally. The main reason for taking this index is the availability of sufficient data from 11/28/2008 to 03/21/2021.

4.3.1.1. The S&P Dow Jones Green Bond Index

The criteria of including any bonds in this market value-weighted index is that any issued bonds in any country or currency are eligible if these bonds are labelled as green by the Climate Bonds Initiative. Such bonds pay particular forms of coupons (fixed, zero-coupon, step-up, floaters,

and fixed-to-float) and exempt bills and strips related to inflation. The S&P Dow Jones green bond index is measured in US Dollars, and weights are revised monthly. This index covers treasury, government, corporate and securitized issues.

4.3.2. Stock Markets

This study measures stock markets based on two leading indices (1) conventional S&P 500 index (2) Dow Jones Islamic Market World Index. The key explanation for taking two markets is that usually there are two categories of investors, first those who do not care about their investment (investing in Halal or Haram investments) and second those who care about their investment and only invest in certain companies that are founded on Islamic values. Therefore, this study considers both conventional and Islamic stock indices. Since Islamic stocks have distinct characteristics, creativity, fast growth and alternative market diversification, and it is also one of the reasons for including Islamic stocks in this study.

Islamic indices are mainly composed of stocks following a stringent screening process. Stocks are screened to eliminate any businesses involved in practices other than Sharia, including gambling and drug and tobacco manufacturing. Islamic finance has basic concepts separate from traditional finance ([Mishra et al., 2019](#)). Unlike conventional finance, which is focused on loans and debt, Islamic finance is centered on the ownership of assets. This study considers the S&P 500 index for conventional stock markets and Dow Jones Islamic Market World Index for the Islamic stock markets. The data are extracted from Datastream from 11/28/2008 to 03/21/2021.

4.3.3. Commodity Markets

Commodity investment is viewed as a way of further diversifying risk. Investigating comovement between commodities and other financial markets is, therefore, an important aspect of modern finance, as efficient analysis of volatility and correlation is required for derivative of pricing, portfolio optimization, risk management and hedging. This study,

therefore, explores the comovement between green bonds and the commodity market. The commodity market is measured by the total return of the commodity S&P GSCI index. The S&P GSCI is a weighted commodity index that evaluates commodity market performance. The S&P GSCI is the commodity equivalent of stock indexes, such as the S&P 500 and the Dow Jones. Before being acquired by Standard & Poor's in 2007, the S&P GSCI was named the Goldman Sachs Commodity Index (GSCI). The data are extracted from Datastream from 11/28/2008 to 03/21/2021.

4.3.4. Digital Currency Markets

The internet has born a new idea and class of financial products in recent years. This new form is known as crypto-currency in generic. Crypto-currency is a digital means of trade that uses cryptography for security purposes. [Briere et al. \(2015\)](#) find that bitcoin (digital currency) assets have substantial advantages in terms of diversification and demonstrate that the addition of only a limited proportion of bitcoins significantly increases risks and returns for well-diversified portfolios. Therefore, this study also included the digital currency market in the current investigation. This study measures the digital currency market by using the “CRypto index”. The data for the crypto index are extracted from The CRIX site ranging from 07/28/2014 to 03/21/2021 (<https://thecrix.de/>). Due to the availability of data restriction for the crypto-currency, this study examines comovement between the green bonds and crypto-currency market for the period ranging from 07/28/2014 to 03/21/2021.

4.3.5. Bond Markets

This study includes both conventional bonds and Islamic bonds to examine portfolio opportunities with the green bonds market. There are various reasons for involving bonds in portfolio diversification; for example, it performs well as hedging in market turmoil's or economic slowdown, capital protection and capital appreciation. Bonds are known as safe securities since they are usually less risky than certain other asset classes, like currencies,

stocks etc. Because of their nature of being less risky, many investors include bonds in their portfolios to minimize the overall volatility of the portfolio. This study measures the conventional bonds market using total returns of the S&P 500 bond index from 11/28/2008 to 03/21/2021. As conventional bonds do not satisfy the need of Islamic investors, therefore, Sukuk introduced, which is also like but based on Islamic principles. There are various studies, which find that Sukuk provides diversification opportunities being part of a portfolio ([Aloui et al., 2015](#); [Scip et al., 2016](#); [Shahzad et al., 2019](#)). Therefore, this study measures the Sukuk market with Dow Jones Sukuk total return index from 11/28/2008 to 03/21/2021.

4.3.6. Foreign Exchange Markets

This study uses the Trade Weighted US Dollar Index (TWEXB) for currency markets. TWEXB is a weighted average of the U.S. dollar's foreign exchange value against a broad group of major U.S. trading partners. This broad currency index includes the “Euro Area, Canada, Japan, Mexico, China, United Kingdom, Taiwan, Korea, Singapore, Hong Kong, Malaysia, Brazil, Switzerland, Thailand, Philippines, Australia, Indonesia, India, Israel, Saudi Arabia, Russia, Sweden, Argentina, Venezuela, Chile and Colombia”. The data for TWEXB was extracted from FRED¹⁹ based on daily frequency from 11/28/2008 to 03/21/2021.

4.4. Methodology

To achieve various objectives of the study, various econometrics methods are being utilized. The following are the econometrics approaches, which are part of the current study.

4.4.1. Unit Root Quantile Autoregression (QAR)

The quantile regression approach (QRA) was initially used for robust inferences that allowed scholars to check conditional quantile functions ([Koenker & Bassett Jr, 1978](#)). In this study, we move one step forward and use the unit root quantile autoregressive approach developed by

¹⁹ <https://fred.stlouisfed.org/series/DTWEXB>

[Koenker and Xiao \(2004\)](#), and then [Galvao \(2009\)](#) further introduced covariates in the model with linear time trends. This study tests the stationarity properties of the data series on the conditional mean as well as conditional distribution at each quantile.

From the above-given information, we set $Y_t = (Y_{t-1}, \dots, Y_{t-s})' \in \mathbb{R}^s$ where " Y_t " denotes strict stationarity.

$$Y_t = \alpha Y_{t-1}, \dots, Y_{t-s} + u_t, t = 1, 2, \dots, s \quad \text{Eq. (4.1)}$$

We focus on $\alpha = 1$ and assume k_t^Y as conditional distribution of " Y_t " and set $F_Y(\tau|k_t^Y)$. As we mentioned above the QAR unit root is an extension of QR and linear QR method is used to perform it that is given as follows:

$$W_\tau^X(X_t|k_t^Y) = \theta_1(\gamma) + \theta_2(\gamma)t + \omega(\gamma)X_{t-1} + \sum_{j=1}^q \omega_j(\gamma)\Delta X_{t-j} + z_u^{-1}(\gamma) \quad \text{Eq. (4.2)}$$

$W_\tau^X(\cdot|k_t^X)$ is characterized as the γ quantile of $F_X(\cdot|k_t^X)$. $\theta_1(\gamma)$ is drift term while t is linear trend and $\omega(\gamma)$ is persistence parameter. z_u^{-1} is labelled as inverse conditional distribution of errors for the quantiles such as $\tau \in T \subset [0,1]$. Hence several tenacity parameters, for instance, $\hat{\alpha}$ for each quantile of the conditional distribution of X_t are estimated. Therefore, QAR follows t-statistics to test the null hypothesis:

$$H_0: \alpha(\tau) = 1 \quad \text{Eq. (4.3)}$$

for quantiles of $\tau \in T$ ([Galvao, 2009](#); [Koenker & Xiao, 2004](#)).

4.4.2. Quantile Cointegration Test

The present study identifies cointegration between green bonds and other financial markets by employing the Quantile Cointegration (QC) test of [Xiao \(2009\)](#). This test decomposes errors of cointegrated equations into lead lags and pure innovation components to remove endogeneity from the model ([Saikkonen, 1991](#)). Moreover, quantile cointegration (QC) is the

extension of Engel and Granger cointegration having a special vector of constants termed as $\beta(\tau)$ (([Engle & Granger, 1987](#))). Therefore, the particular case of QC is:

$$Y_t = \alpha + \beta'Z_t + \sum_{j=-k}^k \Delta Z'_{t-j} \Pi_j + u_t \quad \text{Eq. (4.4)}$$

and

$$W_\tau^y(Y_t | k_t^y, k_t^z) = \alpha(\tau) + \beta(\tau)'Z_t + \sum_{j=-k}^k \Delta Z'_{t-j} \Pi_j + F_u^{-1}(\tau) \quad \text{Eq. (4.5)}$$

We added a quadratic term to represent the regressor in the above given QC. So, the same is represented below:

$$W_\tau^y(Y_t | k_t^y, k_t^z) = \alpha(\tau) + \beta(\tau)'Z_t + \gamma(\tau)'Z_t^2 + \sum_{j=-k}^k \Delta Z'_{t-j} \Pi_j + F_u^{-1}(\tau) \quad \text{Eq.(4.6)}$$

From the above equation, [Xiao \(2009\)](#) removed cointegrating coefficients' instability testing and introduced the null hypothesis as:

$$H_0: \beta(\tau) = \beta \quad \text{Eq.(4.7)}$$

on all the quantiles. Here the null hypothesis states that supermum rule is applied for the absolute value of difference, which is used in test statistics as follows:

$$\widehat{V}_n(\tau) = (\widehat{\beta}(\tau) - \widehat{\beta}) \quad \text{Eq. (4.8)}$$

Based on these test statistics, the present study employs test statistic $\sup_\tau |\widehat{V}_n(\tau)|$ across all the quantiles' distribution. This test gives 1000 simulations of Monte Carlo while estimating critical values in test statistics of:

$$\sup_\tau |\widehat{V}_n(\tau)| \quad \text{Eq. (4.9)}$$

4.4.3. Quantile on Quantile Regression (QQR)

It is the objective (objective 1 and 2) of this study to examine the dependency structure between green bonds and other financial markets. Therefore, this section underpins the critical features

of model specifications of the QQR approach introduced by [Sim and Zhou \(2015\)](#). The QQR is a generalization of quantile regression (QR) in which conditional quantiles of one variable affect another variable. At the same time, QR is an extension of the classical linear regression model similar to the methodology of ordinary least squares. On the contrary, QR checks the variation in data at different periods by taking and comparing upper and lower quantiles of both dependent and independent variables.

So, in the beginning when QR was initiated and used in analyzing data researchers first used to employ OLS and then in the second step they check and validate the results by QR to check time dependency and time-varying degree between two data sets of time series. One drawback of the QR framework is its failure to completely grasp dependency.

Instead of employing the QR technique, this study adopts a QQR technique, as proposed by Sim and Zhou (2015). The QQR method calculates quantiles of green bond returns as a function of other financial markets' returns, or vice versa. Estimation of QQR model uses two approaches viz a viz: first is the triangular equations system ([Ma & Koenker, 2006](#)) and second is single equation regression analysis ([Sim & Zhou, 2015](#)). This study uses the latter approach that is explained briefly as follows.

Operationally, we define a flexible model that allows for the modelling of correlations from non-extreme to extreme occurrences, where the quantile of one variable is dependent on the quantile of another. Following we postulate a model for the θ -quantile of S&P_GB as a function of past and other financial markets denoted as follows:

$$S\&P_GB_t = \beta^\theta S\&P_500_t + \alpha^\theta S\&P_GB_t + \varepsilon_t^\theta \quad \text{Eq. (4.10)}$$

$$S\&P_GB_t = \beta^\theta DJ_IMWI_t + \alpha^\theta S\&P_GB_t + \varepsilon_t^\theta \quad \text{Eq. (4.11)}$$

$$S\&P_GB_t = \beta^\theta S\&P_GSCI_t + \alpha^\theta S\&P_GB_t + \varepsilon_t^\theta \quad \text{Eq. (4.12)}$$

$$S\&P_GB_t = \beta^\theta CRIX_t + \alpha^\theta S\&P_GB_t + \varepsilon_t^\theta \quad \text{Eq. (4.13)}$$

$$S\&P_GB_t = \beta^\theta S\&P_BD_t + \alpha^\theta S\&P_GB_t + \varepsilon_t^\theta \quad \text{Eq. (4.14)}$$

$$S\&P_GB_t = \beta^\theta DJ_SUK_t + \alpha^\theta S\&P_GB_t + \varepsilon_t^\theta \quad \text{Eq. (4.15)}$$

$$S\&P_GB_t = \beta^\theta FRX_t + \alpha^\theta S\&P_GB_t + \varepsilon_t^\theta \quad \text{Eq. (4.16)}$$

Where ε_t^θ is an error term that has a zero θ -quantile. This study uses a single equation regression analysis ([Sim & Zhou, 2015](#)). The quantile of green bonds market (S&P_GB) is denoted by θ . primarily, we modelled θ -quantile of S&P_GB on its previous lag $S\&P_GB_{t-1}$ while other financial markets (including, S&P_500, DJ_IMWI, S&P_GSCI, CRIX, S&P_BD, DJ_SUK and FRX). It is represented in the form of an equation as:

$$S\&P_GB_t = \beta^\theta S\&P_500_t + \varepsilon_t^\theta \quad \text{Eq. (4.17)}$$

$$S\&P_GB_t = \beta^\theta DJ_IMWI_t + \varepsilon_t^\theta \quad \text{Eq. (4.18)}$$

$$S\&P_GB_t = \beta^\theta S\&P_GSCI_t + \varepsilon_t^\theta \quad \text{Eq. (4.19)}$$

$$S\&P_GB_t = \beta^\theta CRIX_t + \varepsilon_t^\theta \quad \text{Eq. (4.20)}$$

$$S\&P_GB_t = \beta^\theta S\&P_BD_t + \varepsilon_t^\theta \quad \text{Eq. (4.21)}$$

$$S\&P_GB_t = \beta^\theta DJ_SUK_t + \varepsilon_t^\theta \quad \text{Eq. (4.22)}$$

$$S\&P_GB_t = \beta^\theta FRX_t + \varepsilon_t^\theta \quad \text{Eq. (4.23)}$$

ε_t^θ is the error term with zero θ -quantile while the associated function $\beta^\theta(.)$ is supposed to be unknown due to no prior knowledge about linkages between green bonds and other financial markets. This study scrutinizes the association between the θ -quantile of dependent and independent variables by linearizing the function $\beta^\theta(.)$ with first-order Taylor approximation of $\beta^\theta(.)$ around other financial markets. The same is denoted as follows:

$$\beta^\theta(S\&P_500_t) \approx \beta^\theta(S\&P_500^\tau) + \beta^{\theta'}(S\&P_500^\tau)(S\&P_500_t - S\&P_500^\tau) \quad \text{Eq. (4.24)}$$

$$\beta^\theta(\text{DJ_IMWI}_t) \approx \beta^\theta(\text{DJ_IMWI}^\tau) + \beta^{\theta'}(\text{DJ_IMWI}^\tau)(\text{DJ_IMWI}_t - \text{DJ_IMWI}^\tau) \quad \text{Eq. (4.25)}$$

$$\beta^\theta(\text{S\&P_GSCI}_t) \approx \beta^\theta(\text{S\&P_GSCI}^\tau) + \beta^{\theta'}(\text{S\&P_GSCI}^\tau)(\text{S\&P_GSCI}_t - \text{S\&P_GSCI}^\tau) \quad \text{Eq. (4.26)}$$

$$\beta^\theta(\text{CRIX}_t) \approx \beta^\theta(\text{CRIX}^\tau) + \beta^{\theta'}(\text{CRIX}^\tau)(\text{CRIX}_t - \text{CRIX}^\tau) \quad \text{Eq. (4.27)}$$

$$\beta^\theta(\text{S\&P_BD}_t) \approx \beta^\theta(\text{S\&P_BD}^\tau) + \beta^{\theta'}(\text{S\&P_BD}^\tau)(\text{S\&P_BD}_t - \text{S\&P_BD}^\tau) \quad \text{Eq. (4.28)}$$

$$\beta^\theta(\text{DJ_SUK}_t) \approx \beta^\theta(\text{DJ_SUK}^\tau) + \beta^{\theta'}(\text{DJ_SUK}^\tau)(\text{DJ_SUK}_t - \text{DJ_SUK}^\tau) \quad \text{Eq. (4.29)}$$

$$\beta^\theta(\text{FRX}_t) \approx \beta^\theta(\text{FRX}^\tau) + \beta^{\theta'}(\text{FRX}^\tau)(\text{FRX}_t - \text{FRX}^\tau) \quad \text{Eq. (4.30)}$$

We can redefine $\beta^\theta(X^\tau)$ (X^τ refers to other financial markets) as $\beta_0(\theta, \tau)$ and $\beta^{\theta'}(X^\tau)$ as $\beta_1(\theta, \tau)$ by following [Sim and Zheng \(2015\)](#). Now we can write equations 4.24 to 4.30 as:

$$\beta^\theta(\text{S\&P_500}_t) \approx \beta_0(\theta, \tau) + \beta_1(\theta, \tau)(\text{S\&P_500}_t - \text{S\&P_500}^\tau) \quad \text{Eq. (4.31)}$$

$$\beta^\theta(\text{DJ_IMWI}_t) \approx \beta_0(\theta, \tau) + \beta_1(\theta, \tau)(\text{DJ_IMWI}_t - \text{DJ_IMWI}^\tau) \quad \text{Eq. (4.32)}$$

$$\beta^\theta(\text{S\&P_GSCI}_t) \approx \beta_0(\theta, \tau) + \beta_1(\theta, \tau)(\text{S\&P_GSCI}_t - \text{S\&P_GSCI}^\tau) \quad \text{Eq. (4.33)}$$

$$\beta^\theta(\text{CRIX}_t) \approx \beta_0(\theta, \tau) + \beta_1(\theta, \tau)(\text{CRIX}_t - \text{CRIX}^\tau) \quad \text{Eq. (4.34)}$$

$$\beta^\theta(\text{S\&P_BD}_t) \approx \beta_0(\theta, \tau) + \beta_1(\theta, \tau)(\text{S\&P_BD}_t - \text{S\&P_BD}^\tau) \quad \text{Eq. (4.35)}$$

$$\beta^\theta(\text{DJ_SUK}_t) \approx \beta_0(\theta, \tau) + \beta_1(\theta, \tau)(\text{DJ_SUK}_t - \text{DJ_SUK}^\tau) \quad \text{Eq. (4.36)}$$

$$\beta^\theta(\text{FRX}_t) \approx \beta_0(\theta, \tau) + \beta_1(\theta, \tau)(\text{FRX}_t - \text{FRX}^\tau) \quad \text{Eq. (4.37)}$$

Now substitute equation 4.31 to 4.37 into equations 4.17 to 4.23, and we get:

$$\text{S\&P_GB}_t = \beta_0(\theta, \tau) + \beta_1(\theta, \tau)(\text{S\&P_500}_t - \text{S\&P_500}^\tau) + \varepsilon_t^\theta \quad \text{Eq. (4.38)}$$

$$\text{S\&P_GB}_t = \beta_0(\theta, \tau) + \beta_1(\theta, \tau)(\text{DJ_IMWI}_t - \text{DJ_IMWI}^\tau) + \varepsilon_t^\theta \quad \text{Eq. (4.39)}$$

$$\text{S\&P_GB}_t = \beta_0(\theta, \tau) + \beta_1(\theta, \tau)(\text{S\&P_GSCI}_t - \text{S\&P_GSCI}^\tau) + \varepsilon_t^\theta \quad \text{Eq. (4.40)}$$

$$S\&P_GB_t = \beta_0(\theta, \tau) + \beta_1(\theta, \tau)(CRIX_t - CRIX^\tau) + \varepsilon_t^\theta \quad \text{Eq. (4.41)}$$

$$S\&P_GB_t = \beta_0(\theta, \tau) + \beta_1(\theta, \tau)(S\&P_BD_t - S\&P_BD^\tau) + \varepsilon_t^\theta \quad \text{Eq. (4.42)}$$

$$S\&P_GB_t = \beta_0(\theta, \tau) + \beta_1(\theta, \tau)(DJ_SUK_t - DJ_SUK^\tau) + \varepsilon_t^\theta \quad \text{Eq. (4.43)}$$

$$S\&P_GB_t = \beta_0(\theta, \tau) + \beta_1(\theta, \tau)(FRX_t - FRX^\tau) + \varepsilon_t^\theta \quad \text{Eq. (4.44)}$$

4.4.4. Mean and Quantile Granger Causality

[Granger \(1969\)](#) found that a variable Z_t does not granger cause to another variable Y_t if lag of Z_t does not forecast Y_t , given the lag of Y_t . Assume here we have an explanatory vector $X_t = (X_t^Y, X_t^Z)' \in \mathbb{R}^{d, d+s+q}$, where X_t^Z is the previous information set of Z_t , $X_t^Y = (z_{t-1}, \dots, z_{t-q})' \in \mathbb{R}^q$. Based on Z_t and Y_t we displayed following H_0 hypothesis of granger non-causality.

$$H_0^{Z \rightarrow Y}: F_Y((y|X_t^Y, X_t^Z) = |F_Y(y|X_t^Y), \quad \text{for all } y \in \mathbb{R}, \quad \text{Eq. (4.45)}$$

Where's $F_Y((y|X_t^Y, X_t^Z) =$ refers to the conditional distribution function of Y_t given (X_t^Y, X_t^Z) .

However, in the present study, we followed [Troster \(2018\)](#) and employed S_t test, a test based on QAR fashion for the entire $\pi \in \Gamma \subset [0,1]$. We formulated the following null hypothesis for the non-granger causality:

$$QAR(1): Q^\tau(Y | X_t^Y, X_t^Z) = \mu_1(\tau) + \mu_2(\tau)Y_{t-1} + \beta(\tau)Z_{t-1} + \sigma_t \Phi_u^{-1}(\tau) \quad \text{Eq. (4.46)}$$

Eq. (4.46) $\theta(\tau) = \mu_1(\tau), \mu_2(\tau)$ is derived using the maximum likelihood technique. While the conventional normal distribution function is represented by the expression of Φ_u^{-1} . Lag variables were used to correct the sign of causation among the purposed variables in Eq. (4.46) by using a QAR framework. Finally, we formulated the QAR (1) model with the help of Eq. (4.46) as successively:

$$Q^\tau(Y | X_t^Y, X_t^Z) = \mu_1(\tau) + \mu_2(\tau)Y_{t-1} + \beta(\tau)Z_{t-1} + \sigma_t \Phi_u^{-1}(\tau). \quad \text{Eq. (4.47)}$$

4.4.5. Wavelets Analysis

The third objective of this research is to look at the time and frequency relationship, or asymmetric relationship, across different investment horizons. As a result, we used wavelet analysis to achieve this objective. Wavelet analysis generally breaks down a signal into transferred (translated) and scaled (dilated or compressed) wavelet forms. The basic functions of wavelet or scaling are the same that is they vary only in the translations and the changes of scale. Wavelets are unique feature forms that consider both time and frequency domain, while each of the sines and cosines that make up Fourier's basic function is itself a frequency-by-frequency function. To obtain time and frequency attributes, the transform wavelet uses a basic approach (named wavelet or mother wavelet), shifted (translated) and scaled (dilated or compressed). Thus, the wavelets are excellent at handling the time-varying features seen in most real-world time series and are a unique solution to research non-stationary time series while avoiding stationary presumption.

4.4.6. Maximum Overlap Discrete Wavelet Transform

The capacity to decompose time series into various components is one of the main advantages of wavelet analysis. This concept has also been used extensively in recent study. Capobianco (2004) uses wavelet techniques (multiresolution high-frequency analysis) to analyses data of Nikkei stock index. He implements [Mallat and Zhang \(1993\)](#) matching pursuit algorithm and claims it fits financial data magnificently. [Crowley and Lee \(2005\)](#) examine European business cycle frequency components with wavelet multi-resolution analysis. [Gençay et al. \(2001\)](#) scrutinize currency scaling properties employing wavelet techniques.

Wavelet analysis incorporates the time and frequency domain of time series data. In contrast to other econometrics techniques, the wavelets break the selected variables into different wavelet scales. As per [Ramsey \(1999\)](#), the wavelets produce orthogonal timescale data decomposition and give the whole time series a non-parametric interpretation. Wavelets

analysis retain time data when conducting series frequency breakdown (decomposition). All the information of series concealed in time and frequency can be get using wavelet transformation ([Gencay et al., 2001](#)). This wavelet function allows dealing with time series non-stationary nature.

4.4.7. Continuous Wavelet Transformation (CWT)

As discussed in the introduction, the earlier literature studied green bonds and other financial markets nexuses using traditional econometrics approaches. There are various studies that find that due to ignoring information hidden in the time and frequency domain of series may provide misleading inference and wavelet analysis accommodate this unique information. The dataset can be divided into different holding periods to reveal the dynamics and co-movements of the proposed variables based on CWT. As a result, it was used in this study to track the movement of green bonds and other financial markets across the various investment periods. The main advantage of the CWT approach is that it focuses on the different investment horizons and delivers robust results by considering the time and frequency domain characteristics of the variables ([Haque et al., 2017](#); [Najeeb et al., 2017](#); [Rahim & Masih, 2016](#)). To obtain the CWT $w_{x(u,s)}$, the mother wavelet Ψ is projected onto the examined time series $x(t) \in l^2(\mathbb{R})$, so that:

$$W_x(u, s) = \int_{-\infty}^{\infty} x(t) \frac{1}{\sqrt{s}} \psi\left(\frac{t-u}{s}\right) dt \quad \text{Eq. (4.48)}$$

In the above equation (4.48) u and s denote the time and frequency domains respectively. However, the following is the definition of wavelet coherence for two-time series u and s :

$$R_n^2(s) = \frac{IS(s^{-1}W_n^{xy}(s))^2}{S(s^{-1}IW_n^x(s))^2 \cdot S(s^{-1}IW_n^y(s))^2} \quad \text{Eq. (4.49)}$$

In equation (4.49): -

S = smoothing operator.

s = wavelet scale.

$Wn^x(S)$ = continuous transformation of the time series X.

$Wn^y(S)$ = the CWT of the time series Y.

$Yn^{xy}(s)$ = cross wavelet transform of the two time series X and Y see details ([Gençay et al., 2001](#); [Madaleno & Pinho, 2012](#)).

4.4.8. The Diebold and Yilmaz (DY) Volatility Spillovers Index

The study's fourth objective is to investigate the pattern of volatility transmission between green bonds and other financial markets. Hence, we used the generalized version of the spillover index, which was first devised by [Diebold and Yilmaz \(2009\)](#) and then modified by [Diebold and Yilmaz \(2014\)](#), to examine volatility spillovers of selected financial markets (S&P_GB, S&P_500, DJ_IMWI, S&P_GSCI, CRIX, S&P_BD, DJ_SUK, and FRX). This index is developed on the principles of VAR (vector autoregressive) and variance decomposition models proposed by [Sims \(1980\)](#). Due to the presence of Cholesky factor orthogonalization in the spillover index of [Diebold and Yilmaz \(2009\)](#), the generalized version of this index eliminates the drawbacks of possibly order-dependent results. Applying the rolling window estimation technique, the dynamic evolution of the significance of the spillover effect can also be examined and depicted via spillover plots. N variable VAR, followed by K^{th} order,

$$\text{serves as the beginning point for the analysis. } y_t = \sum_{k=1}^K \theta_k y_{t-k} + \varepsilon_t \quad \text{Eq. (4.50)}$$

Where, the vector of endogenous variables can be represented by $y_t = (y_{1t}, y_{2t}, \dots, y_{Nt})$, $\theta_k, K=1, \dots, K$, are $N \times N$. Vector of disturbances is denoted by $\varepsilon_t \sim (0, \Sigma)$, which is independently (not essential to be identical) allocated over time; while t refers to time ranging from 11/28/2008 to 03/21/2021.

In equation 4.58, the moving average illustration denoted by $y_t = \sum_{\rho=0}^{\infty} A_{\rho} \varepsilon_{t-\rho}$, is crucial to the dynamics of the system. A_{ρ} is $N \times N$ coefficient matrices, which is recursively explained as $A_{\rho} = \theta_1 A_{\rho-1} + \theta_2 A_{\rho-2} + \dots + \theta_{\rho} A_{\rho-1}$, where, $N \times N$ identity matrix can be represented by A_0 while $A_{\rho}=0$ for $\rho < 0$. In fact, for the VAR model, it is difficult to justify any specific orders of the variables (which encompasses various financial markets as well as a time frame that contains the recent COVID-19 pandemic). So, we have used the novel version of the spillover index by [Diebold and Yilmaz \(2014\)](#), which relies on the generalized framework of VAR ([Koop et al., 1996](#); [Pesaran & Shin, 1998](#)), where the variable ordering does not affect the predictive error variance decompositions. This appears as the best option in the present situation, where the main purpose is to evaluate the volatility spillovers (as determinants of (the share of) variables' forecast error variances) instead of examining the effects of structural shocks.

In the generalized VAR approach, the variance decomposition of H-step-ahead forecast error is expressed as follows:

$$\phi_{ij}(H) = \frac{\sigma_{jj}^{-1} \sum_{h=0}^{H-1} (e_i' A_h \sum e_j)^2}{\sum_{h=0}^{H-1} (e_i' A_h \sum A_h' e_i)} \quad \text{Eq. (4.51)}$$

Where Σ represents the matrix of calculated variance of error vector ε . The approximate value of the standard deviation of the residual term is denoted by σ_{jj} , the volatility of variable j . A selection vector is represented by e_i with 1 (one) as the i^{th} element and 0 (zero) otherwise. This will generate a matrix of $N \times N$ dimension as $\phi(H) = [\phi_{ij}(H)]$, in which, each entry provides the share of variable j for the volatility of variable i to forecast error variance. The main diagonal elements contain the contributions of volatility shocks to the variable i 's own predictive error variance. On the other hand, the cross-market volatility spillovers represented by the shares of

other variables j to the predictive error variance of variable i , are contained in the off-diagonal elements.

Under the generalized decomposition, the cross-variable and own-variable variance shares

should not add up to one, i.e., $\sum_{j=1}^N \phi_{ij}(H) \neq 1$. The row sum of each entry can be normalized in

variance decomposition matrix as follows:

$$\phi_{ij}^{\%}(H) = \frac{\phi_{ij}(H)}{\sum_{j=1}^N \phi_{ij}(H)} \quad \text{Eq. (4.52)}$$

With $\sum_{j=1}^N \phi_{ij}(H) = 1$ and $\sum_{i,j=1}^N \phi_{ij}^{\%}(H) = N$ by construction.

This enables us for the calculation of an overall spillover index, defined as follows:

$$TS(H) = \frac{\sum_{i,j=1,i \neq j}^N \phi_{ij}^{\%}(H)}{\sum_{i,j=1}^N \phi_{ij}^{\%}(H)} \times 100 = \frac{\sum_{i,j=1,i \neq j}^N \phi_{ij}^{\%}(H)}{N} \times 100 \quad \text{Eq. (4.53)}$$

It calculates the average values of the fraction of volatility spillovers from shocks to all (other) variables in terms of overall forecast error variance. This method is highly adaptable and provides a more distinct appearance by taking directional volatility spillovers into consideration. Variable i 's directional volatility spillovers from all other variables j can be described as bellow:

$$DS_{i \rightarrow j}(H) = \frac{\sum_{j=1,j \neq i}^N \phi_{ij}^{\%}(H)}{\sum_{i,j=1}^N \phi_{ij}^{\%}(H)} \times 100 = \frac{\sum_{j=1,j \neq i}^N \phi_{ij}^{\%}(H)}{N} \times 100 \quad \text{Eq. (4.54)}$$

The directional volatility spillovers from variable i to all other variables j are as follows:

$$DS_{i \rightarrow j}(H) = \frac{\sum_{j=1, j \neq i}^N \phi_{ji}^{\%}(N)}{\sum_{i, j=1}^N \phi_{ji}^{\%}(H)} \times 100 = \frac{\sum_{j=1, j \neq i}^N \phi_{ji}^{\%}(H)}{N} \times 100 \quad \text{Eq. (4.55)}$$

It's worth noting that the set of directional volatility spillovers divides overall volatility spillovers from those that come from a specific variable.

The net volatility spillovers from variable i to all other variables j can be extracted by the subtraction of equation (4.54) from the equation (4.55).

$$NS_i(H) = DS_{i \rightarrow j}(H) - DS_{i \leftarrow j}(H) \quad \text{Eq. (4.56)}$$

In net terms, equation (4.54) explains whether a market receives or transmits volatility shocks. In other words, equation (4.54) summarizes how much the volatility of each variable shares with the volatility of the other variables. The net pairwise volatility spillovers can then be computed as follows:

$$NPS_{ij}(H) = \left(\frac{\phi_{ji}^{\%}(H)}{\sum_{i, m=1}^N \phi_{im}^{\%}(H)} - \frac{\phi_{ij}^{\%}(H)}{\sum_{j, m=1}^N \phi_{jm}^{\%}(H)} \right) \times 100 = \left(\frac{\phi_{ji}^{\%}(H) - \phi_{ij}^{\%}(H)}{N} \right) \times 100 \quad \text{Eq. (4.57)}$$

There are two types of gross volatility shocks. The first is conveyed from variable j to variable i and the second is communicated from variable i to variable j . Equation (4.63) defines the difference between these two types of volatility shocks. This difference is represented by the net pairwise volatility spillovers between markets j and i .

4.4.9. Dynamic Conditional Correlations (DCC) Models

The fifth objective of the study is to examine whether green bonds market can act as a diversifier, a hedge or a safe haven against other financial markets. Therefore, this study used the DCC-GARCH model introduced by ([Engle, 2002](#)) to check contagion during pandemic uncertainty /crises. The DCC-GARCH model has a feature of testing time-varying variations in the conditional correlation of series, and this model helps in examination dynamic behaviour

of investors due to news and innovations. Also, in times of financial crisis, the dynamic conditional correlations test is ideal for investigating potential contagion effects because of herding behaviour ([Chiang et al., 2007](#); [Syllignakis & Kouretas, 2011](#)). This approach is commonly used in a gold hedge and safe haven literature (see ([Bouri et al., 2017](#); [Ratner & Chiu, 2013](#))).

This study examines the dynamic nature of green bonds as a hedge, a diversifier or a safe haven. Literature suggests various models that can easily find dynamic nature, for example, exponential smoothing methods and rolling windows ([Ratner and Chiu, 2013](#)). However, the rolling window does not capture sudden variations in volatility and this method is requisite ad hoc method to decide window width ([Engle, 2002](#)). Even though rolling window capture time-varying correlation but it poses concerns about the correct rolling window length. Another feature/benefit of the DCC-GARCH model is that it directly accommodates heteroscedasticity problems ([Chiang et al., 2007](#)). As the time-varying- volatility is adjusted in the DCC-GARCH model hence it is the superior approach of correlation measurement ([Cho & Parhizgari, 2009](#)). [Engle \(2002\)](#) DCC-GARCH model is based on two steps; (1) estimation of univariate GARCH model (2) estimation of time-varying conditional correlation. Following Eq. (4.58) is an expression of the DCC-GARCH Model;

$$X_t = \mu_t + H_t^{1/2} \varepsilon_t \quad \text{Eq. (4.58)}$$

$$H_t = D_t R_t D_t$$

$$R_t = (\text{diag}(Q_t))^{-\frac{1}{2}} Q_t (\text{diag}(Q_t))^{-\frac{1}{2}}$$

$$D_t = \text{diag} (\sqrt{h_{11,t}}, \sqrt{h_{22,t}}, \dots, \sqrt{h_{NN,t}})$$

In Eq.(4.58) $X_t = (X_{1t}, \dots, X_{nt})$ refers to a vector of past observations, the multivariate conditional variance is represented by H_t , while conditional returns are presented by μ_t , ε_t is standardized residuals, R_t is N X N linear dynamic correlations matrix and D_t refers conditional

standard deviation for return series based on univariate GARCH model with $\sqrt{h_{ii,t}}$ on the i^{th} diagonal, $i=1, 2, \dots, N$. The following Eq. (4.58) is DCC specification;

$$Q_t = (1 - \psi - \zeta)\bar{Q} + \zeta Q_{t-1} + \psi \delta_{i,t-1} \delta_{j,t-1} \quad \text{Eq. (4.58)}$$

$$R_t = Q_t^{*-1} Q_t Q_t^{*-1}$$

Where $Q_t = [q_{ij,t}]$ is (N X N) time-varying covariance matrix of standardized residuals ($\delta_{it} = \frac{\varepsilon_{it}}{\sqrt{h_{it}}}$), $\bar{Q}$ refer as $\delta_{i,t}, \delta_{j,t}$ unconditional correlations, while nonnegative scalar parameters refer with ψ and ζ That satisfies $\psi + \zeta < 1$. $Q_t^* = [q_{ii,t}^*] = \sqrt{q_{ii,t}}$ is a diagonal matrix with the square root of the i^{th} diagonal element of Q_t on its i^{th} diagonal position.

Therefore, DCC between purposed assets can be expressed as:

$$\rho_{ij,t} = \frac{(1-\psi-\zeta)\bar{q}_{ij} + \psi\delta_{i,t-1}\delta_{j,t-1} + \zeta q_{ij,t-1}}{[(1-\psi-\zeta)\bar{q}_{ii} + \psi\delta_{i,t-1}^2 + \zeta q_{ii,t-1}]^{1/2} [(1-\psi-\zeta)\bar{q}_{jj} + \psi\delta_{j,t-1}^2 + \zeta q_{jj,t-1}]^{1/2}} \quad \text{Eq. (4.59)}$$

4.4.9.1. Diversifier, Hedge and Safe Haven

We are following the methodology used by [Ratner and Chiu \(2013\)](#) and [Buri et al. \(2017\)](#) to analyze the green bonds capabilities as a diversifying, hedge and safe haven against fluctuations in other financial markets (including, stock, commodity, digital currency, bonds and foreign exchange markets). We obtained pairwise dynamic conditional correlation between green bonds and other financial markets (including, stock, commodity, digital currency, bonds and foreign exchange markets) from equation (4.58) following DCC-GARCH estimates. DCC_t are regressed on dummy variables (D).

$$DCC_t = C_0 + C_1 D(r_{asset} q_1) + C_2 D(r_{asset} q_5) + C_3 D(r_{asset} q_{10}) \quad \text{Eq. (4.60)}$$

D reflects extreme movements (fluctuations) and equals one if the return on assets reaches a certain threshold provided by the 1st, 5th and 10th percentiles of the return distribution. If we find C_0 positive and significant it shows that green bonds serve as a diversifier against other assets. If we find C_0 as zero green bonds will serve as a week hedge against other assets and

green bonds serve as a strong hedge against other assets if C_0 is negative and significant. However, green bonds perform as weak safe haven against other assets if C_1C_2 or C_3 are insignificantly different from 0. However, if C_1C_2 or C_3 are negative and significant in this case green bonds perform as a strong safe haven.

4.5. Research Hypothesis

Following are the research hypothesis, which are tested, in the current study.

H1: There is an asymmetric comovement between green bonds and other financial markets under different market conditions (e.g., bearish, mild bearish, optimistic or bullish).

H2: COVID-19 pandemic does change correlations between green bonds and other financial markets.

H3: There is an asymmetric relationship between green bonds and other financial markets across various investment horizons.

H4: There is a volatility spillover effect between the green bonds market and other financial markets.

H5: Green bonds act as a diversifier, hedge, or safe-haven against other financial markets.

CHAPTER 5: RESULTS AND DISCUSSION

5.1. Introduction

Chapter five includes findings that have been empirically investigated and a discussion of these findings in a theoretical and conceptual context. The chapter is structured as follows: first, this chapter analyses the trend of selected financial markets (S&P_GB, S&P_500, DJ_IMWI, S&P_GSCI, CRIX, S&P_BD, DJ_SUK, and FRX) in order to get a better understanding of their pattern of movement through time. Second, to fully comprehend the nature of the data, it includes summary statistics, pairwise correlation, and unit root tests such as the Augmented Dickey-Fuller test (ADF), Phillips–Perron test (PP), and quantiles unit root test (QRA). Third, to investigate quantile dependency between green bonds and other financial markets, it provides a detailed discussion on quantiles cointegration, quantiles on quantiles regression, and Granger-causality in quantiles. Fourth, it discusses briefly maximal overlap discrete wavelet transforms (MODWT), wavelet covariance, wavelet correlation, continuous wavelet transformation (CWT), and wavelet-based Granger causality in order to analyze the time and frequency relationship between projected financial markets. Finally, this chapter analyzes the transmission of volatility shocks among the S&P_GB, S&P_500, DJ_IMWI, S&P_GSCI, CRIX, S&P_BD, DJ_SUK, and FRX and diversifier, hedge or safe-haven properties of green bonds market against other financial markets.

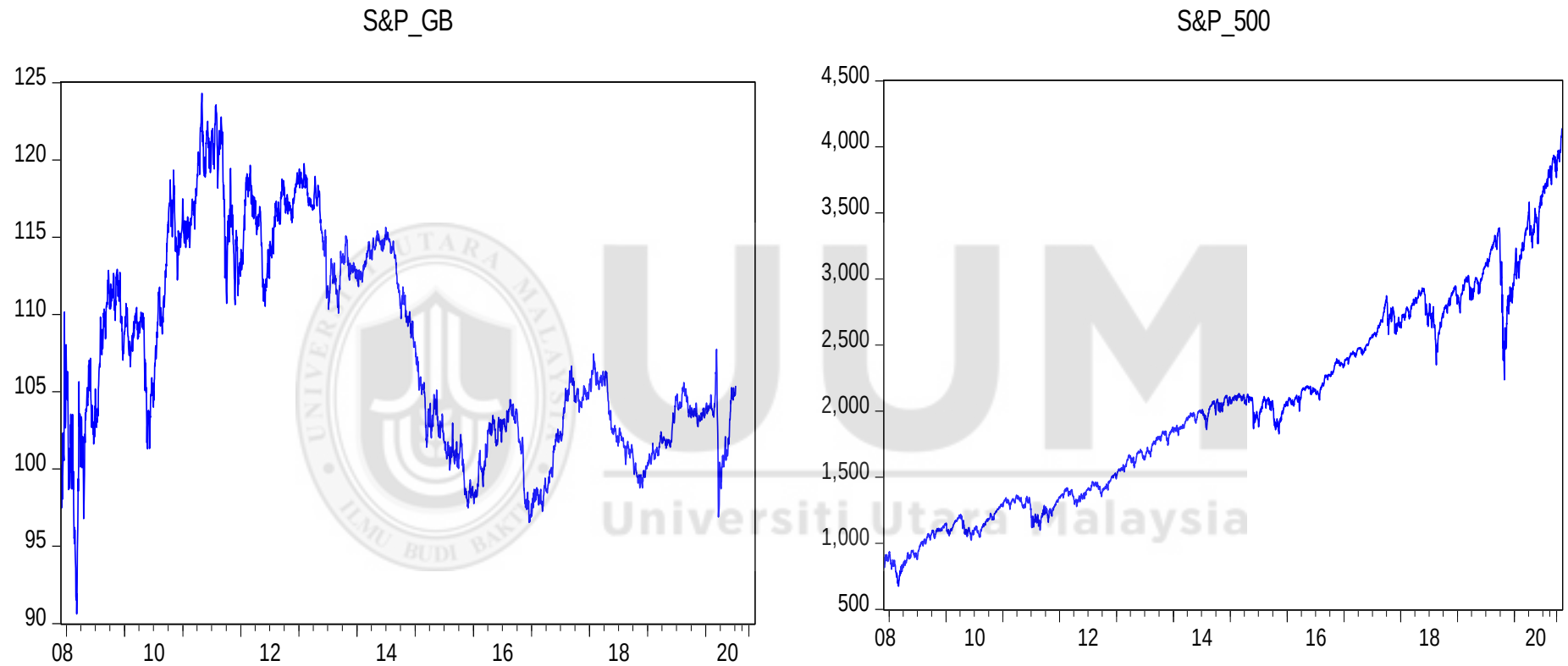
5.2. Time Series Trend Analysis

Fig 5.1 depicts the time-movement of the series across the sample period. In the green bonds market (S&P_GB), a positive upward trend can be observed in the initial years since its inception from 2008 to 2011. However, there is a continuous decreasing trend from 2012 through 2021, indicating lessened engagement of investors in green bonds. Looking at the performance of the conventional stock market (S&P_500) and the Islamic stock market (DJ_IMWI), there is a strong rising trend in both equity markets over the sample period,

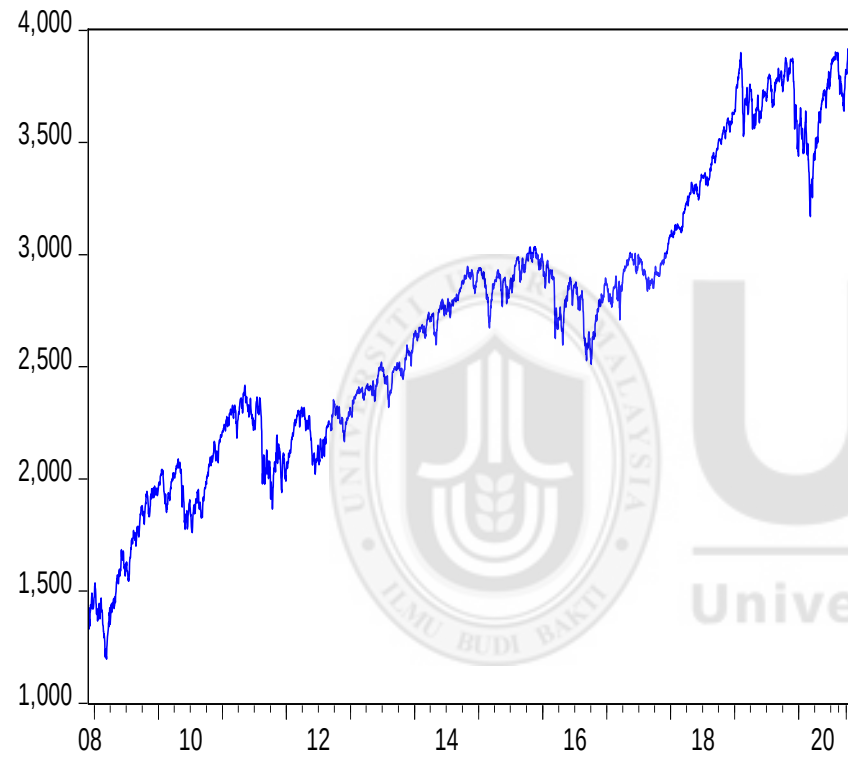
indicating active involvement of investors in both markets. This study also includes a global commodities market index (S&P_GSCI), which indicates significant growth in the global commodity market. The CRIX, a cryptocurrency index that measures how cryptocurrencies perform in the market, is showing early-stage rising price movements. However, in 2018 the global crypto market index exhibited a steep fall, but by the end of 2019, the crypto market had once again returned to a positive rising trend. This study also takes into account the world's two largest bond markets, including the global conventional bond market index (S&P_BD) and the Islamic Sukuk index (DJ_SUK). Both markets are trending upward, although the Islamic Sukuk index has more volatility than the conventional bond index. Finally, the global foreign exchange market (FRX) has shown a positive rising trend throughout time, although the FRX market is volatile.

Overall trend analysis indicates that all financial markets performed well over the sample period except the green bonds market (S&P_GB). There are several causes for this drop, starting with the fact that this is a new financial product with low awareness among investors in comparison to other financial markets. Second, because of its recent entrant into the market, policymakers, investors, especially individual and intuitional investors, have poor trust in its portfolio diversification, among other things.

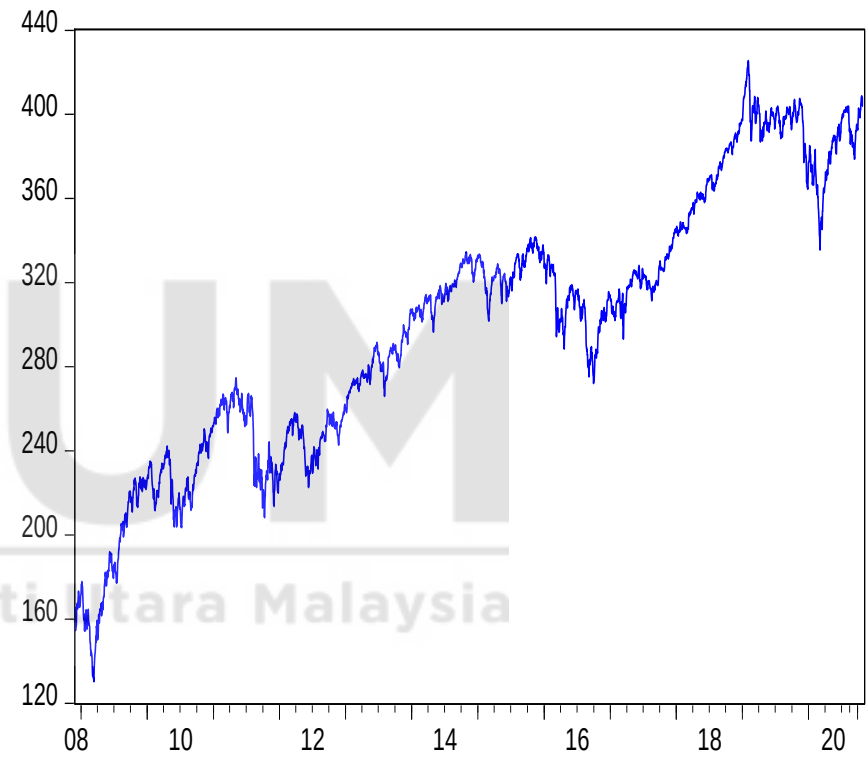
Figure 5.1: Plot of Raw S&P_GB, S&P_500, DJ_IMWI, S&P_GSCI, CRIX, S&P_BD, DJ_SUK and FRX



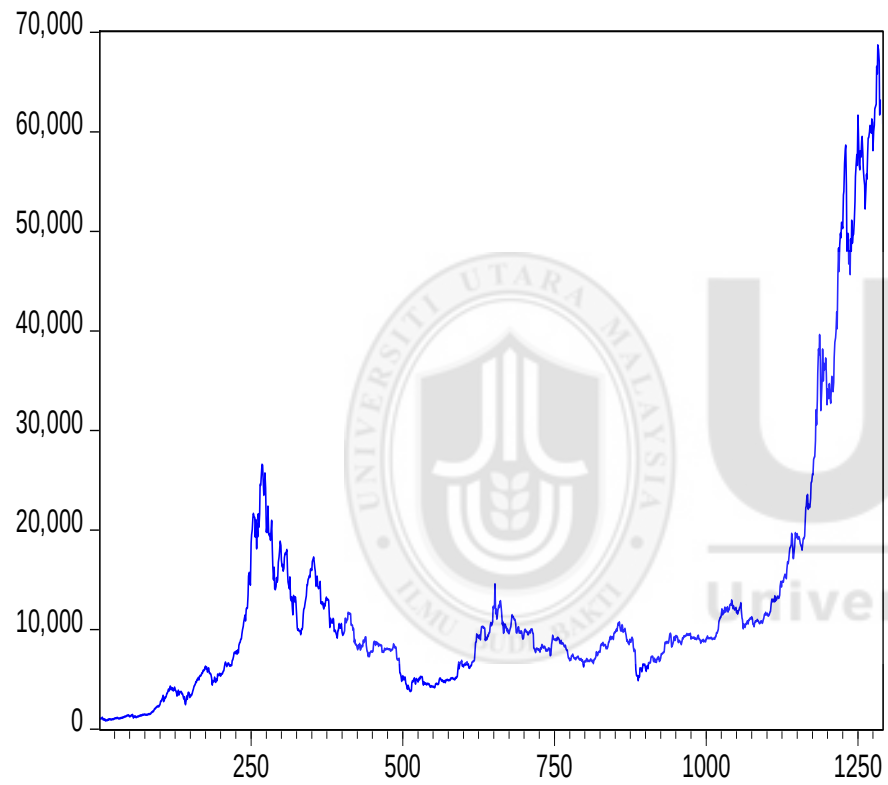
DJ_IMWI



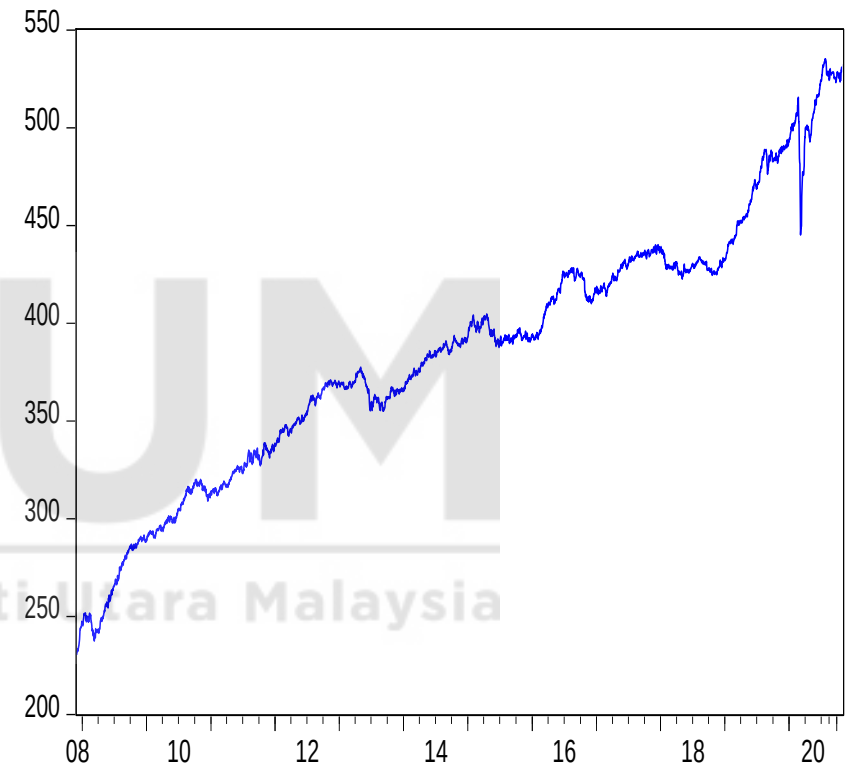
S&P_GSCI



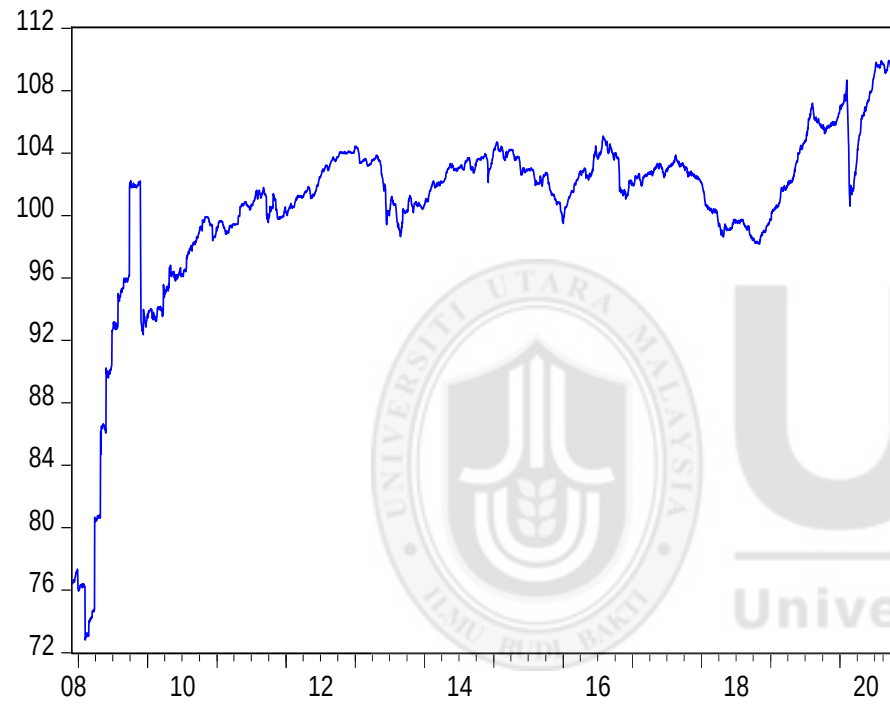
CRIX



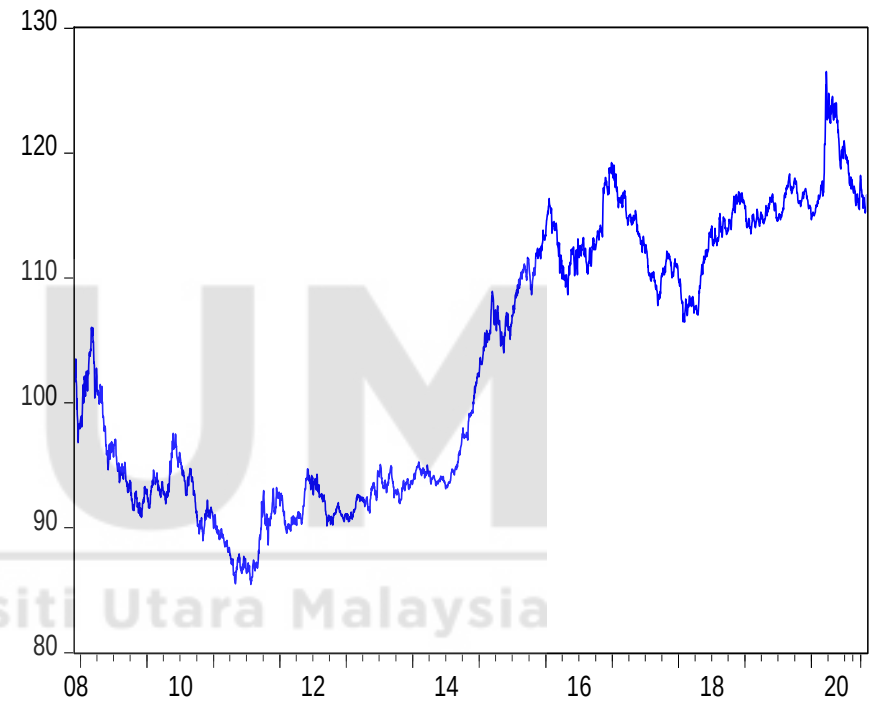
S&P_BD



DJ_SUK



FRX



5.3. Descriptive Statistics

Table 5.1 shows descriptive statistics for price returns of selected financial markets (S&P_GB, S&P_500, DJ_IMWI, S&P_GSCI, CRIX, S&P_BD, DJ_SUK and FRX). The standard deviation value shows variation in returns of selected financial markets. While volatility assessed by standard deviation reveals that the CRIX market is very volatile and S&P_500 is the second most volatile market globally among the sample financial markets.

Table 5-1: Summary Statistics of the Financial Markets

	S&P_GB	S&P_500	DJ_IMWI	S&P_GSCI	CRIX	S&P_BD	DJ_SUK	FRX
Mean	107.745	1965.063	2660.327	295.992	12457.00	380.508	100.467	102.649
Maximum	124.305	3699.120	3898.300	425.410	68690.00	526.740	109.524	126.524
Minimum	90.623	676.530	1197.140	130.290	849.400	230.370	72.819	85.469
Std. Dev.	6.773	712.225	619.709	63.076	12709.200	63.568	5.651	10.657
Skewness	1.317	1.267	2.031	-1.168	2.589	-0.177	-2.895	0.155
Kurtosis	1.906	2.037	2.361	2.396	6.501	2.554	12.840	1.480
JB	201.731	152.947	52.001	60.234	3679.099	40.917	16442.830	303.654
Probability	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***

Note: S&P_GB, S&P_500, DJ_IMWI, S&P_GSCI, CRIX, S&P_BD, DJ_SUK and FRX is S&P green bond index, S&P 500 index, Dow Jones Islamic market world index, S&P GSCI index, Crypto index, S&P 500 bond index, Dow Jones Sukuk index and Foreign exchange index respectively. The symbol *** denotes a level of significance of one percent, while JB denotes the Jarque-Bera normality test.

Table 5.1 further demonstrates that the S&P_GSCI, S&P_BD and DJ_SUK are negatively skewed, whereas the S&P_GB, S&P_500, DJ_IMWI, CRIX and FRX are positively skewed. For the normal distribution, skewness is always 0, and any value other than zero indicates a non-normal distribution. While the kurtosis value shows that all the series are leptokurtic because all the series having high peaked than a normal distribution. For the normal distribution of the series, kurtosis value should be 3 and the kurtosis value for our series are far away from 3 which shows the non-normal distribution of the series.

In addition, the Jarque-Bera test is used in this study to determine whether or not the sample series are normally distributed. All of the series in the JB test results are found to be non-normally distributed with a significance level of 1 percent. Hence, non-normal distribution of the series encourages non-parametric analysis for the valid estimation ([Meo & Karim, 2021](#)).

Accordingly, because the sample series does not follow a normal distribution, this study uses nonparametric estimation techniques.

5.4. Pairwise Correlation

Table 5.2 shows the results of the pairwise correlation. The pairwise correlation is useful in determining the strength of a relationship between two variables. According to [Evans \(1996\)](#) correlation coefficients ranging from 0.00 to 0.19, 0.20 to 0.39, 0.40 to 0.59, 0.60 to 0.79 and 0.80 to 1.0 show very weak, weak, moderate, strong, and very strong correlation between two variables respectively. The correlation analysis between financial instruments has huge importance in the financial world because [Markowitz \(1952\)](#) presented his modern portfolio theory (MPT) in 1952 which is based on correlation analysis. [Markowitz \(1952\)](#) advised diversifying investment by investing in different assets which are negatively correlated or less correlated to minimize risk.



Table 5-2: Pairwise Correlation between Financial Markets

	S&P_GB	S&P_500	DJ_IMWI	S&P_GSCI	CRIX	S&P_BD	DJ_SUK	FRX
S&P_GB	1							
S&P_500	-0.018***	1						
DJ_IMWI	-0.087***	0.081***	1					
S&P_GSCI	-0.011***	0.045*	0.116***	1				
CRIX	-0.003*	0.007**	-0.028	0.014	1			
S&P_BD	-0.037*	-0.075***	0.052**	0.093***	-0.001	1		
DJ_SUK	-0.019*	0.080***	0.034	-0.026	-0.020	-0.0348	1	
FRX	-0.897***	-0.014**	-0.066**	-0.048*	-0.001**	0.046***	0.022**	1

Note: ***, ** & * refers to the level of significance at 1%, 5% and 10% .While, S&P_GB, S&P_500, DJ_IMWI, S&P_GSCI, CRIX, S&P_BD, DJ_SUK and FRX is S&P green bond index, S&P 500 index, Dow Jones Islamic market world index, S&P GSCI index, Crypto index, S&P 500 bond index, Dow Jones Sukuk index and Foreign exchange index respectively.

Table 5.2 demonstrates that the correlation coefficient (-0.018) between S&P_GB and S&P_500 is weak and negative which suggests the potential for diversification. According to MPT theory investing in S&P_GB and S&P_500 reduce portfolio risk and provide diversification opportunity to investors. The pairwise correlation coefficient (-0.087) between S&P_GB and DJ_IMWI also suggest that investment between green bonds and Islamic stocks reduce risk and provide diversification opportunity to the investors. Moreover, the correlation between S&P_GB, S&P_GSCI and CRIX is also weak that shows risk reduction characteristics of both assets. While findings confirm a weak negative correlation between S&P_GB, S&P_BD and DJ_SUK which also shows investing in these financial markets reduce the risk of investment. However, the correlation coefficient (-0.997) between S&P_GB and FRX shows a very strong negative correlation, which indicates the best portfolio diversification. In general, pairwise correlation indicates that green bonds, like other financial markets, provide investors with diversification opportunities.

5.5. Unit Root Analyses

Unit root checking is most important in regression analysis. A series whose means and variances changes over time is known as non-stationary or unit root series. In the presence of non-stationary series in the model, estimation provides misleading inferences. Therefore, it is most important in time series analysis to check the unit root or stationarity of series to avoid misleading inferences. Therefore, considering the importance of unit root, this study employs various unit root tests, such as Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP). Table 5.3 comprising results of ADF and PP unit root tests at the level and first difference.

Table 5-3: Time Series Unit Root Tests

Variables	Unit Root at Level I (0)		Unit Root at Difference I (1)		Decision
	ADF	PP	ADF	PP	
S&P_GB	-2.459	-2.307	-55.991***	-56.169***	I(1)
S&P_500	0.785	1.013	-17.389***	-66.056***	I(1)
DJ_IMWI	-1.157	-0.918	-50.522***	-50.323***	I(1)
S&P_GSCI	-1.609	-1.374	-49.229***	-49.010***	I(1)
CRIX	-1.032	-1.212	-23.932***	-26.584***	I(1)
S&P_BD	-0.673	-0.757	-21.486***	-49.617***	I(1)
DJ_SUK	-3.988***	-3.935***	-28.925***	-50.083***	I(0)
FRX	-0.527	-2.820	-53.672***	-53.704***	I(1)

Note: ADF and PP refer to [Augmented Dickey-Fuller \(1979\)](#) and [Phillips and Perron \(1988\)](#) unit root tests. *** refers to the level of significance at 1% level of significance. While, S&P_GB, S&P_500, DJ_IMWI, S&P_GSCI, CRIX, S&P_BD, DJ_SUK and FRX is S&P green bond index, S&P 500 index, Dow Jones Islamic market world index, S&P GSCI index, Crypto index, S&P 500 bond index, Dow Jones Sukuk index and Foreign exchange index respectively.

The findings confirm that all the variables are non-stationary at level except DJ_SUK. The ADF and PP unit root tests findings confirm that at first difference all the variables are stationarity. Moreover, the findings presented in table 5.1 also show that all the series are non-normally distributed which required non-parametric estimation of the selected financial markets or series ([Mishra et al.,2019](#); [Meo and Karim,2021](#)). Moreover, in the presence of structural breaks ADF and PP unit root test does not perform well.

Therefore, considering the nature of the data, this study also employed an advance non-parametric quantiles unit root test ([Troster et al., 2018](#)). Table 5.4 summarizes the findings of the quantile's unit root test. The quantiles unit root test illustrates the estimates of persistence

and the t-statistics for the null hypothesis postulating that $H_0: \alpha(\tau) = 1$ for equation 4.2 for the grid of 19 quantiles $T = \{0.05:0.95\}$. This study employed 10 lags of the endogenous variable to overcome serial correlation. The findings of quantiles unit root test presented in table 5.4 documents that S&P_GB, S&P_500, DJ_IMWI, S&P_GSCI, S&P_BD, DJ_SUK and FRX has a unit root at low quantiles (0.05), however at high quantiles (0.75 to 0.95) S&P_GB, S&P_500, DJ_IMWI, S&P_GSCI, S&P_BD, and FRX do not have a unit root. Though findings of the quantile unit root test confirm that CRIX does not have unit root at low quantiles (0.25), however, CRIX has a unit root at medium to high quantiles. However, all the series are stationarity at a 5 % level of significance at first difference.

5.6. Quantiles Analysis

The first objective of the study is to examine quantiles dependency between green bonds and other financial markets. Therefore, to achieve this objective we apply quantiles analysis (including quantiles cointegration (QR), quantiles on quantiles regression (QQR) and quantiles Granger-causality). The prime objective of examining quantiles dependency between proposed financial markets is to examine correlation or comovement in bullish, bearish and normal market states for the comprehensive understanding of relationship to device best policies for the portfolio diversification. And the second objective of the study is to examine either COVID-19 changes correlation between green bonds and other financial markets. To achieve the second objective of the study we divide our analysis into two sample periods. The first sample period as a before COVID-19 ranging from 11/28/2008 to 03/10/2020 and the second sample period represent during COVID-19 ranging from 03/11/2020 to 03/21/2021. Hence, we applied QQR estimation for during the COVID-19 sample period to see changes in correlation between proposed financial markets in these two sample periods.

5.6.1. Quantiles Cointegration Analyses

Following the quantiles unit root test, this study enriches quantiles analyses by applying the quantiles cointegration test developed by [Xiao \(2009\)](#). This study examined quantiles cointegration among the proposed financial markets by applying an alike spaced grid of 19 quantiles (0.05 to 0.95). The primary justification for using the quantiles cointegration test is that it provides a full picture of whether the cointegration relationship between the variables varies over the quantile's distribution. Table 5.5 shows findings of quantiles cointegration for the proposed variables/markets. The quantiles cointegration test offers detailed long-run relationship information as compare to conventional cointegration tests. The findings confirm that S&P_GB has cointegration with S&P_500, CRIX, and FRX at medium quantiles and on the rest of the quantiles, there are no cointegrations. While it is also confirmed that S&P_GB has cointegration with DJ_IMWI, S&P_GSCI, S&P_BD and DJ_SUK at low quantiles only and absence of cointegration at the rest of the quantiles. Hence, we find a statistically asymmetric long-run association (cointegration) between the proposed financial markets.

Table 5-4: Quantiles Unit Root Test

Quantiles	S&P GB			S&P 500			DJ IMWI			S&P GSCI		
	$\alpha(\tau)$	t-values	C.V	$\alpha(\tau)$	t-values	C.V	$\alpha(\tau)$	t-values	C.V	$\alpha(\tau)$	t-values	C.V
0.05	1.022	2.663	-2.764	1.082	5.493	-3.262	1.034	4.646	-3.065	1.040	6.224	-3.092
0.25	1.004	1.959	-2.852	1.013	3.342	-3.139	1.004	1.902	-3.327	1.008	3.945	-3.309
0.50	0.998	-1.137	-2.747	0.989	-4.476	-2.846	0.998	-0.918	-3.116	0.997	-1.889	-3.143
0.75	0.986	-6.782	-2.635	0.960	-11.607	-2.370	0.988	-8.480	-2.649	0.979	-9.905	-2.661
0.95	0.970	-4.994	-2.422	0.904	-11.952	-2.311	0.941	-10.796	-2.311	0.946	-12.038	-2.312
Quantiles	CRIX			S&P BD			DJ SUK			FRX		
	$\alpha(\tau)$	t-values	C.V	$\alpha(\tau)$	t-values	C.V	$\alpha(\tau)$	t-values	C.V	$\alpha(\tau)$	t-values	C.V
0.05	0.990	-1.374	-2.813	1.004	1.093	-3.123	1.003	0.602	-2.940	0.971	-9.087	-2.406
0.25	0.991	-3.938	-3.075	0.998	-1.300	-2.999	1.002	3.980	-2.913	0.988	-7.779	-2.875
0.45	0.998	-1.131	-3.235	0.998	-1.945	-2.822	0.999	-2.256	-2.838	0.997	-2.180	-3.100
0.50	1.004	1.981	-2.931	0.993	-4.486	-2.632	0.997	-6.175	-2.681	1.005	3.783	-3.085
0.75	1.004	0.846	-2.358	0.984	-4.525	-2.314	0.989	-2.300	-2.390	1.015	4.067	-2.827
0.95	0.990	-1.374	-2.813	1.004	1.093	-3.123	1.003	0.602	-2.940	0.971	-9.087	-2.406

Note: Table 5.4 presenting points estimated and t-values at a 5 % level of significance. In the table t-value < C. V, so we reject the null hypothesis of $\alpha(\tau)=1$. While quantiles bold values > C.V which means $\alpha(\tau) \neq 1$ on different quantiles. While, S&P_GB, S&P_500, DJ_IMWI, S&P_GSCI, CRIX, S&P_BD, DJ_SUK and FRX is S&P green bond index, S&P 500 index, Dow Jones Islamic market world index, S&P GSCI index, Crypto index, S&P 500 bond index, Dow Jones Sukuk index and Foreign exchange index respectively.

Table 5-5: Quantiles Cointegration

Quantiles	S&P_GB _t vs S&P_500 _t		S&P_GB _t vs DJ_IMWI _t		S&P_GB _t vs S&P_GSCI _t		S&P_GB _t vs CRIX _t	
	$\beta(\tau)$	$\gamma((\tau))$	$\beta(\tau)$	$\gamma((\tau))$	$\beta(\tau)$	$\gamma((\tau))$	$\beta(\tau)$	$\gamma((\tau))$
0.05	1.579	-0.383	-191.403***	11.251***	-104.365**	13.500**	-1.431	0.228
0.25	0.713	-0.539	-159.868***	9.283***	-94.075**	11.178**	-1.596	0.227
0.50	-77.492**	11.523**	-1.547	0.422	-2.116	1.09	-1904.815***	503.478***
0.75	-66.882**	10.479**	-0.660	0.151	5.158	-0.794	-1856.854**	491.514***
0.95	2.856	-0.626	-1.476	0.601	3.195	-0.49	-1825.527	484.527
Quantiles	S&P_GB _t vs S&P_BD _t		S&P_GB _t vs DJ_SUK _t		S&P_GB _t vs FRX _t			
	$\beta(\tau)$	$\gamma((\tau))$	$\beta(\tau)$	$\gamma((\tau))$	$\beta(\tau)$	$\gamma((\tau))$		
0.05	-382.593***	34.797***	-209.164**	23.853**	-1.739	0.856		
0.25	-571.771***	51.965***	-165.435**	19.002**	-1.509	0.011		
0.45	-1.354	0.134	-1.276	0.759	-296.246***	40.025***		
0.75	-1.679	0.116	-1.332	2.991	-143.263***	23.236***		
0.95	-1.626	1.765	-1.500	-0.730	-0.215	91.107		

Note: Table 5.5 table shows estimated coefficients over the various quantiles of two variables. While, S&P_GB, S&P_500, DJ_IMWI, S&P_GSCI, CRIX, S&P_BD, DJ_SUK and FRX is the S&P green bond index, S&P 500 index, Dow Jones Islamic market world index, S&P GSCI index, Crypto index, S&P 500 bond index, Dow Jones Sukuk index and Foreign exchange index respectively. ***, ** & * refers to the rejection of the null hypothesis of no cointegration at 1%, 5%, and 10% level of significance.

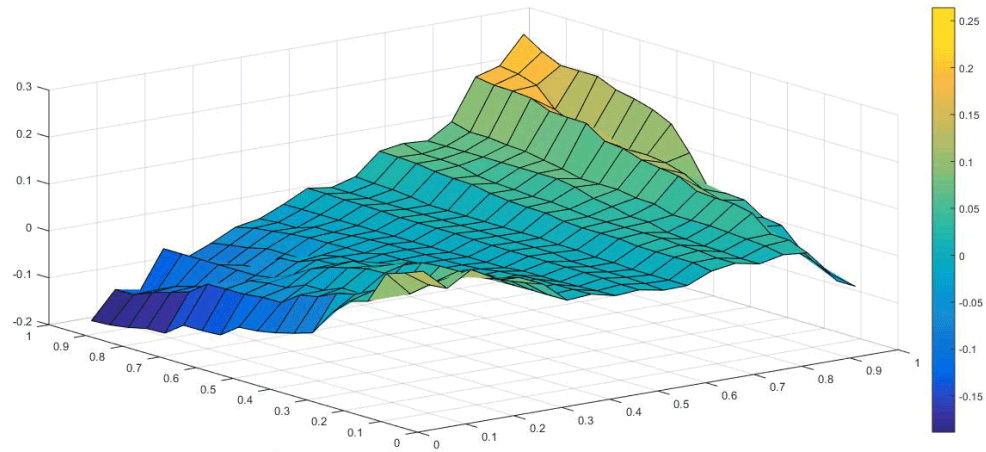
5.6.2. Quantile on Quantile (QQR) Analysis

After the quantile unit root and quantiles cointegration test, this study carried QQR estimation. This section presents main QQR findings between S&P_GB, S&P_500, DJ_IMWI, S&P_GSCI, CRIX, S&P_BD, DJ_SUK and FRX for the sample period. Fig 5.2 shows the estimates of the slope coefficient, $\beta_1(\theta, \tau)$, which captures the effect of the τ^{th} quantile of S&P_GB on the θ^{th} quantile of S&P_500, DJ_IMWI, S&P_GSCI, CRIX, S&P_BD, DJ_SUK and FRX respectively.

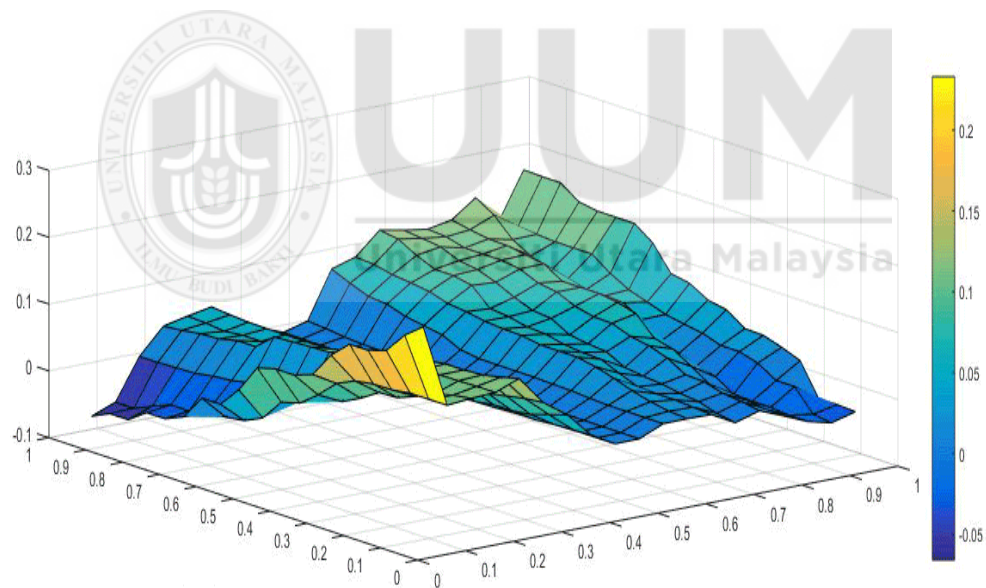
[Baur and Lucey \(2010\)](#) suggested that green bonds serve as a hedge when their correlation with other financial markets is negative, a diversifier when their correlation is positive but less than perfect, and a safe haven when they act as a hedge in financial meltdown market scenarios. Furthermore, it is the beauty of the QQR approach that we can find the correlation between two financial markets when these markets perform bearish, normal or bullish. A market is considered bearish at 10th, 20th and 30th quantiles, normal at 40th, 50th & 60th bullish at 70th, 80th & 90th (Bouoiyour et al., 2018).

Figure 5.2: Quantile Dependency Between Green Bonds and other Financial Markets (Before COVID-19)

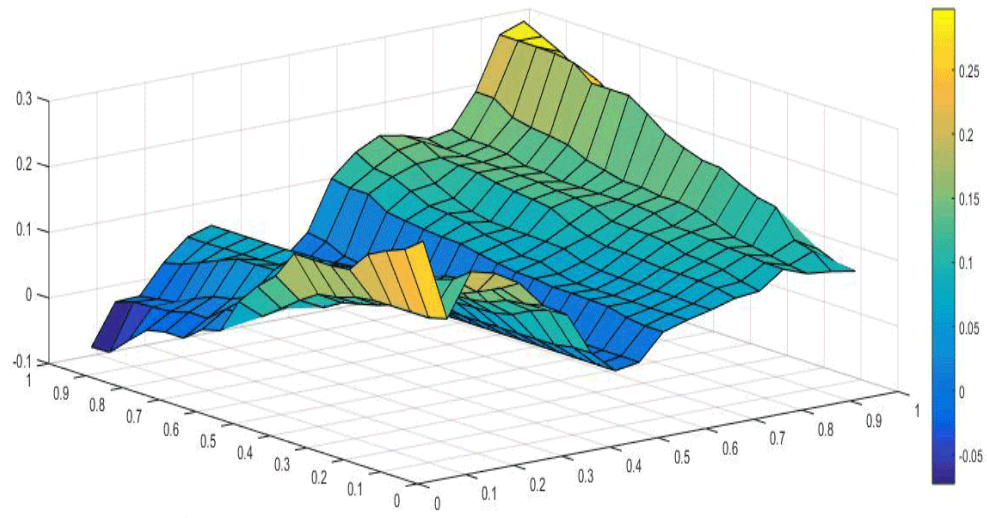
a) S&P_GB and S&P_500



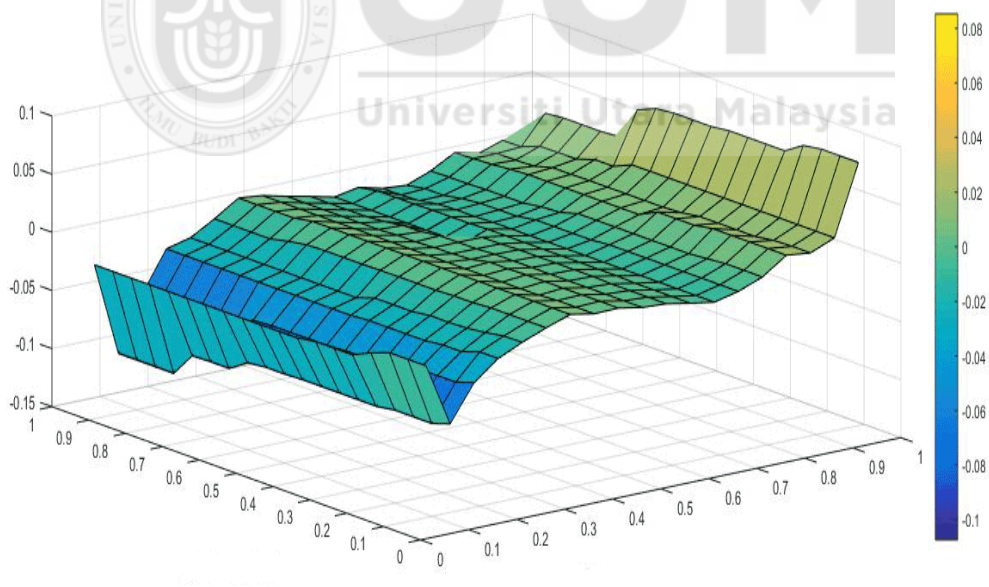
b) S&P_GB and DJ_IMWI



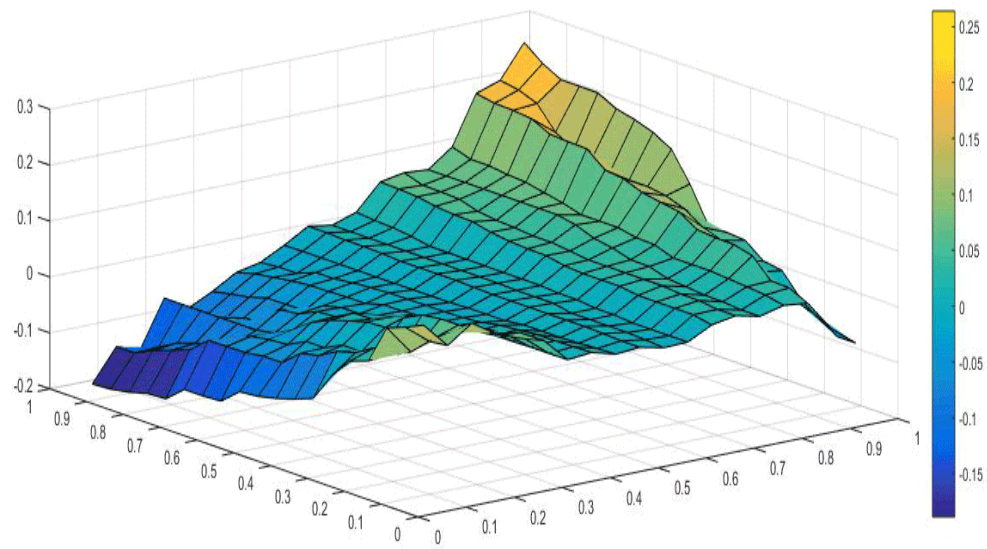
c) S&P_GB and S&P_GSCI



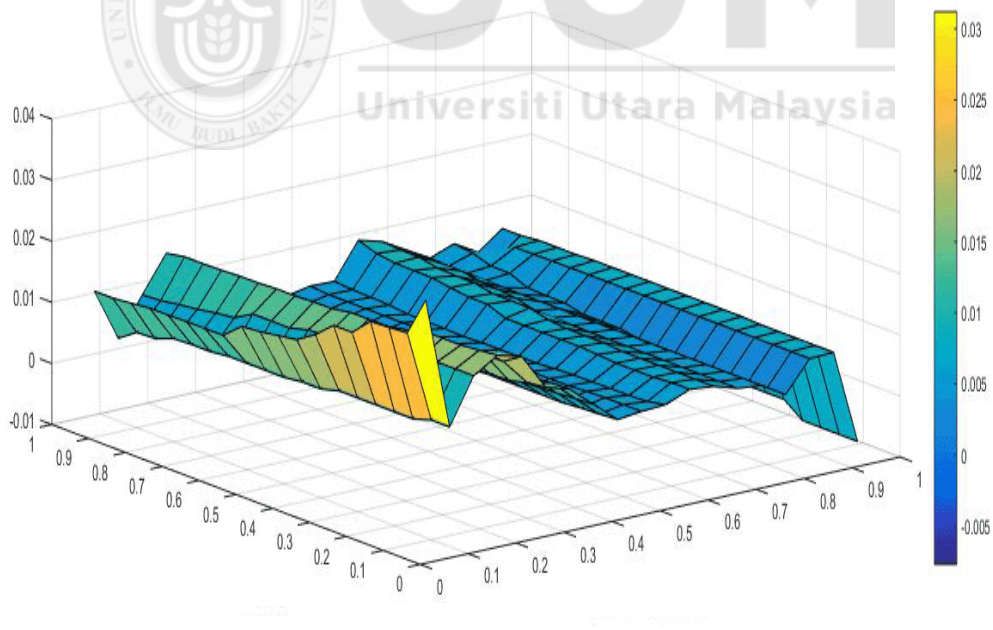
d) S&P_GB and CRIX



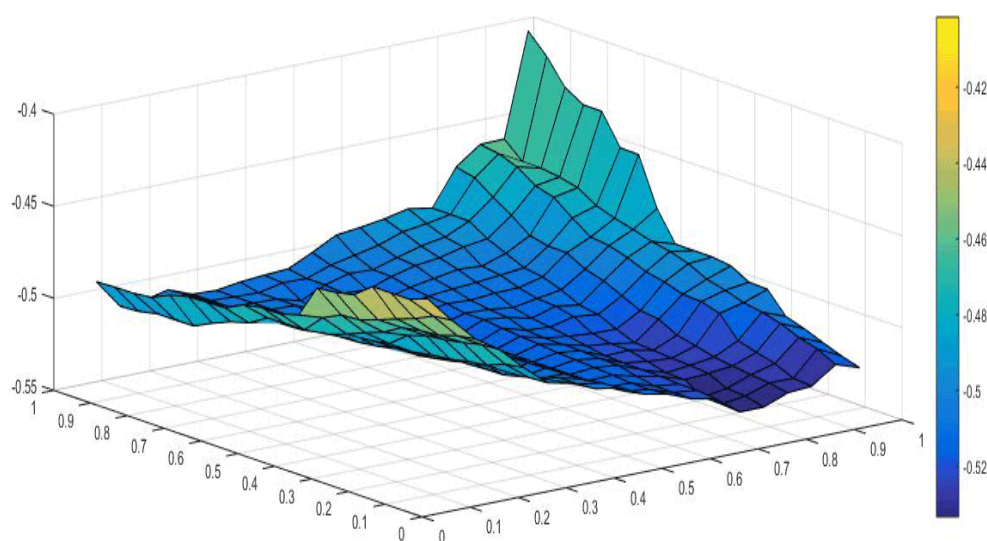
e) S&P_GB and S&P_BD



f) S&P_GB and DJ_SUK



g) S&P_GB and FRX



Note: Fig5.2 (a -g) presents estimates of the slope coefficient, which is placed on the z-axis, (θ) refers to S&P_GB and (τ) refers to S&P_500, DJ_IMWI, S&P_GSCI, CRIX, S&P_BD, DJ_SUK and FRX. The colours in the colour bar represent the degree to which the two variables are correlated with one another (S&P_GB, S&P_500, DJ_IMWI, S&P_GSCI, CRIX, S&P_BD, DJ_SUK and FRX). The yellow colour demonstrates a high positive association, while the strong blue colour demonstrates a strong negative association between proposed variables. While, light green and light blue colours, on the other hand, demonstrate a weak or insignificant association.

The QQR findings are presented in fig 5.2 which appear very interesting and heterogeneous/asymmetric over the quantiles of green bonds and other financial markets. Sometimes, green bonds and other financial markets have a positive correlation; other times, they have a negative correlation depending on whether the markets are functioning in a bear, normal, or bull market state. Generally speaking, a positive correlation means both markets move together in the same direction, while a negative correlation means both financial markets move in the opposite direction. Investors and traders will often attempt to incorporate negatively correlated assets into portfolios to combat high volatility and risks. We propose green bonds to work as a hedge, diversifier, or safe haven when their correlation with other financial markets is negative, a diversifier when their correlation is positive but less than perfect, and a safe haven when they act as a hedge in a financial crisis.

The findings reveal overall a negative relationship between S&P_GB and S&P_500, however, this relationship does not remain the same but changes depending on market conditions (normal, bearish or bullish). It is found that S&P_GB and S&P_500 is positively correlated at the 80th and 90th quantiles of S&P_500 (bull state) and the 70th, 80th and 90th quantiles of S&P_GB (bull state). However, at the 5th to 60th quantiles of S&P_500 (normal state) and the 5th to 50th quantiles of S&P_GB (normal state) both variables have a weak and negative correlation. Moreover, at the 5th to 10th quantiles of S&P_500 (normal state) and the 70th to 90th quantiles of S&P_GB (bull state) both financial markets have a strong negative correlation. The findings validate portfolio opportunities for investors by using both financial instruments in portfolio selection. The findings are consistent with ([Nguyen et al., 2021](#); [Reboredo et al., 2020](#); [Yousaf et al., 2021](#)). The findings suggest that in bullish market conditions, green bonds do not serve as a hedge against the stock market. However, under normal and bearish conditions, the green bonds market has a weak (negative) correlation with the stock market and offers hedging and diversification opportunities.

The fig 5.2 (b) shows relationship between S&P_GB and DJ_IMWI. It is found that at the 5th to 30th quantiles of S&P_GB (bearish state) and the 5th to 30th quantiles of DJ_IMWI (bearish) a strong positive correlation exists between both variables. However, at the 5th to 90th quantiles of S&P_GB and at the 40th to 60th quantiles of DJ_IMWI (normal state) a negative correlation exists. While at the 5th to 30th quantiles of S&P_GB (bearish state) and at the 40th to 90th quantiles of DJ_IMWI (normal to bullish state) a weak negative correlation exists. Moreover, at the 90th quantiles of S&P_GB (when investors are optimistic in the green bonds market) and at the 5th to 10th quantiles of DJ_IMWI (when investors are pessimistic in the Islamic stock market) a strong negative correlation formed. Overall, the findings point to a negative association between the S&P_GB and the DJ_IMWI, which is heterogeneous and dependent on the market situation. It can be concluded that the green bonds market (S&P_GB) does not

provide any hedging or diversification opportunity against the DJ_IMWI in bearish market conditions because both markets positively correlate with each other and, during stress periods, both markets may co-crash together. This conclusion can be supported by the results of (Shahzad et al.,2017). These findings are noteworthy and call for caution, as investors may suffer losses in their search for safe havens for their investments. While in normal and bullish market states S&P_GB act as a hedge and diversifier.

In the case of the S&P_500 and S&P_GSCI, the correlation shown in Fig 5.2 (c) is similar to that seen in the S&P_GB and DJ_IMWI cases. The findings reveal that at the 5th to 30th quantiles of S&P_GB (when green bonds market is bearish) and at the 5th to 30th quantiles of S&P_GSCI (when commodity market is also bearish) both financial markets positively correlate. While at the 5th to 90th quantiles of S&P_GB (in all market states) and 40th to 50th quantiles of S&P_GSCI (when commodity market is in normal state) a negative correlation exists between these markets. It is also observed that at 30th to 90th quantiles of S&P_GB and 70th to 90th quantiles of S&P_GSCI a positive correlation forms, while this positive correlation becomes stronger at upper quantiles of both financial markets. Finally, at 70th to 90th quantiles of S&P_GB (when investors are optimistic in the green bonds market) and 5th to 30th quantiles of S&P_GSCI (when investors in the commodity market are pessimistic) a strong negative correlation appears. Overall findings confirm a negative association between S&P_500 and S&P_GSCI but this relationship varies over the market states. In bearish market conditions, the green bonds market (S&P_GB) does not provide any hedging or diversification opportunity against the S&P_GSCI because both markets are positively correlated and may co-crash together during stress periods. These findings are noteworthy and should be viewed with caution, as investors may lose money while looking for safe havens for their investment. While in normal and bullish market states S&P_GB act as a hedge and diversifier (Reboredo,2018).

The findings in Fig 5.2 (d) for S&P_GB and CRIX also show a heterogeneous relationship. Overall findings show a very weak correlation but are subject to market conditions. In all the market conditions from 5th to 90th quantiles of S&P_GB and 5th to 10th quantiles of CRIX (when cryptocurrency market perform poorly or bearish) a strong negative correlation exists. While in all the market conditions from 5th to 90th quantiles of S&P_GB and 70th to 90th quantiles of CRIX (when cryptocurrency market perform bullish) a weak positive correlation exists. The findings confirm that green bonds and CRIX must be a part of investors portfolio selection. Overall, it is found that S&P_GB act as a hedge when the market is normal and bearish and diversifier against CRIX when the market is bullish.

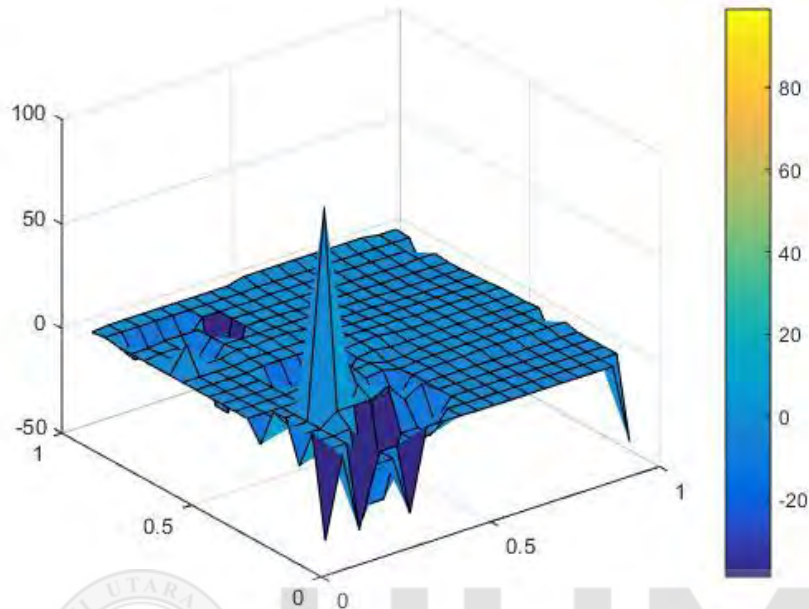
Interdependence between S&P_GB and S&P_BD is presented in Fig 5.2 (e). A strong negative correlation appears between S&P_GB (at the 40th to 90th quantiles) and S&P_BD (at the 5th to 30th quantiles). However, findings confirm an insignificant correlation at 5th to 90th quantiles of S&P_GB and 40th to 60th quantiles of S&P_BD. While at the time when investors are optimistic in both markets (70th to 90th quantiles of S&P_GB and S&P_BD) a strong positive correlation exists. The QQR results reveal an asymmetric relationship between S&P_GB and S&P_BD that varies depending on market conditions. The S&P_GB and S&P_BD are found to provide portfolio diversification benefits, but this is contingent on market performance. It can be seen that in the bullish market condition both markets strongly positively correlate hence S&P_GB does not act as a hedge or diversifier against S&P_BD, but in normal conditions, S&P_GB acts as diversifier. The findings are aligning with [Reboredo \(2018\)](#) who also find a positive correlation between the green bonds market and corporate and treasury bond market. Furthermore, [Reboredo, Ugolini, & Aiube, \(2020\)](#) also find a weak comovement between the green bond and high-yield corporate bond. While, [Broadstock and Cheng \(2019\)](#), assessing the comovement between the green and black bonds, realized the time-varying feature of their correlation.

The QQR findings presented in Fig5.2 (f) present a correlation between S&P_GB and DJ_SUK. It is found that from 5th to 90th quantiles of S&P_GB (normal to bullish) and 5th to 30th quantiles of DJ_SUK (bearish) a positive correlation occurs between these markets. However, at the 5th to 90th quantiles of S&P_GB and 50th to 90th quantiles of DJ_SUK a weak negative (insignificant) correlation appears. Overall, it is found that there is a very weak positive (insignificant) correlation between S&P_GB and DJ_SUK. It shows that S&P_GB act diversifier in normal to bullish market condition against DJ_SUK. It shows portfolio diversification opportunities. Finally, the correlation between S&P_GB and FRX is examined. The findings show that there is a strong negative correlation between S&P_GB and FRX at all the market conditions (bearish, bullish, normal). Finally, most interesting it can be seen that S&P_GB acts as a hedge and safe- haven against FRX in all market conditions.

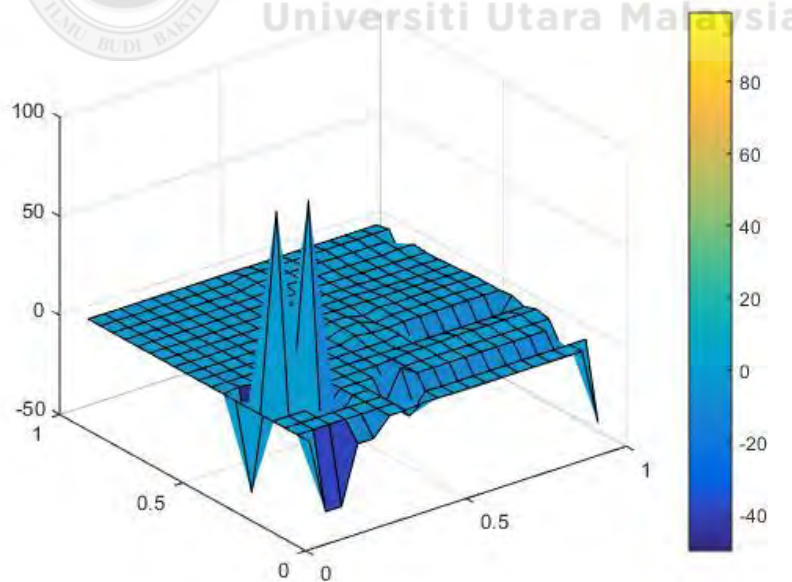
Table 5.6 summarizes the positive and negative correlation between S&P_GB (τ) and other financial markets (θ) based on QQR estimation. While Figure 5.3 shows QQR results during COVID-19. The findings confirm that S&P_GB negatively correlate with all the proposed financial markets (S&P_500, DJ_IMWI S&P_GSCI, CRIX, S&P_BD, DJ_SUK and FRX) during COVID-19. It shows that S&P_GB act as a strong safe haven against S&P_500, DJ_IMWI S&P_GSCI, CRIX, S&P_BD, DJ_SUK and FRX during market uncertainty or turbulences.

Figure 5.3: Quantile Dependency between Green Bonds and Financial Markets (During COVID-19)

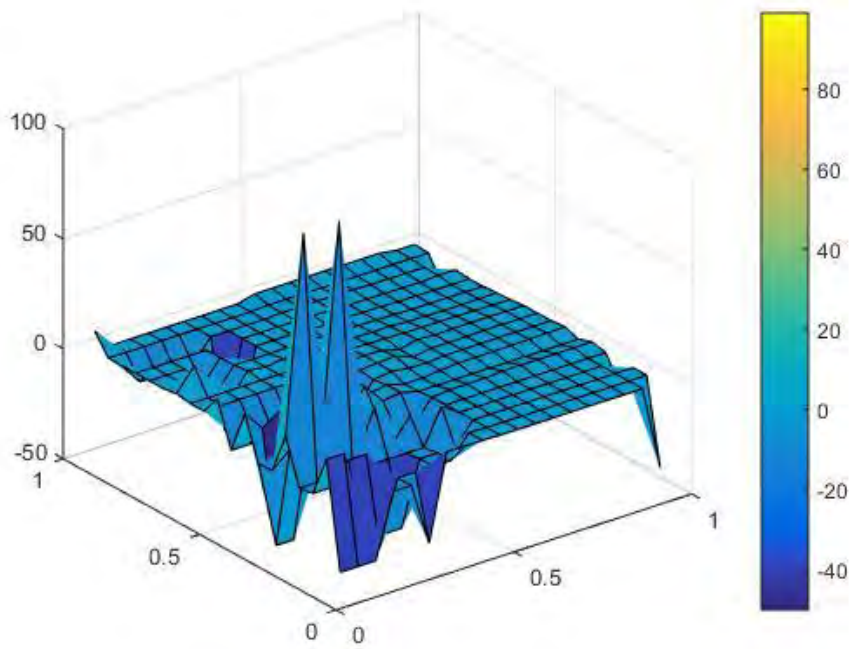
a) S&P_GB and S&P_500



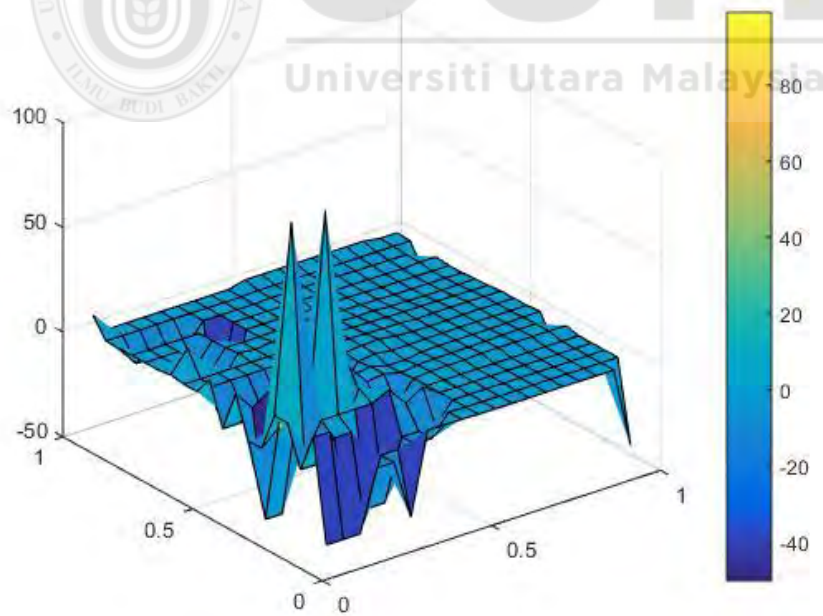
b) S&P_GB and DJ_IMWI



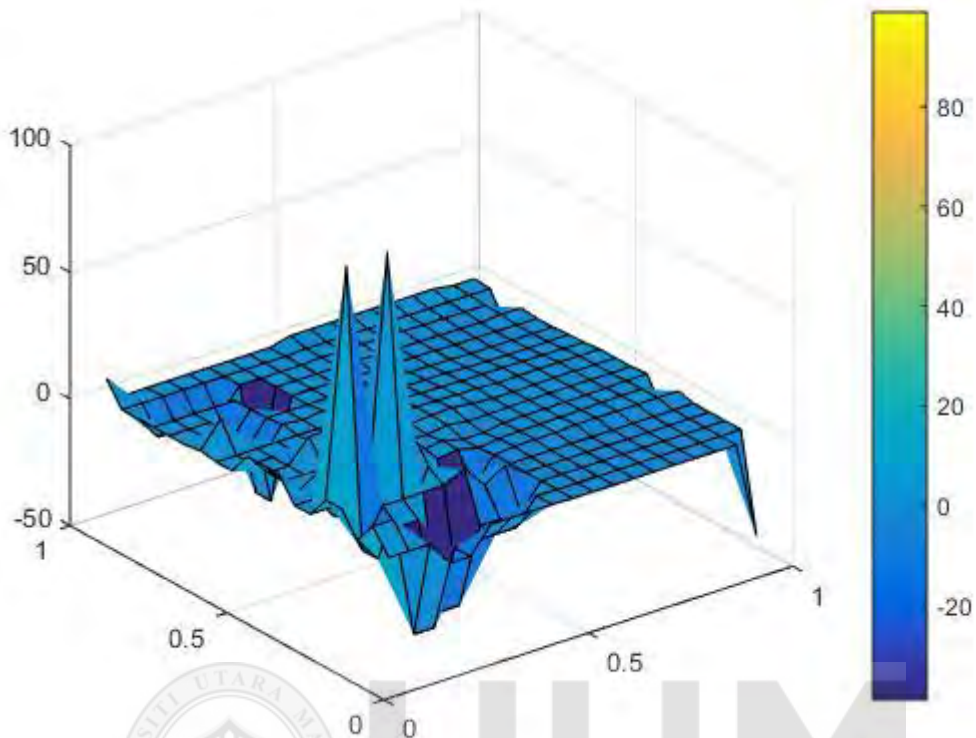
c) S&P_GB and S&P_GSCI



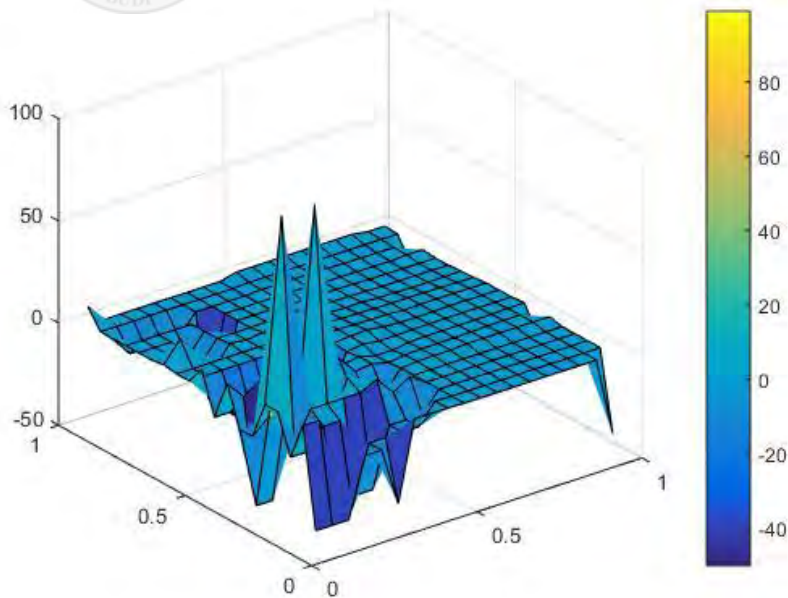
d) S&P_GB and CRIX



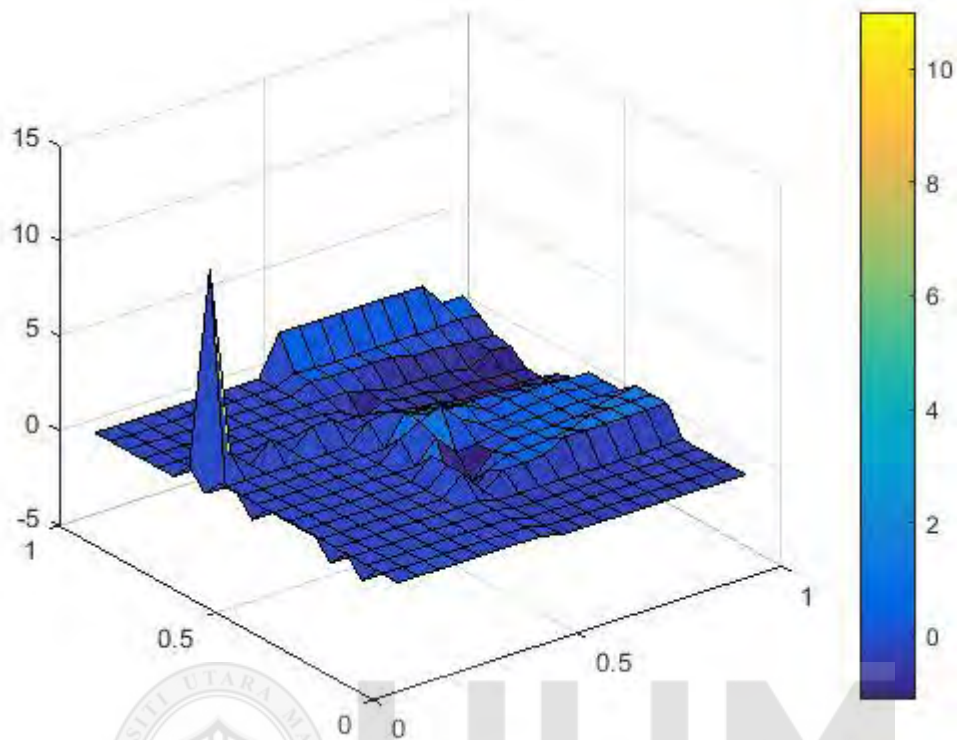
e) S&P_GB and S&P_BD



f) S&P_GB and DJ_SUK



g) S&P_GB and FRX



Note: Fig5.3 (a -g) presents estimates of the slope coefficient, which is placed on the z-axis, (θ) refers to S&P_GB and (τ) refers to S&P_500, DJ_IMWI, S&P_GSCI, CRIX, S&P_BD, DJ_SUK and FRX. The colours in the colour bar represent the degree to which the two variables are correlated with one another (S&P_GB, S&P_500, DJ_IMWI, S&P_GSCI, CRIX, S&P_BD, DJ_SUK and FRX). The yellow colour demonstrates a high positive association, while the strong blue colour demonstrates a strong negative association between proposed variables. While, light green and light blue colours, on the other hand, demonstrate a weak or insignificant association.

Table 5-6: Summary of the QQR Results: Quantile Dependency between Green Bond and Other Financial Markets (Before COVID-19)

	S&P_GB and S&P_500	S&P_GB and DJ_IMWI	S&P_GB and S&P_GSCI	S&P_GB and CRIX
Positive correlation	$(\tau = 0.80 - 0.9 : \theta = 0.9)$	$(\tau = 0.2 : \theta = 0.1)$ $(\tau = 0.9 : \theta = 0.6 - 0.7)$	$(\tau = 0.1 - 0.3 : \theta = 0.1)$ $(\tau = 0.4 - 0.9 : \theta = 0.7 - 0.9)$	$(\tau=0.1 - 0.6 : \theta = 0.8 - 0.9)$
Negative correlation	$(\tau = 0.9 : \theta = 0.1 - 0.2)$ $(\tau = 0.7 : \theta = 0.5)$	$(\tau = 0.8 - 0.9 : \theta = 0.4 - 0.5)$ $(\tau = 0.2 : \theta = 0.9)$	$(\tau=0.6 - 0.9 : \theta = 0.1 - 0.2)$ $(\tau= 0.1 - 0.9 : \theta = 0.4 - 0.5)$	$(\tau=0.1 - 0.9 : \theta = 0.1 - 0.2)$
	S&P_GB and S&P_BD	S&P_GB and DJ_SUK	S&P_GB and FRX	
Positive correlation	$(\tau=0.1 - 0.9 : \theta = 0.6 - 0.9)$	$(\tau = 0.1 - 0.9 : \theta = 0.1 - 0.9)$		
Negative correlation	$(\tau=0.4 - 0.9 : \theta = 0.1 - 0.4)$		$(\tau = 0.1 - 0.9 : \theta = 0.1 - 0.9)$	
Note: Positive shows positive correlation between S&P_GB and other financial markets at various quantiles or market states and negative shows negative correlation between S&P_GB and other financial markets at various quantiles or market states. S&P_GB, S&P_500,DJ_IMWI, S&P_GSCI , CRIX , S&P_BD, DJ_SUK and FRX is S&P green bond index, S&P 500 index, Dow Jones Islamic market world index, S&P GSCI index, Crypto index, S&P 500 bond index, Dow Jones sukuk index and Foreign exchange index respectively.				

5.6.3. Validity of Quantile on Quantile (QQR) Estimates

In the QQR technique, conventional quantile regression model estimates are decomposed and specific estimates are produced for various quantiles of the explanatory variable. In the framework of the present study, the quantile regression model is based on regressing the τ^{th} quantile of S&P_GB on θ^{th} quantiles of other financial markets; hence, the quantile regression parameters are only indexed by θ . Moreover, as previously mentioned, the QQR approach regresses the τ^{th} quantile of S&P_GB on the θ^{th} quantile of other financial markets; therefore, its parameters are indexed by both θ and τ . As a result, the QQR technique includes more disaggregated information on the green bonds and other financial markets association than the quantile regression model, since the QQR method perceives the relationship as possibly heterogeneous across market quantiles.

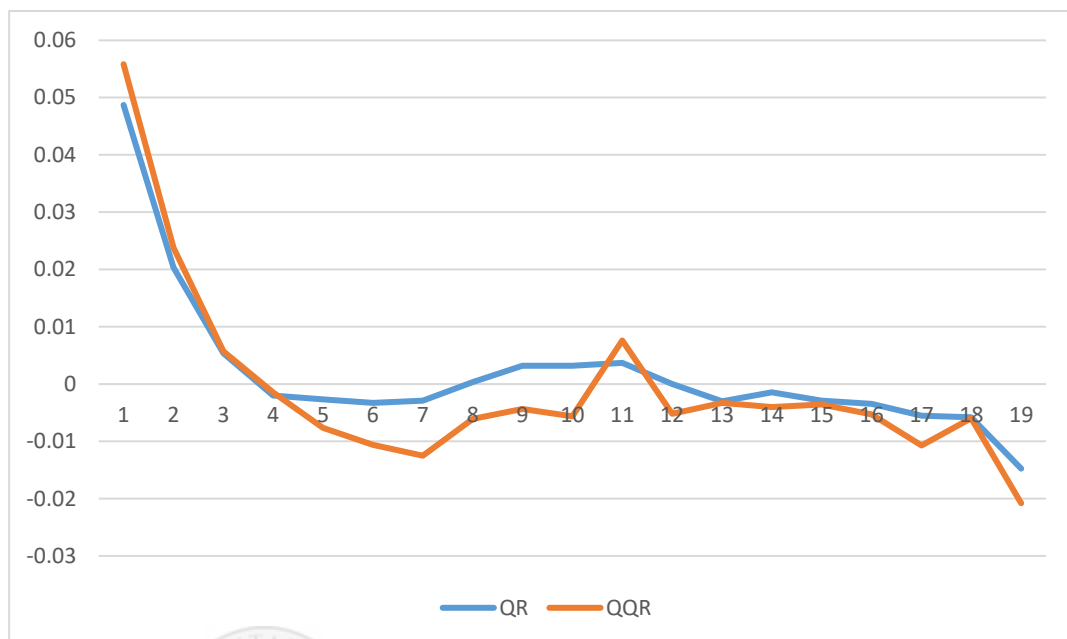
The characteristics of the QR approach may be retrieved utilizing quantile on the quantile method because of its capacity of “decomposition”. Fundamentally, the parameters of the QR approach are indexed by θ and may be generated by taking an average of QQR parameters along τ . To make quantile regression estimates, we summarize the estimated QQR parameters by averaging along τ .

$$\gamma_1(\theta) = \bar{\beta} = \frac{1}{S} \sum \tau \hat{\beta}_1(\theta, \tau) \quad \text{Eq. (5.1)}$$

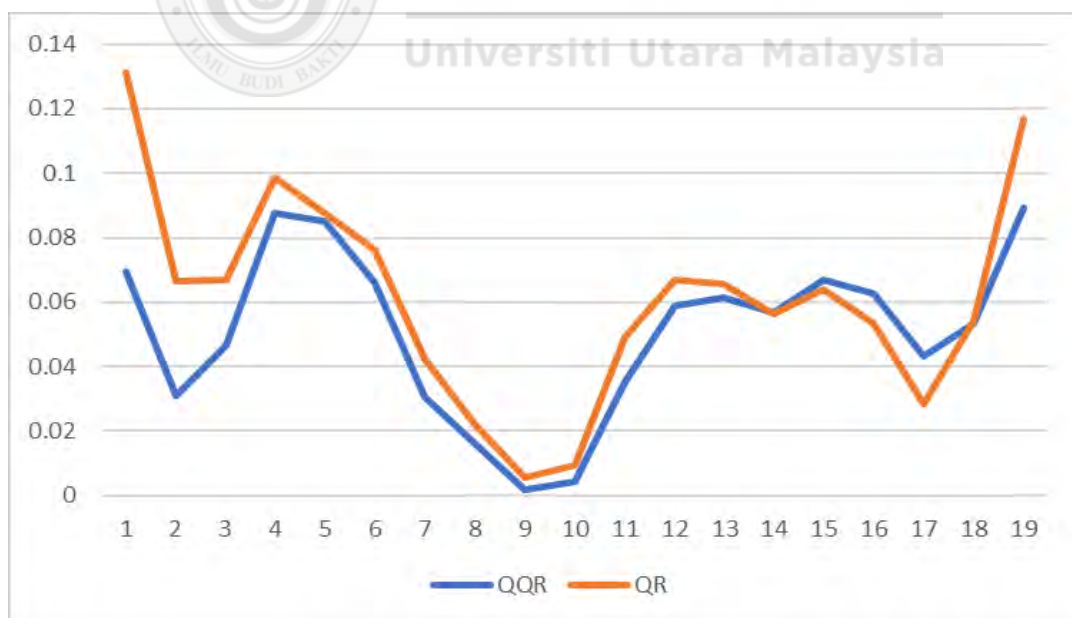
The validity of quantile on quantile parameters is being checked by comparing estimates of the QR approach with averaging τ parameters of the QQR approach. Therefore, fig.5.4 (a-g) comprises the estimates of QR and QQR for green bonds and other financial markets. From fig.5.4 (a-g), it can be confirmed that both QR and QQR estimates show the same pattern for all the financial markets. Hence the graphical presentation in Fig.5.4 (a-g) confirmed the validity of quantile on quantile estimates.

Figure 5.4: Validity of Quantile on Quantile (QQR)

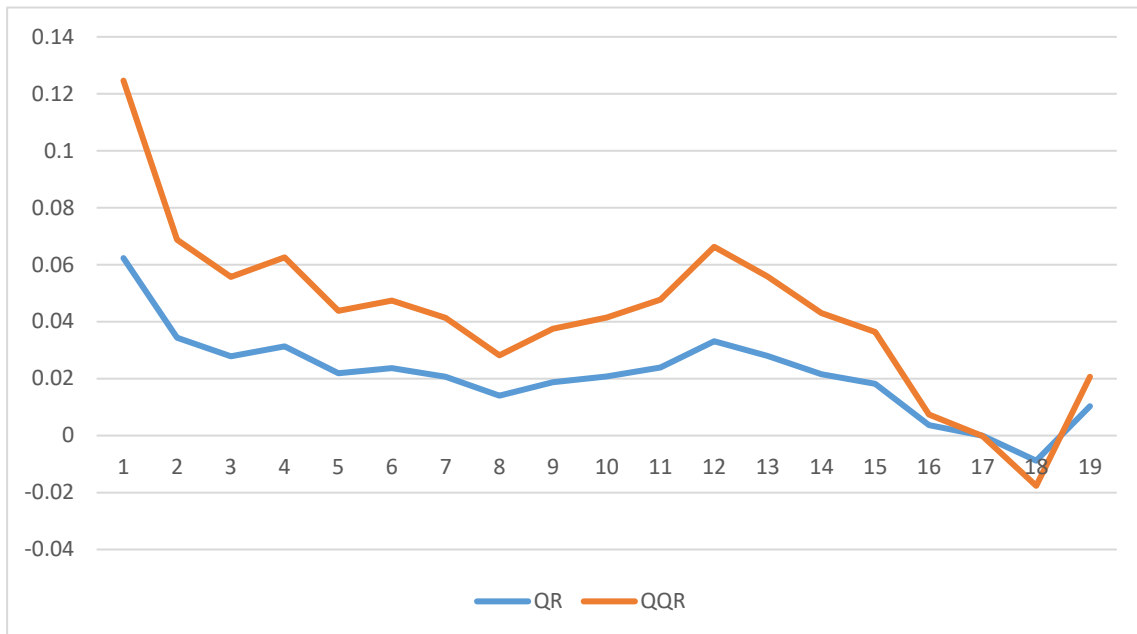
a) S&P_GB and S&P_500



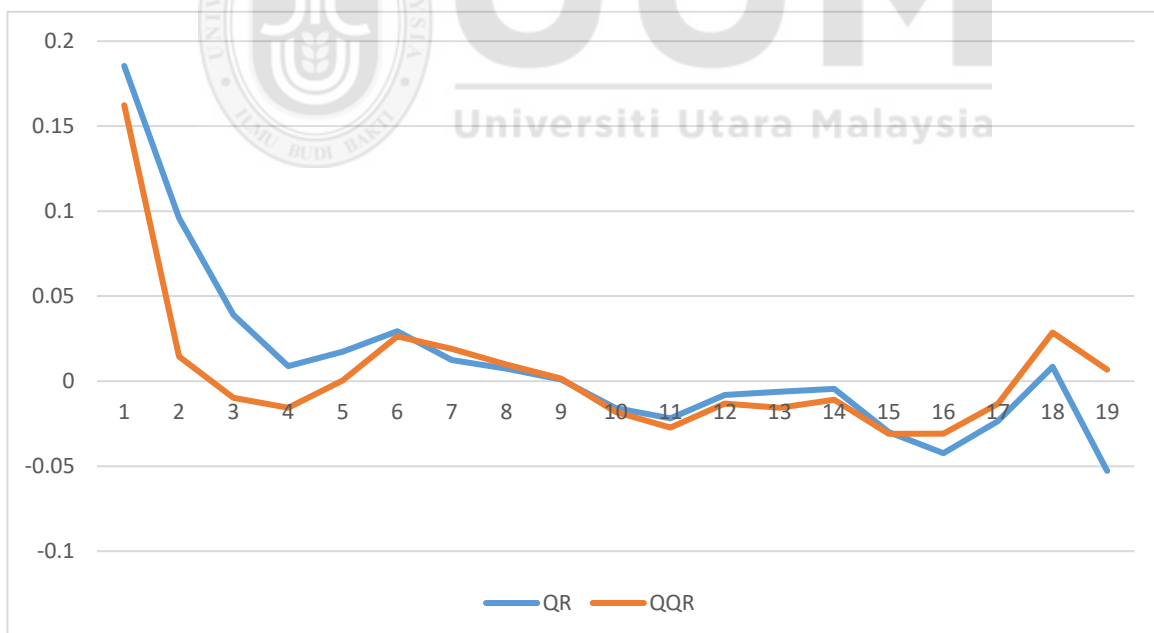
b) S&P_GB and DJ_IMWI



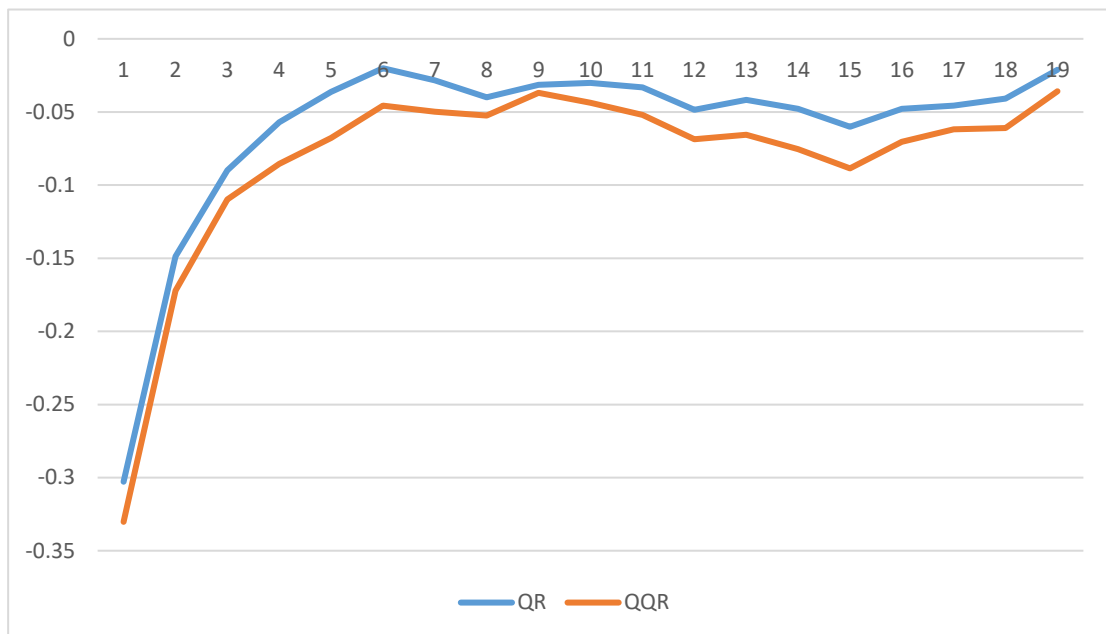
c) S&P_GB and S&P_GSCI



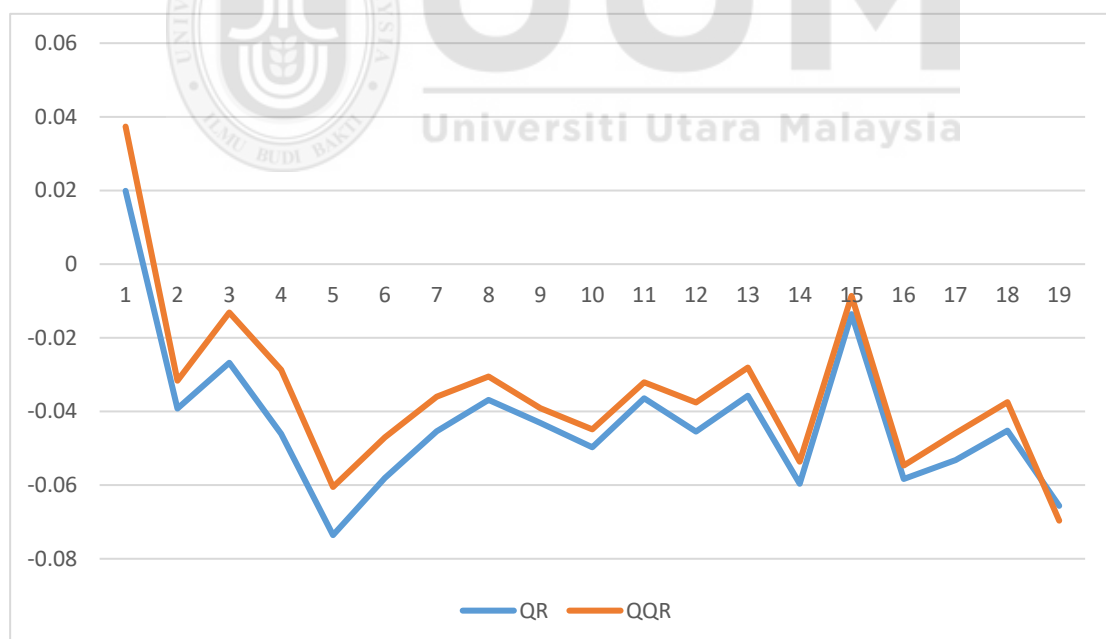
d) S&P_GB and CRIX



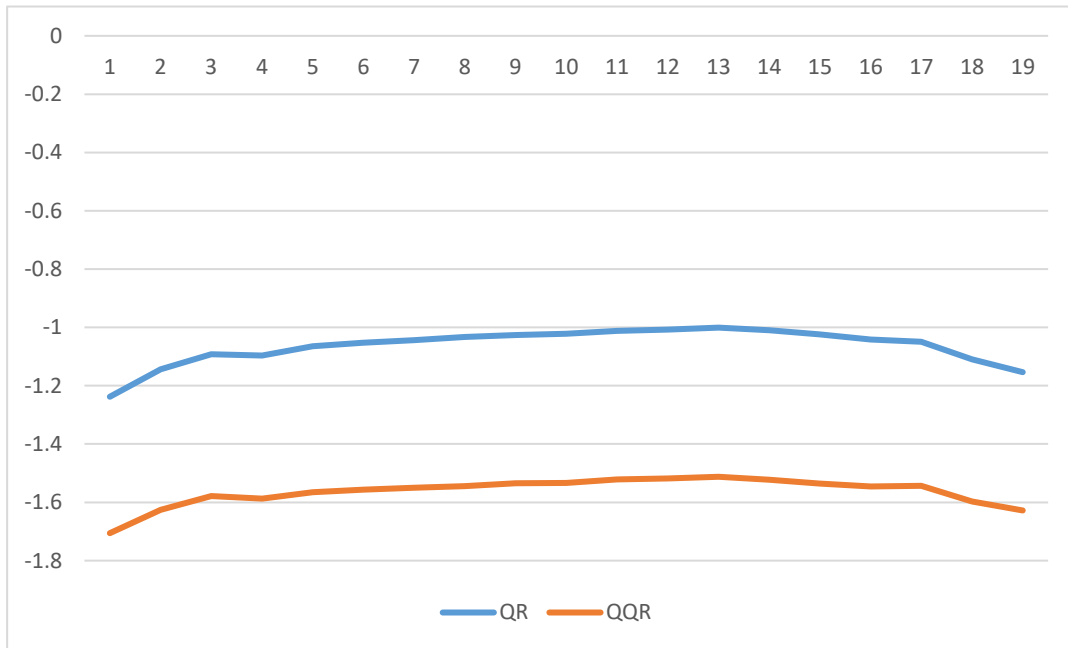
e) S&P_GB and S&P_BD



f) S&P_GB and DJ_SUK



g) S&P_GB and FRX



Note: Fig5.4 (a-g): shows standard quantile regression (QR) and quantile on quantile regression (QQR). The blue lines show estimates of QR, and the orange colour line shows estimates of quantile on quantile regression. The QQR estimates are based on various quantiles of green bonds and other financial markets, and standard quantile estimates are based on average. While, S&P_GB, S&P_500, DJ_IMWI, S&P_GSCI, CRIX, S&P_BD, DJ_SUK and FRX is S&P green bond index, S&P 500 index, Dow Jones Islamic market world index, S&P GSCI index, Crypto index, S&P 500 bond index, Dow Jones Sukuk index and Foreign exchange index respectively.

5.6.4. Granger-Causality in Quantiles

After performing quantile on quantile (QQR) estimation, we extend our analysis with a quantiles Granger-causality test, the results of which are shown in table 5.8. We used an S_t test for the projected log-difference series based on 19 grids equally spaced (0.5 to 0.95). The findings show that there is bidirectional causality between S&P_500 and S&P_GB at high quantiles, however, but no causality between both markets at low quantiles. It is also found for S&P_GB and DJ_IMWI that there is no causality between both markets at low quantiles, while there is bidirectional causality between both financial markets at medium and high quantiles. Moreover, we find bi-directional causality between S&P_GB and S&P_GSCI, S&P_GB and CRIX, S&P_GB and S&P_BD, S&P_GB and DJ_SUK and S&P_GB and FRX at all the quantiles (bearish, normal or bullish market states).

5.7. Traditional Granger Causality

Table 5.7 shows the results of the traditional Granger-causality test. The findings presented in Table 5.8 shows that there is unidirectional causality at 10% and 5% level of significance respectively, running from S&P_500, DJ_IMWI, *S&P_GSCI* , to S&P_GB. The outcomes of the Granger causality test also show bidirectional causality running between S&P_GB and DJ_SUK at a 1% level of significance. Unidirectional causality also confirmed running from CRIX and FRX to S&P_GB. In addition, it is also found that no causality between S&P_GB and S&P_BD.

Table 5-7: Traditional Granger Causality

Null Hypothesis:	F-Statistic	Prob.
S&P_GB $\nRightarrow$ S&P_500	0.141	0.868
S&P_500 $\nRightarrow$ S&P_GB	2.570	0.076*
S&P_GB $\nRightarrow$ DJ_IMWI	0.369	0.691
DJ_IMWI $\nRightarrow$ S&P_GB	3.859	0.021**
S&P_GB $\nRightarrow$ <i>S&P_GSCI</i>	0.017	0.982
<i>S&P_GSCI</i> $\nRightarrow$ S&P_GB	3.819	0.022**
S&P_GB $\nRightarrow$ CRIX	2.953	0.052*
CRIX $\nRightarrow$ S&P_GB	2.111	0.121
S&P_GB $\nRightarrow$ S&P_BD	0.120	0.886
S&P_BD $\nRightarrow$ S&P_GB	0.165	0.847
S&P_GB $\nRightarrow$ DJ_SUK	4.157	0.015***
DJ_SUK $\nRightarrow$ S&P_GB	15.390	0.000***
S&P_GB $\nRightarrow$ FRX	11.380	0.000***
FRX $\nRightarrow$ S&P_GB	0.254	0.775

Note: S&P_GB, S&P_500, DJ_IMWI, S&P_GSCI , CRIX , S&P_BD, DJ_SUK and FRX is S&P green bond index, S&P 500 index, Dow Jones Islamic market world index, S&P GSCI index, Crypto index, S&P 500 bond index, Dow Jones Sukuk index and Foreign exchange index respectively. ***, ** & * refers to level of significance at 1%, 5% and 10%

Table 5-8: Granger Causality in Quantiles

S&P_500 and S&P_GB																			
Quantiles	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95
S&P_GB $\Rightarrow$ S&P_500	0.45	0.86	0.80	0.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S&P_500 $\Rightarrow$ S&P_GB	0.12	0.30	0.32	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S&P_GB and DJ_IMWI																			
Quantiles	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95
S&P_GB $\Rightarrow$ DJ_IMWI	0.12	0.12	0.12	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DJ_IMWI $\Rightarrow$ S&P_GB	0.43	0.12	0.43	0.54	0.00	0.00	0.00	0.00	0.00	0.23	0.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S&P_GB and S&P_GSCI																			
Quantiles	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95
S&P_GB $\Rightarrow$ S&P_GSCI	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S&P_GSCI $\Rightarrow$ S&P_GB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.43	0.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S&P_GB and CRIX																			
Quantiles	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95
S&P_GB $\Rightarrow$ CRIX	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CRIX $\Rightarrow$ S&P_GB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S&P_GB and S&P_BD																			
Quantiles	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95
S&P_GB $\Rightarrow$ S&P_BD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S&P_BD $\Rightarrow$ S&P_GB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S&P_GB and DJ_SUK																			
Quantiles	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95
S&P_GB $\Rightarrow$ DJ_SUK	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DJ_SUK $\Rightarrow$ S&P_GB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.93	0.00	0.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S&P_GB and FRX																			
Quantiles	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95
S&P_GB $\Rightarrow$ FRX	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FRX $\Rightarrow$ S&P_GB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.43	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00

Note: This table presents the subsampling p-values of the S_T test. S&P_GB, S&P_500, DJ_IMWI, S&P_GSCI, CRIX, S&P_BD, DJ_SUK and FRX is the log-difference of S&P green bond index, S&P 500 index, Dow Jones Islamic market world index, S&P GSCI index, Crypto index, S&P 500 bond index, Dow Jones Sukuk index and Foreign exchange index respectively. The bold values show the level of significance at 1%.

5.8. Wavelet Analysis

The third objective of the study is to explore the dependency between green bonds and other financial markets across various investment horizons in order to identify portfolio diversification opportunities. We used wavelet-based approaches such as maximal overlap discrete wavelet transforms (MODWT), wavelet correlation, and continuous wavelet transformation (CWT).

5.8.1. Maximal Overlap Discrete Wavelet Transform (MODWT)

According to the literature, a very small number of scholars have worked on analyzing the relationship between proposed financial markets within the wavelet framework. The dataset, which consists of multiple different variables, includes several periods, all of which are required to explain the right time scales in the specific analysis ([Gallegati et al., 2011](#)). This demand analyzing the association between variables at various time horizons in various time series data sets using time frequency-based approaches, commonly referred to as Wavelets. The Wavelets technique considers non-stationarity to be an inherent quality of data and does not need it to be addressed through data pre-processing.

First, we conduct a time-scale decomposition analysis on all financial markets (S&P_GB, S&P_500, DJ_IMWI, S&P_GSCI, CRIX, S&P_BD, DJ_SUK and FRX) by applying the MODWT technique. The MODWT is a modified version of the DWT, which can manage any sample size, is symmetric in translation, gives an improved resolution on more coarser scales and provides a more efficacious wavelet variance estimator than a DWT. Previous research has found that $L = 8$, the recommended filter length for dealing with characteristics of high-frequency data, is sufficient to handle the characteristics of these types of data ([Gençay et al., 2001](#)). Therefore, we employ the Daubechies efficiently based least asymmetric (LA) wavelet filter of length $L = 8$, abbreviated by LA (8), which is based on 8 non-zero coefficients ([Daubechies, 1992](#)).

A wavelet filter called the LA was developed by [Daubechies \(1992\)](#), and it is the most frequently used wavelet because it offers the most accurate time alignment between wavelet coefficients at various scales and the original time series, and it can be applied to a wide variety of data types. It is necessary to employ the wavelet transform in order to uncover hidden patterns in projected variables. The intrinsic multiresolution analysis of the wavelet transforms aids in the isolation and localization of effects that would otherwise be difficult to detect. In Fig 5.5 (see appendix Fig 5.5), we present the orthogonal components (D1, D2,...) of the original series that describe the various frequency components as well as a smoothed component (D8) of the original series (S8). According to the figures, high frequencies are seen in the short term of the time series under investigation, with the fluctuations becoming more stable in the longer period of the time series under investigation.

5.8.2. Wavelet Covariance

In Fig. 5.6 (see appendix Fig. 5.6) we show the estimated wavelet covariance coefficients between the proposed financial markets at various time scales. We discussed the wavelet covariance findings in terms of our previously determined four major periods, namely (D1 + D2) represents the short-run, (D3 + D4) represents the medium-run, (D5 + D6) represents the long-run, and (S6) represents the very long-run. The results shown in Fig 5.6 show that the wavelet covariance between S&P_GB and S&P_500 varies across wavelet scales. It is discovered that a negative covariance exists between both variables in the short run. However, after 4 days, this negative covariance turns positive and remains so in the long run (32 days). It is also worth noting that in the very long run, the covariance between S&P_GB and S&P_500 becomes very weak or non-existent.

In the case of S&P_GB and DJ_IMWI, it is observed that in the short-run S&P_GB and DJ_IMWI, there is a positive covariance between both financial markets but this covariance becomes negative after 4 days to 8 days. However, after 8 days, the covariance between both

variables becomes positive again. It is also worth noting that, similar to the case of S&P_GB and S&P_500, there is week covariance between S&P_GB and DJ_IMWI in the very long run. There is a strong implication of covariance between proposed financial assets as it helps in portfolio diversifications.

In the case of the S&P_GB and S&P_GSCI, it is observed that both markets have a positive covariance in the short run, but this covariance decreases and becomes negative after 3 days. It should be noted that in the long run, this covariance becomes weak. While S&P_GB and CRIX are negatively covariates in the short-run, after 2 days this covariance turns positive and remains so till the long run. However, the covariance of both variables becomes negative in the very long run. We observe extremely interesting findings of S&P_GB and S&P_BD; it is revealed that covariance between both variables remains negative and significant from short to long run; nevertheless, the covariance between both variables becomes very weak or insignificant in the very long run. We find similar findings for S&P_GB and DJ_SUK, it is observed that there is a very strong negative covariance between both markets at the frequency of 1 to 16 days. However, at the frequency of 32 to 128, a weak positive covariance exists between both markets.

Finally, Fig 5.6 shows covariance for the S&P_GB and FRX and it is observed that both markets negatively and significantly covariate with each other on all the frequency levels. However, in the very long run, this covariance becomes very weak. The overall findings of wavelet covariance show that covariance among the proposed markets is heterogeneous or asymmetric as a function of wavelet scales.

5.8.3. Wavelet Correlation

The computed wavelet correlation coefficients between the proposed financial markets over different time scales are shown in Fig 5.7. We reviewed the wavelet correlation findings based on our previously determined four major periods, namely (D1 + D2) represents the short-run,

(D3 + D4) represents the medium-run, (D5 + D6) represents the long-run, and (S6) represents the very long-run. From the perspective of portfolio diversification, it is critical to investigate the correlation between financial markets, because the lower the correlation between financial markets, the lower the risk ([Dajcman et al., 2012](#); [Grubel & Fadner, 1971](#)). Hence, increased comovement/correlation across financial markets, as a result, has the potential to erode the advantage of globally diversified investment portfolios ([Xiao & Dhesi, 2010](#)).

Furthermore, [Engle \(2002\)](#) finds that the correlation between financial markets changes over time. Therefore, asset returns must be monitored constantly to identify any shifts in market correlations that impact portfolio diversification strategies. According to current research, it is now thought that market returns may not only be time-varying (changing with time), but may also be tied to time scales, emphasizing the significance of investment horizons ([Gençay et al., 2002](#)). Understanding the time-frequency nature of the financial market's correlation is critical because a “one size fits all” portfolio diversification strategy is ineffective when there is a time-frequency asymmetric correlation between proposed financial markets. Consequently, this study attempts to empirically study the diversification aspects across heterogeneous investment horizons for the proposed financial markets.

The Monte Carlo technique is used to perform wavelet correlation analysis across four different wavelet scales. The graph presented in Fig 5.7 shows a correlation between proposed financial markets at different wavelet scales. If the value of correlation is close to zero, this shows no dependency between proposed financial markets. The higher the magnitude towards one, the stronger the correlation, indicating that the two variables are interconnected. A negative correlation indicates that there is an inverse dependency between proposed financial markets.

Fig 5.7 shows that S&P_GB and S&P_500 have no significant correlation at short to medium-term frequencies. However, from long to very long-term frequencies, both financial markets

show an increasingly positive correlation. It demonstrates that the S&P_GB acts as a diversifier rather than a hedge. In the case of S&P_GB and DJ_IMWI, it can be seen that in the short to medium-term frequencies both markets don't share any significant correlation. While in the long-term frequencies both markets share a positive correlation but are less than perfect. Hence, S&P_GB acts as a diversifier against DJ_IMWI. [Arif et al. \(2021\)](#) also find that green bonds serve as a diversifier asset for medium and long-term equity investors. Some interesting findings emerge for S&P_GB and S&P_GSCI because a very weak positive correlation exists between both markets in the short to medium-term frequencies, but in the medium-term frequencies, this correlation becomes negative, confirming that in the medium-term frequencies, S&P_GB acts as a hedge against S&P_GSCI. [Arif et al. \(2021\)](#) also find that green bonds serve as a hedge and safe haven instrument commodity investments.

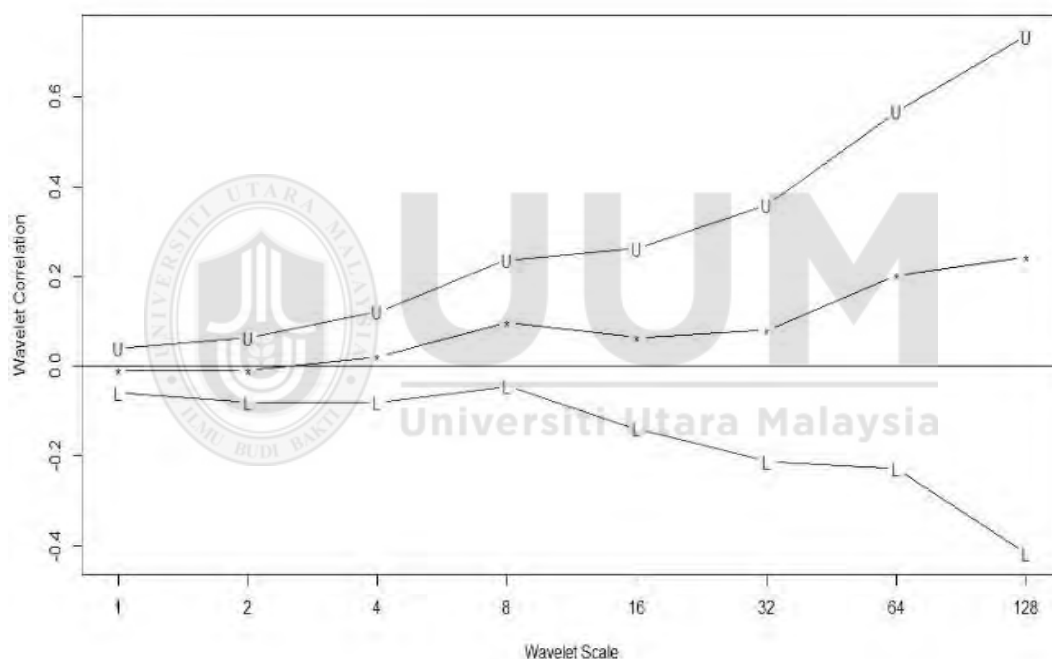
While in the long-term frequencies both markets show a strong positive correlation. It implies that in long-term frequencies S&P_GB does not diversify risk with S&P_GSCI. For the S&P_GB and CRIX, it is found that both markets share no significant correlation from short to medium-term frequencies but in long-term frequencies, both markets show a negative correlation. It implies that in short to medium-term frequencies S&P_GB acts as a hedge and diversifier.

Moreover, S&P_GB & S&P_BD and S&P_GB & DJ_SUK show a similar pattern of correlation in the short to medium-term frequencies S&P_GB negatively correlate with S&P_BD and DJ_SUK. It implies that in the short to medium-term S&P_GB acts as a hedge against S&P_BD and DJ_SUK. However, in the long-term frequencies, both markets positively correlate with, S&P_GB. It shows in long-term frequencies S&P_GB does not act as a hedge, diversifier or safe haven. However, very interesting findings emerge when wavelet correlation is observed for S&P_GB and FRX. It is observed both markets share a negative correlation from short to long-term frequencies. It is also important to note that in the short run S&P_GB

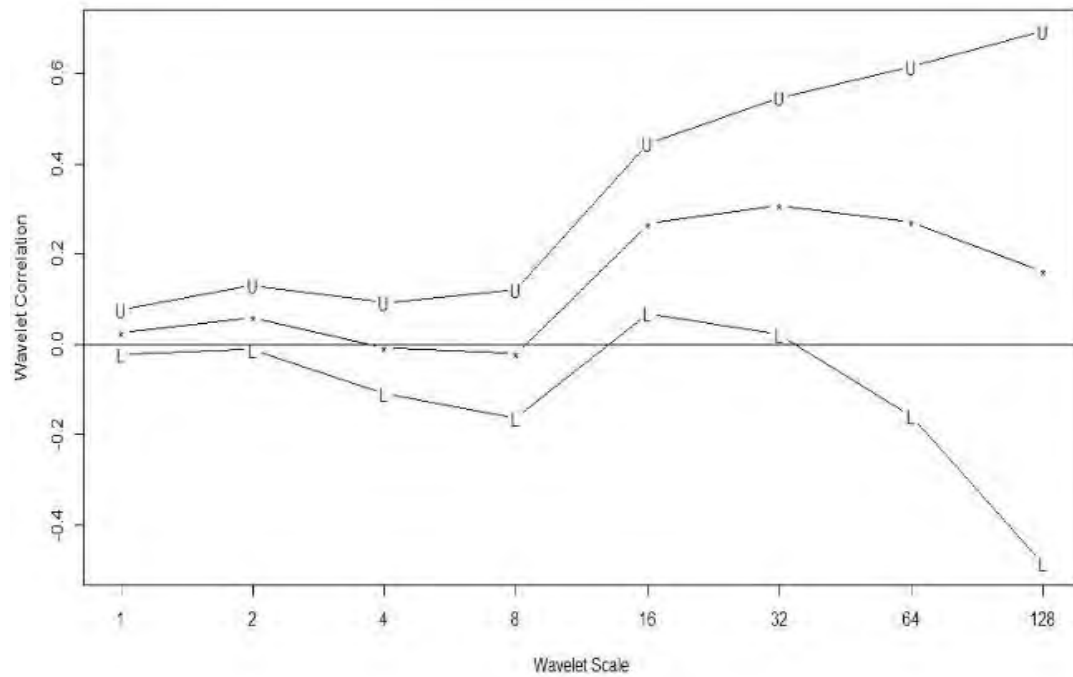
act as a hedge, however in the long run it acts as a safe haven against FRX. [Arif et al. \(2021\)](#) also find that green bonds serve as a diversifier asset for medium and long-term equity investors. Furthermore, green bonds also can be used as a hedging and safe haven financial instrument for the currency. Furthermore, it is important to note that all green bond issuers and holders can achieve environmental sustainability goals while also avoiding extreme financial market fluctuations.

Figure 5.5: Wavelet Correlation

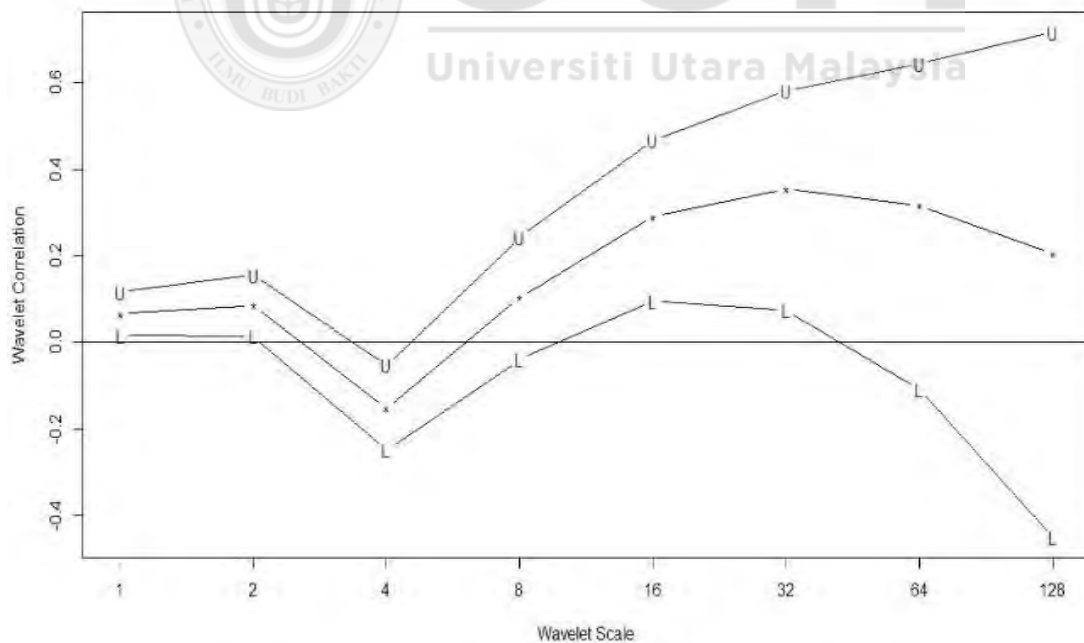
a) S&P_GB VS S&P_500



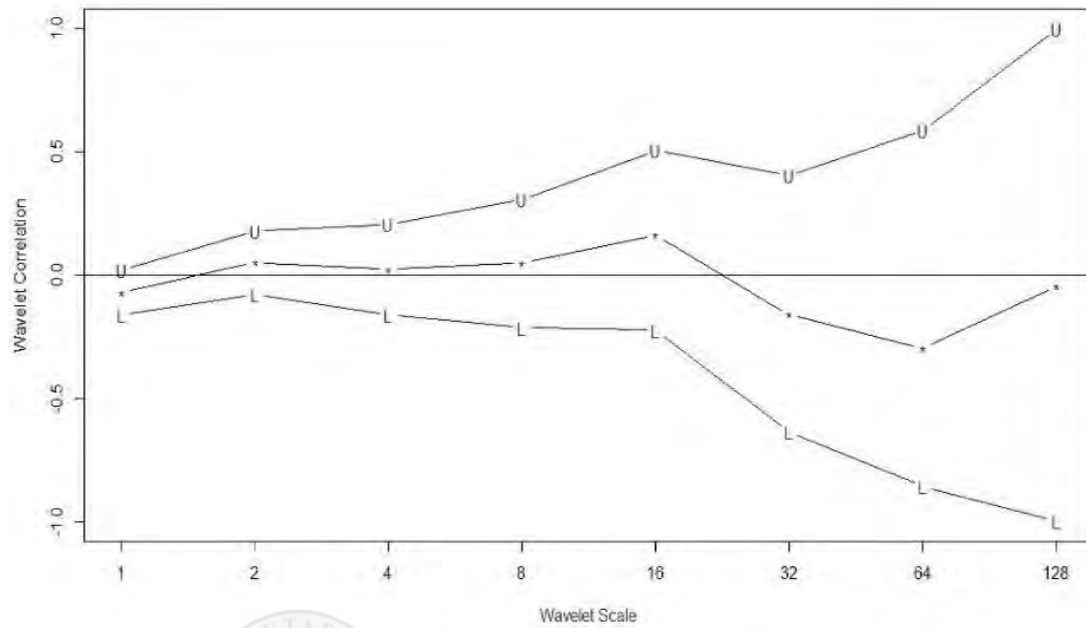
b) S&P_GB VS DJ_IMWI



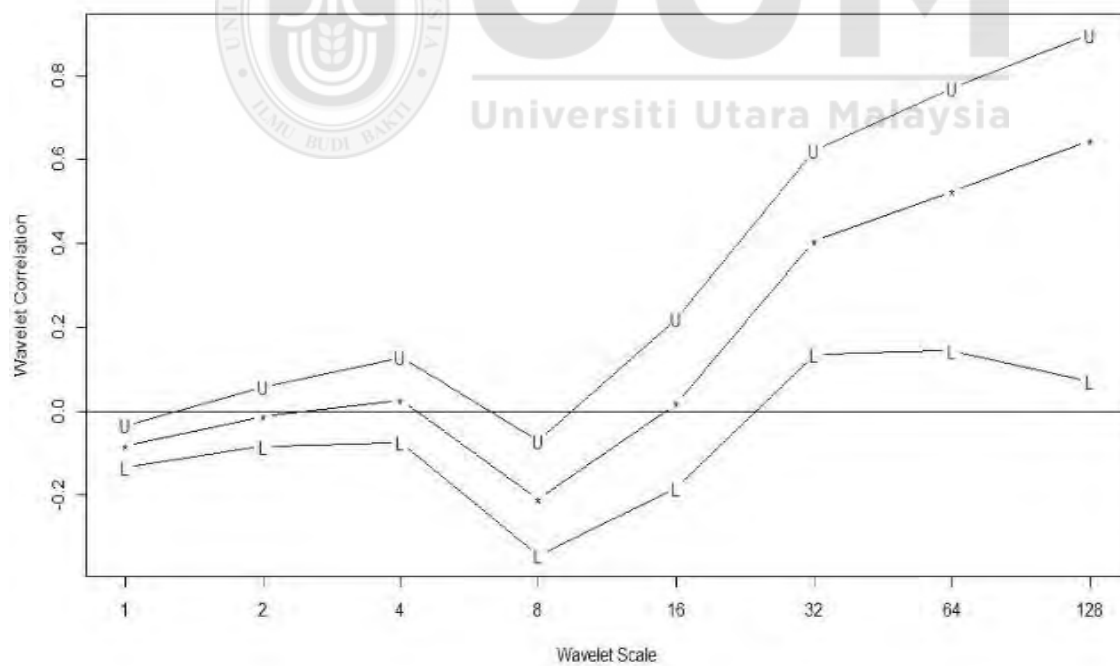
c) S&P_GB VS S&P_GSCI



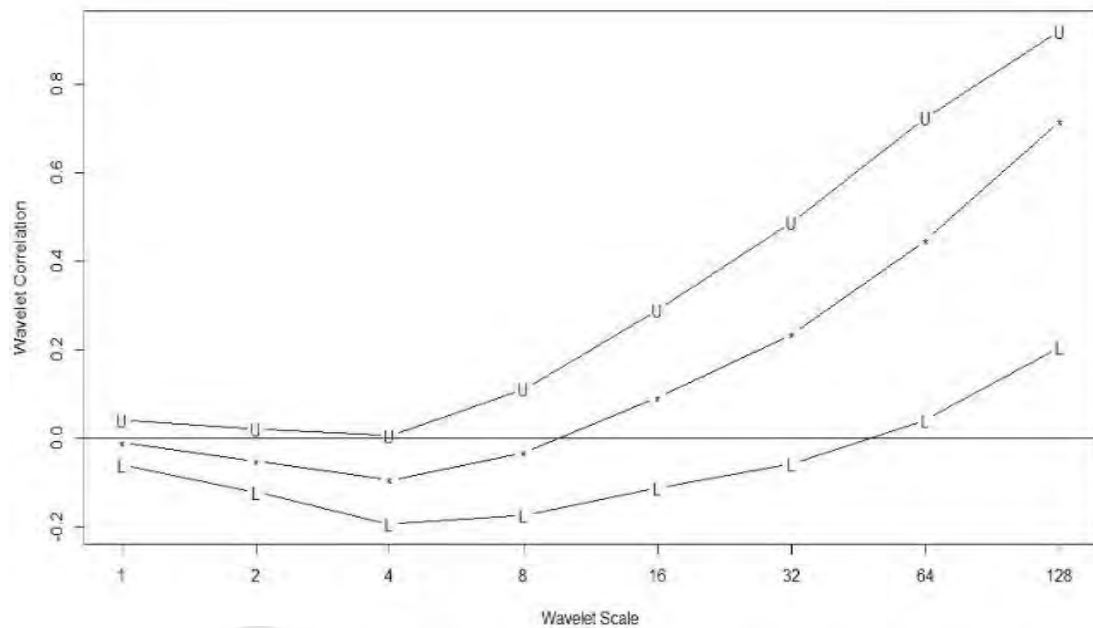
d) S&P_GB VS CRIX



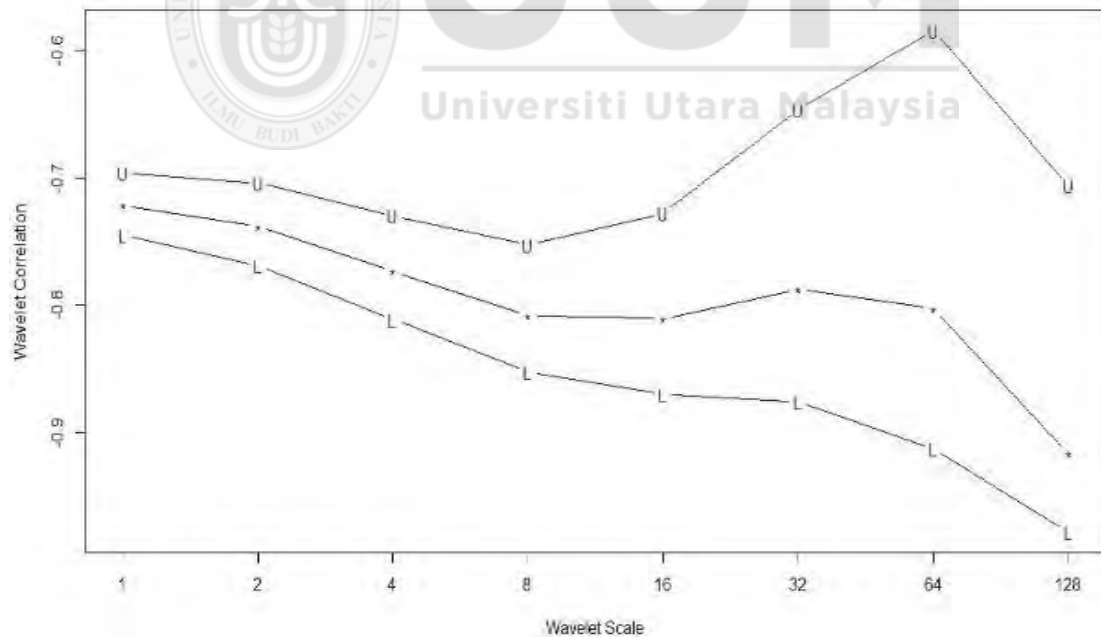
e) S&P_GB VS S&P_BD



f) S&P_GB VS DJ_SUK



g) S&P_GB VS FRX



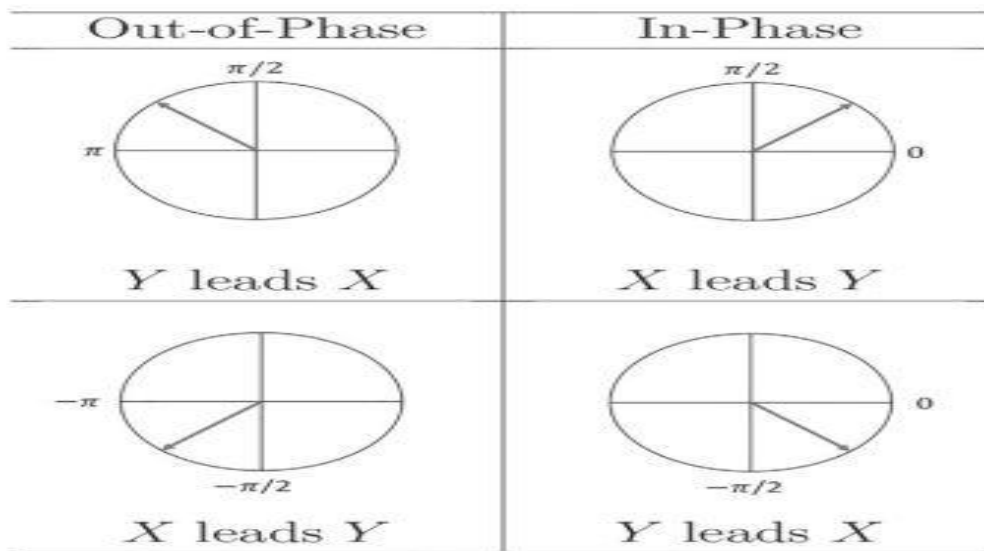
Note: Fig.5.7 estimated wavelet correlation of S&P_GB with other financial markets. The “U” and “L” lines correspond to the upper and lower bounds of the corresponding 95% confidence interval. While, S&P_GB, S&P 500, DJ IMWI, S&P GSCI, CRIX, S&P BD, DJ SUK and FRX is the log-difference of S&P green bond index, S&P 500 index, Dow Jones Islamic market world index, S&P GSCI index, Crypto index, S&P 500 bond index, Dow Jones Sukuk index and Foreign exchange index respectively.

5.8.4. Continuous Wavelet Transformation (CWT) Estimate

After MODWT and wavelet correlation approaches we enrich our wavelet analysis by applying continuous wavelet transformation for green bonds and other financial markets. This is illustrated in Fig 5.9 the wavelet power spectrum is defined as the absolute value of the square of the wavelet transform. It gives us a measure of the time-series variance for each time and each scale (frequency). The horizontal axis of CWT comprises the time component, however, the vertical axis of CWT shows the frequency component. As the vertical axis having a frequency component and it ranges from scale 1 (1 day) up to scale 1024 (1024 days). The black contours in the CWT graph show region with a 5% level of significance. The continuous wavelet transformation is estimated by Monte Carlo simulation with phase-randomized surrogate series. While the solid curved line illustrates the cone of influence or the zone affected by edge effects.

Fig 5.9 demonstrates the continuous wavelet transformation and phase difference among S&P_GB, S&P_500, DJ_IMWI, S&P_GSCI, CRIX, S&P_BD, DJ_SUK and FRX markets. To indicate the degree of comovement, the coherency varies from yellow (high coherency) to blue (low coherency). Thus, a yellow show strong comovement; while a blue colour signifies low comovement between proposed financial markets. Additionally, we discern causality and phase differences between S&P_GB, S&P_500, DJ_IMWI, S&P_GSCI, CRIX, S&P_BD, DJ_SUK and FRX markets. The arrows specify the phase differences between proposed financial markets. For instance, $\rightarrow$ and $\leftarrow$ indicate that two markets (Let suppose X and Y) are in phase and out of phase. Being in phase (out of phase) shows a positive (negative) correlation between two markets (Let suppose X and Y). Moreover, $\nearrow$ and $\searrow$ indicate that “X market” is leading “Y market”, while $\swarrow$ and $\nwarrow$ indicate “X market” is lagging those of “Y market” respectively. Further following figure 5.8 shows the lead-lag relationship in detail as well.

Figure 5.6 Phase Interpretation

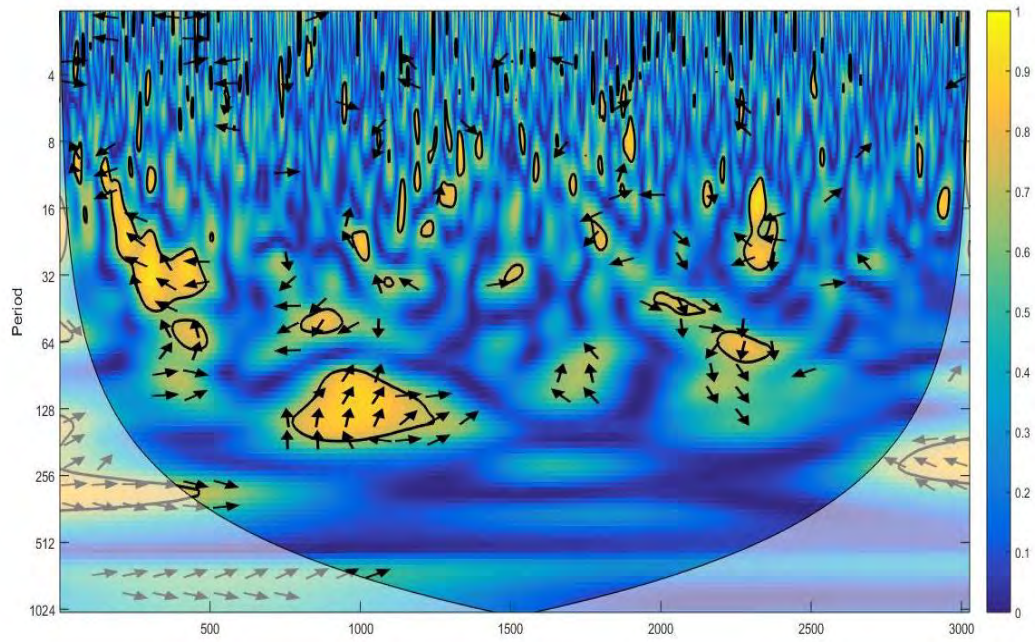


Source: [Firouzi & Wang, 2019](#)

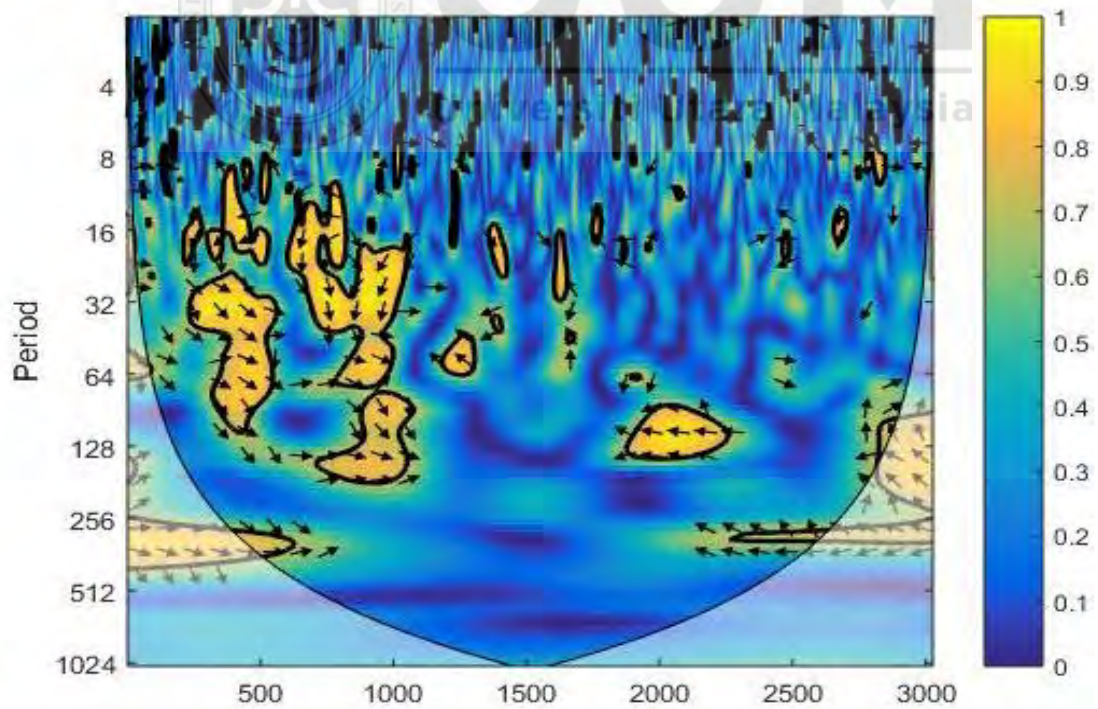
In Fig 5.9, the horizontal axis represents time spanning from November 28, 2008 to March 21, 2021, while the vertical axis relates to stock holding durations (e.g., 2 to 4 days, 4 to 8 days, 8 to 16 days, etc.). The curved line in fig 5.9 displays a 5% level of significance based on Monte Carlo simulations, and the area beyond this curved line is not crucial for interpretation because it is statistically insignificant at a 95% level of significance.

Figure 5.7: Continuous Wavelet Transformation (CWT)

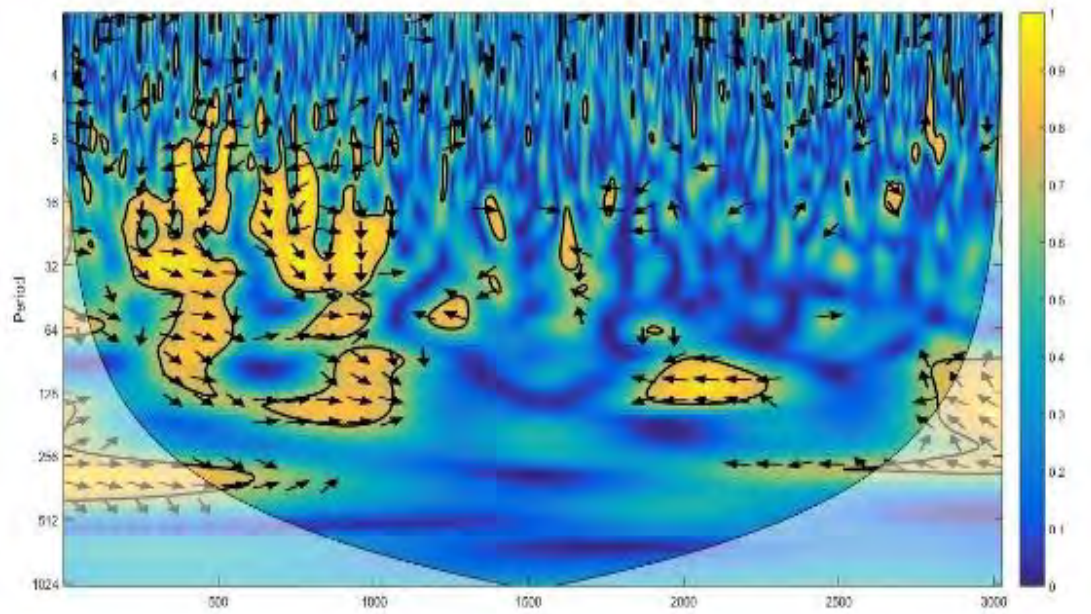
a) S&P_GB VS S&P_500



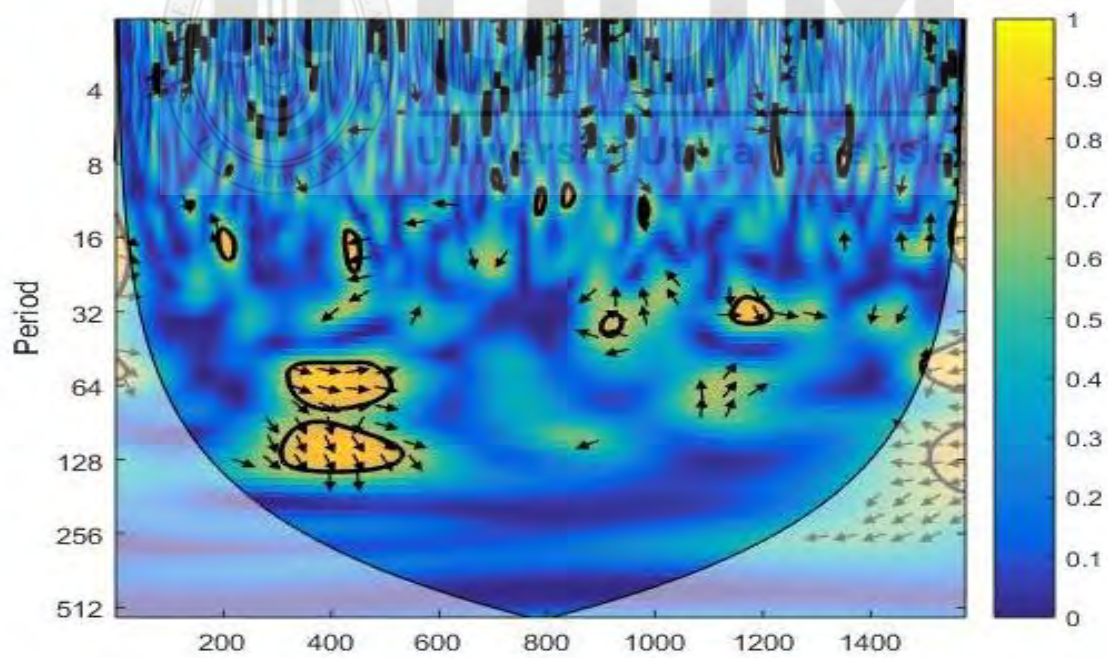
b) S&P_GB VS DJ_IMWI



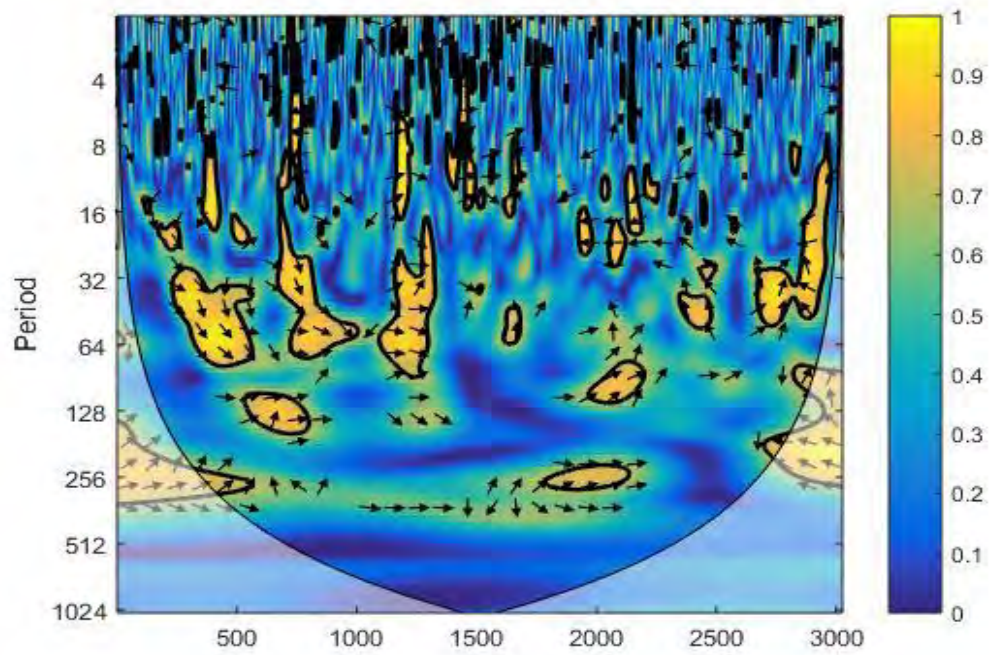
c) S&P_GB VS S&P_GSCI



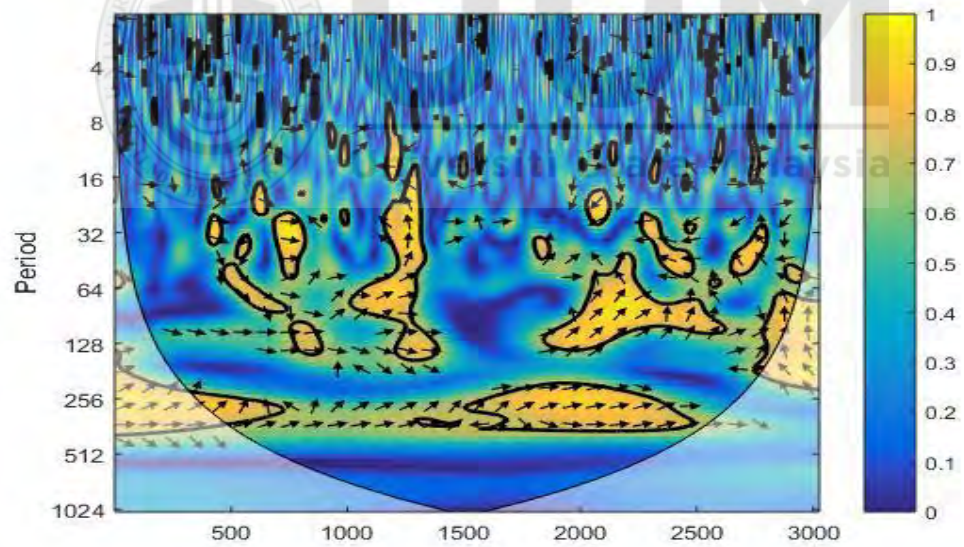
d) S&P_GB VS CRIX



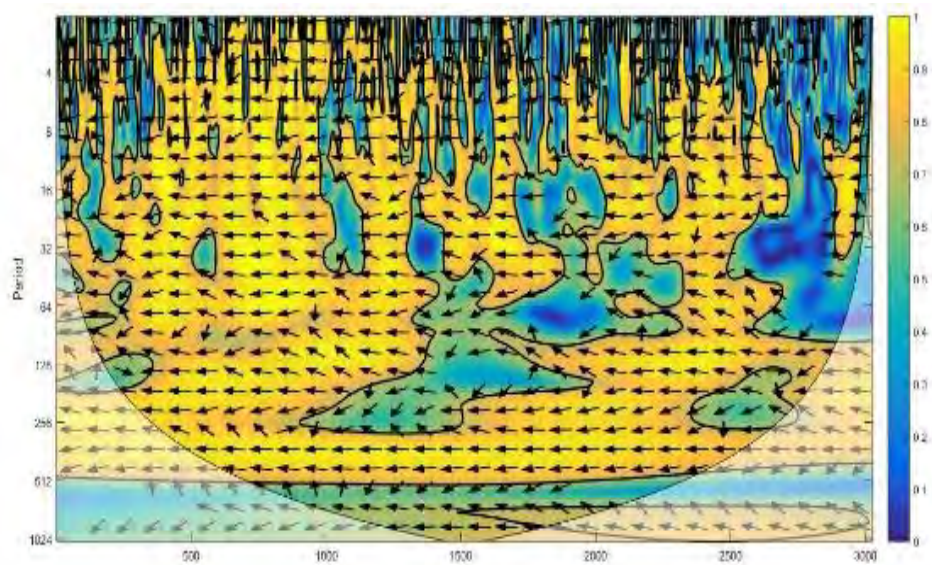
e) S&P_GB VS S&P_BD



f) S&P_GB VS DJ_SUK



g) S&P_GB VS FRX



Note: S&P_GB, S&P_500, DJ_IMWI, S&P_GSCI, CRIX, S&P_BD, DJ_SUK and FRX is the log-difference of S&P green bond index, S&P 500 index, Dow Jones Islamic market world index, S&P GSCI index, Crypto index, S&P 500 bond index, Dow Jones Sukuk index and Foreign exchange index respectively. The yellow colour shows high correlation (coherence), while the blue colour shows low correlation (coherence). While, $\nearrow$ and $\searrow$ indicate that “X market” is leading “Y market”, while $\nwarrow$ and $\swarrow$ indicate “X market” is lagging those of “Y market” respectively.

Fig 5.9 shows that there is no comovement between the S&P_GB and the S&P_500 across short investment horizons (2 to 16 days). However, from 16 to 64 days, the arrows point left up, indicating that the S&P_500 is leading the S&P GB. However, from 64 to 128 days arrows are point to right up which shows that S&P_GB is leading to S&P_500. It is most important to consider that from 256 to 1024 days there is no comovement between both financial markets, which means in very long-run investment horizons, neither S&P_GB lead to S&P_500 nor S&P_500 lead to S&P_GB.

Similar findings for S&P_GB and DJ_IMWI confirm that there is no comovement between S&P_GB and DJ_IMWI across short investment horizons (2 to 16 days). From 16 to 128 investment holding period it seems that DJ_IMWI leads to S&P_GB. It is also confirmed that in a very long-term investment holding period both markets do not comove with each other. In

the case of S&P_GB and S&P_GSCI, it again confirmed that in a short investment holding period there is no comovement between S&P_GB and S&P_GSCI. It is very clear that from 32 to 128 investment holding period S&P_GSCI leads to S&P_GB and in very long investment holding periods (256 to 1024 days) there is no comovement between both markets. However, very different findings emerge for the S&P_GB and CRIX, it is found that from 2 to 32 days there is no correlation between S&P_GB and CRIX. While from 32 to 128 days there is dominantly influence of CRIX on S&P_GB, means CRIX market leads to S&P_GB. However, after 128 days there is no comovement between aforementioned both markets.

For the case of S&P_GB and S&P_BD very mixed findings emerge. For example, in a short investment holding period, there is no comovement between S&P_GB and S&P_BD. However, from 32 to 64 days S&P_BD market leads to S&P_GB. Similar to other financial markets comovement with S&P_GB, in the long run, there is no correlation between S&P_GB and S&P_BD. During discussing comovement between S&P_GB and DJ_SUK, we observe very interesting findings that like other financial markets comovement with S&P_GB in short investment holding period both markets depicts no correlation but from 32 to 256 investment holding days S&P_GB leads to DJ_SUK markets. However, after 512 days no significant comovement exists between both markets. Finally, it is found that S&P_GB and FRX significantly comovement with each other from short to the long investment holding period.

Furthermore, it is also most important to note that throughout the investment holding periods (short to long) FRX market leads to S&P_GB. [Nguyen et al. \(2021\)](#) also find that in the short-term investment horizon green bonds market does not commove with other financial markets. They find that comovement between financial markets highly depends on maturity. The green bonds market, which was established in 2007 and has seen steady growth since then, remains small in comparison to the other bond markets that are now available ([Pham & Huynh, 2020](#)). A similar finding was reported by [Taghizadeh-Hesary and Yoshino \(2019\)](#), who found that

green bonds were essential to the achievement of sustainable development goals despite the fact that they represent only a small fraction of the global financial market currently. [Nguyen et al. \(2021\)](#) also discovered that the most dependency between green bonds and other assets is on a long-term scale instead of a short-term scale, indicating that it takes time for assets to reflect their comovement.

5.8.5. Wavelet-Based Granger Causality

Furthermore, to enrich wavelet analysis or for the robustness check of wavelet analysis, we applied wavelet-based Granger causality. Wavelet-based Granger causality test is being employed by decomposing series into different wavelet scales. It is found that in the short investment holding period both markets S&P_GB and S&P_500 does not affect each other. However, from 32 to 128 days S&P_GB Granger caused to S&P_500 significantly. However, in very long period all the proposed financial markets do not Granger cause to each other. While for the S&P_GB and DJ_IMWI it is observed that S&P_GB does not Granger cause to DJ_IMWI on any wavelet scales. However, only from 16 to 32 days DJ_IMWI Granger cause to S&P_GB. Though, on short wavelet scales or long wavelet scales, both markets do not Granger cause to each other. In a summary, it is found that S&P_GB does not Granger cause to S&P_GSCI, CRIX, S&P_BD and FRX in short investment holding period to long investment holding period. However, S&P_GSCI, CRIX, S&P_BD and FRX Granger cause to S&P_GB only from 16 to 64 days. In addition, it is also found that S&P_GB Granger causes to DJ_SUK from 16 to 128 days but DJ_SUK does not Granger cause to S&P_GB at any wavelet scales. It is also found that there is a unidirectional causality running from FRX to S&P_GB on all the wavelet scales. However, S&P_GB does not Granger cause to FRX on any wavelet scales.

Overall findings from the wavelet-based Granger causality test can be summarized that there is a unidirectional causality running from S&P_GSCI, CRIX, S&P_BD, and FRX to S&P_GB.

While there is a unidirectional causality running from S&P_GB to DJ_SUK and bidirectional causality only exists between S&P_GB and S&P_500. It is most important to note that asymmetric causality exists between proposed variables which are subject to wavelet scales. The wavelet-based Granger causality test also confirms the findings of continuous wavelet transformation.



Table 5-9: Wavelet-Based Granger Causality

	D1	D2	D3	D4	D5	D6	D7	D8
S&P_GB⇒S&P_500	0.32	0.34	0.43	0.32	0.00***	0.00***	0.53	0.08*
S&P_500⇒S&P_GB	0.75	0.52	0.03**	0.02**	0.65	0.07	0.24	0.78
S&P_GB⇒DJ_IMWI	0.65	0.59	0.11	0.23	0.45	0.12	.68	0.54
DJ_IMWI⇒S&P_GB	0.55	0.31	0.02**	0.03**	0.41	0.15	0.45	0.98
S&P_GB⇒S&P_GSCI	0.53	0.45	0.33	0.23	0.43	0.32	0.89	0.21
S&P_GSCI⇒S&P_GB	0.53	0.61	0.00***	0.00***	0.30	0.43	0.82	0.54
S&P_GB⇒CRIX	0.14	0.09	0.43	0.43	0.54	0.56	0.84	0.63
CRIX⇒S&P_GB	0.76	0.21	0.03**	0.04**	0.02**	0.04**	0.81	0.51
S&P_GB⇒ S&P_BD	0.67	0.54	0.56	0.62	0.52	0.75	0.61	0.54
S&P_BD ⇒S&P_GB	0.65	0.67	0.00***	0.00***	0.87	0.67	0.53	0.21
S&P_GB⇒ DJ_SUK	0.12	0.35	0.00***	0.00***	0.00***	0.00***	0.56	0.76
DJ_SUK⇒S&P_GB	0.32	0.34	0.20	0.18	0.95	0.78	0.87	0.65
S&P_GB⇒ FRX	0.78	0.11	0.32	0.34	0.41	0.90	0.21	0.43
FRX⇒S&P_GB	0.00***	0.00***	0.00***	0.00***	0.00***	0.00***	0.03**	0.01***

Note: ***, ** & * refers to level of significance at 1%,5%&10% respectively. While, S&P_GB, S&P_500, DJ_IMWI, S&P_GSCI , CRIX , S&P_BD, DJ_SUK and FRX is the log-difference of S&P green bond index, S&P 500 index, Dow Jones Islamic market world index, S&P GSCI index, Crypto index, S&P 500 bond index, Dow Jones Sukuk index and Foreign exchange index respectively . D1 –D8 indicates the oscillations of periods 2–4, 4–8, 8–16, 16–32, 32–64, 64–128,128-256, 256-512 (and more than 512) days.

5.9. Diebold and Yilmaz (2014) Volatility Spillovers Index

The fourth objective of the study is to find net volatility transmitters and receivers between green bonds and other financial markets. While, the fifth objective of the study is to examine whether the green bonds market can act as a diversifier, a hedge or a safe haven against other financial markets. To achieve these objectives, we use [Diebold and Yilmaz \(2014\)](#) volatility spillovers index (including static connectedness analysis, dynamic connectedness analysis, directional volatility spillovers from, directional volatility spillovers to, net total directional connectedness, net pairwise directional connectedness) and DCC-GARCH model.

To examine connectedness among the financial markets this study uses daily data from 11/28/2008 to 03/21/2021. Data for all the financial markets are gathered from various renowned sources. According to [Diebold and Yilmaz \(2009, 2012\)](#), financial market conditions change over time. Because of the high interdependence of financial markets, changes in one market have a significant impact on the performance of the other. During times of market turbulence, the spillover effects become more prominent. Due to the time-varying nature of financial markets, using a single fixed parameter model for the entire sample period is highly inappropriate.

In order to overcome this issue, we estimated the dynamic spillover effects employing 200 days rolling window samples, which we found to be accurate. It is also important to be noted that the use of a short rolling window length increases variation and produces high mean square forecast errors ([Pesaran & Timmermann, 2002](#)). The choice of length of the rolling window should be made in such a way that the increases in variance and the loss of data in the initial window are not outweighed due to the inappropriate length of rolling window selection ([Clark & West, 2007](#)). In order to ensure that we do not capture unnecessary information or lose vital information, the 200-day rolling window has been selected in order to gather enough information. It is essential to consider the direction of the spillover effect from and towards a

particular market when doing a spillover analysis. Knowing the systems through which financial markets transmit volatility to one another can be beneficial for portfolio managers, policymakers, and speculators in the development of exploitable trading techniques.

The fig 5.10 containing results of the return series for the proposed financial markets. Throughout the sample period, all of the financial series exhibit high volatility. However, volatility in all of the series continues to be quite high during the 2020 timeframe, with the CRIX series being the most unpredictable. COVID-19 is the primary cause of the excessive volatility experienced by the proposed financial markets during the 2020 timeframe. At the beginning of March 2021, the World Health Organization (WHO) recognized COVID-19 as a pandemic, which is defined as a disease outbreak that has spread over a large geographic area and is affecting a proportionally large proportion of the population. As a result, COVID-19 causes frustration among investors around the world.

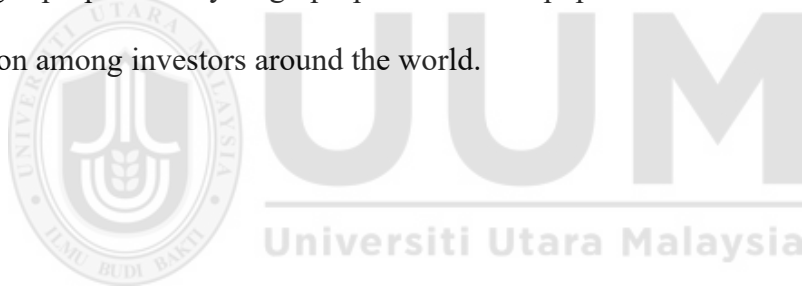
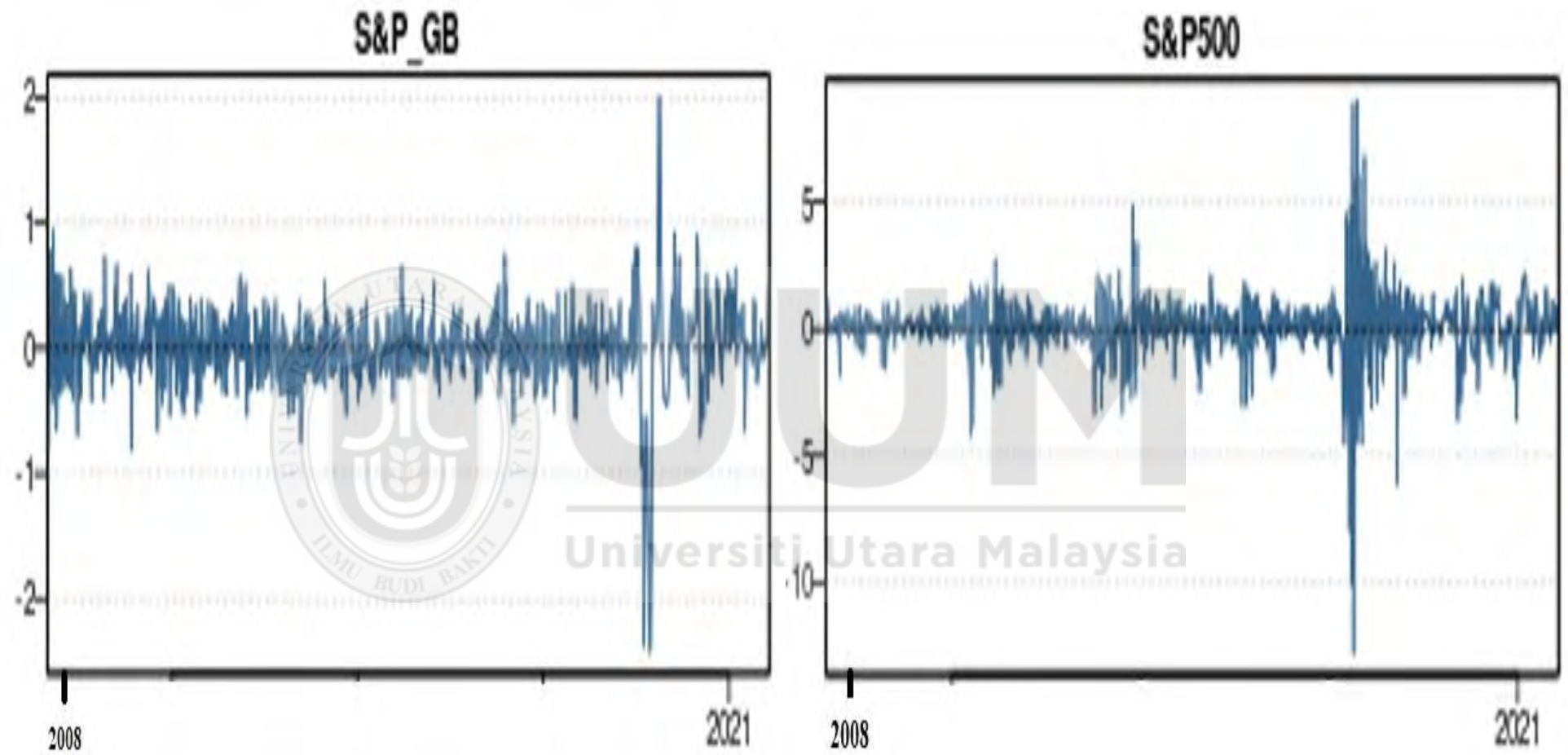
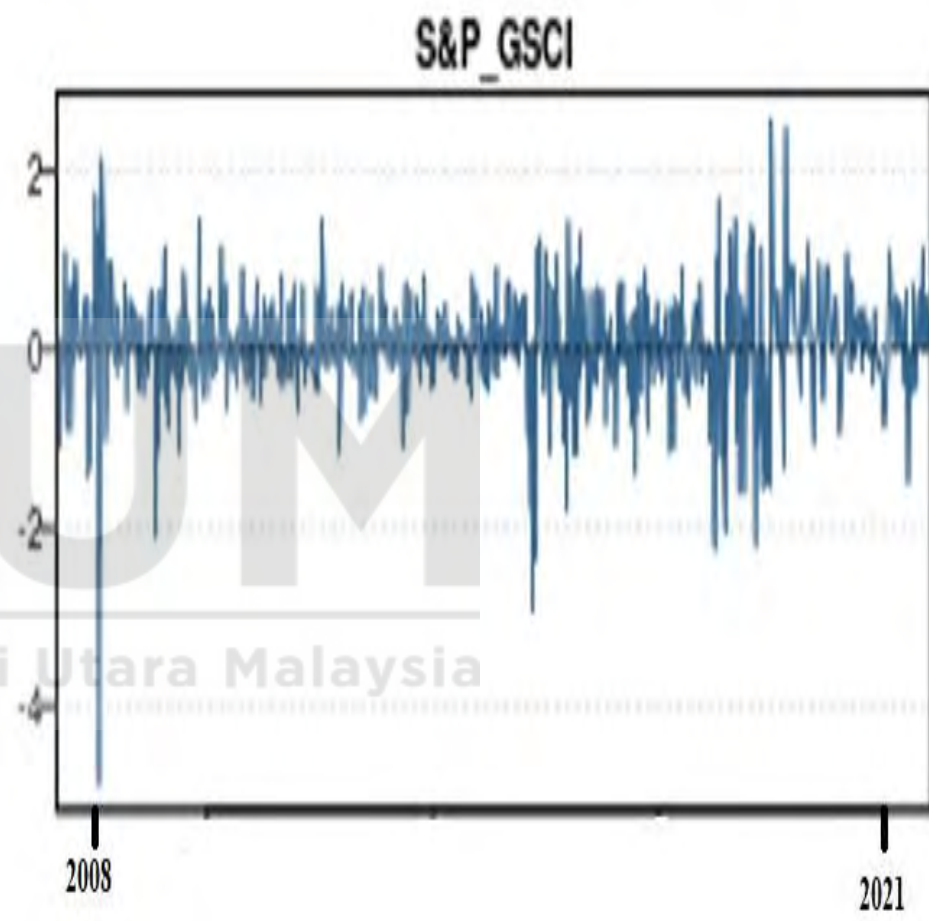
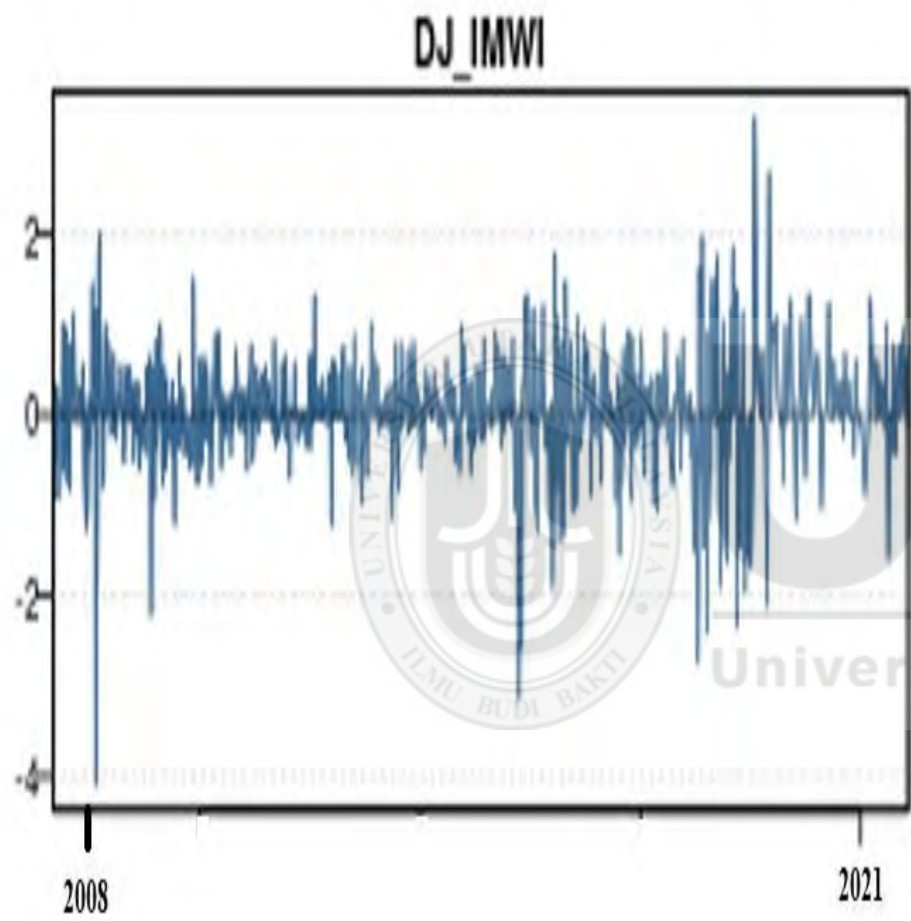
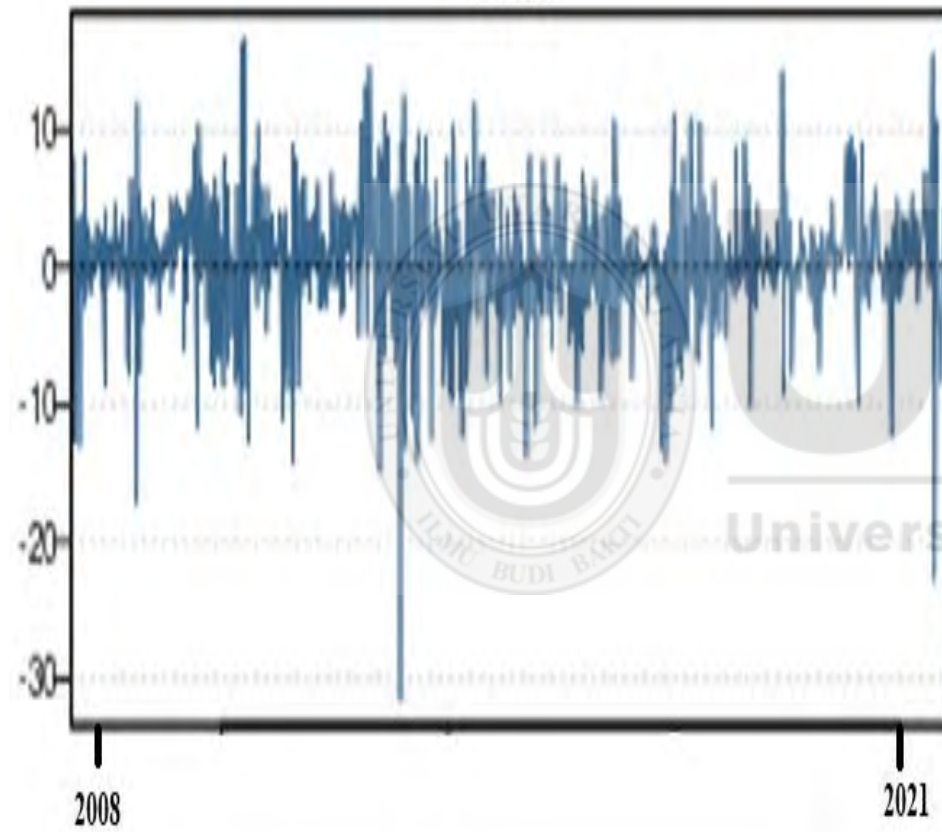


Figure 5.8: Plot of Return Series

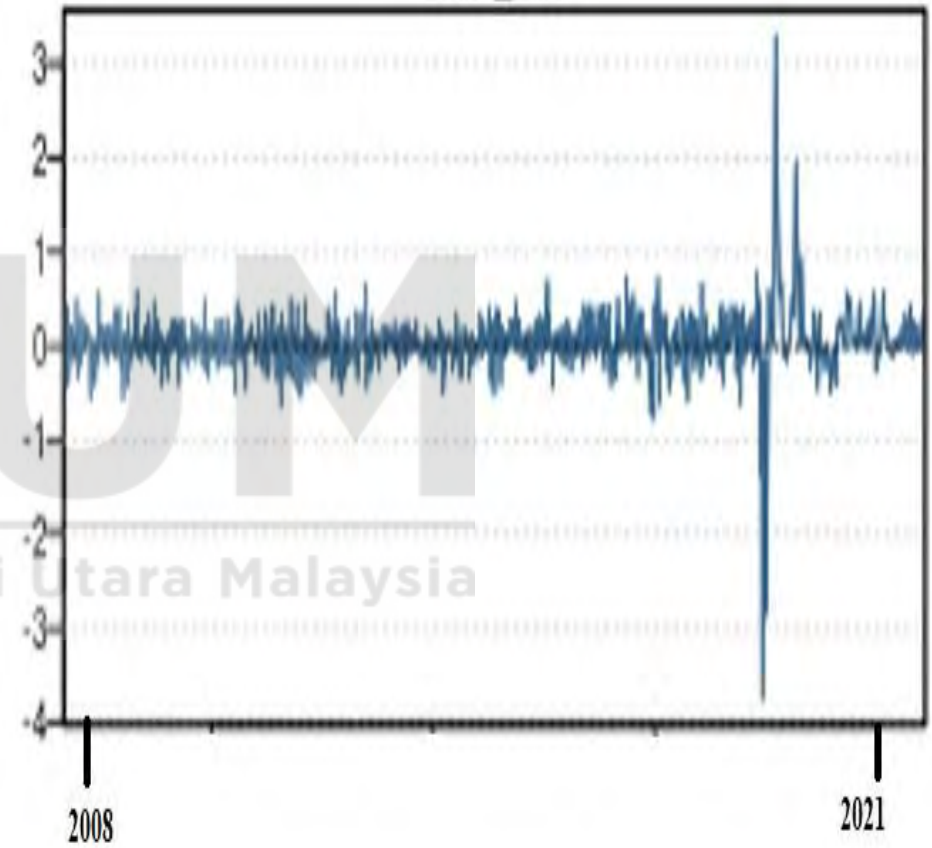




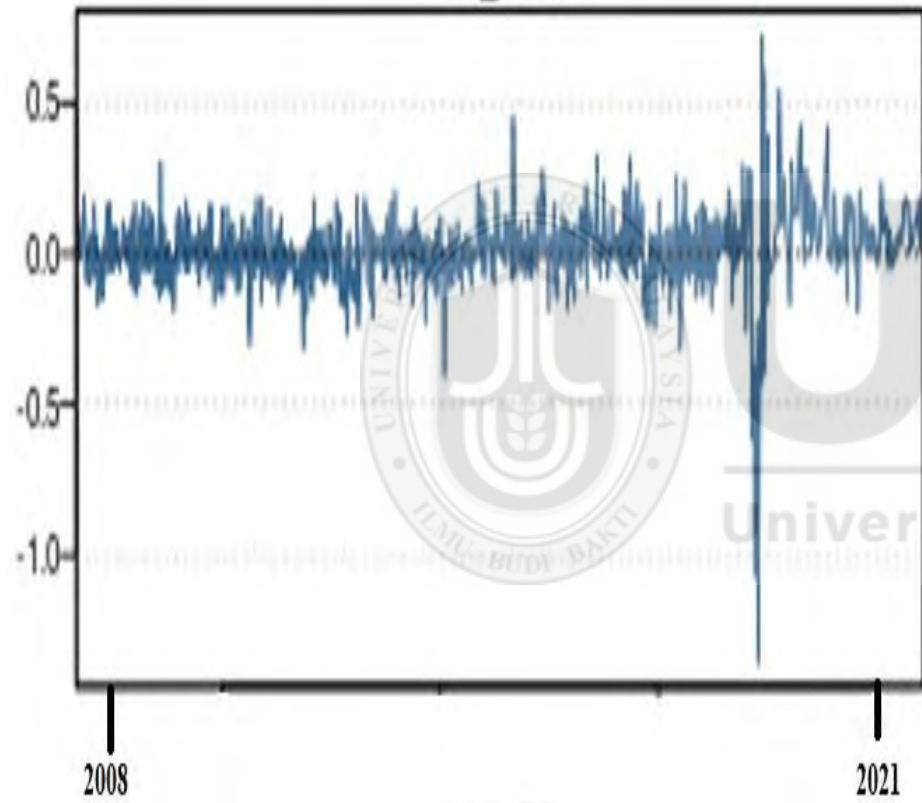
CRIX



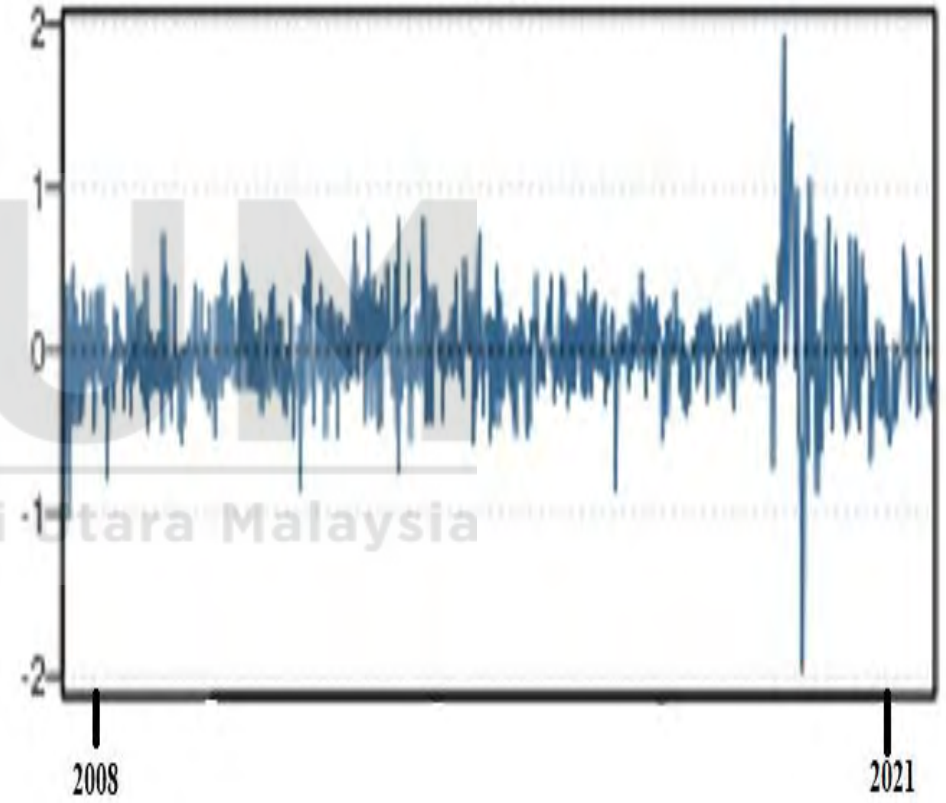
S&P_BD



DJ_SUK



FRX



5.9.1. Dynamic Connectedness Approach

5.9.1.1. Static Connectedness Analysis (SCA)

We now estimate the volatility spillover matrix among S&P_GB, S&P_500, DJ_IMWI, S&P_GSCI, CRIX, S&P_BD, DJ_SUK and FRX. Table 5.9 presents the result highlighting total volatility spillovers. The i^{th} and j^{th} entry in each panel are estimated contributions to the forecast-error variance of variable i coming from market j .

Table 5-10: Volatility Spillovers

	S&P_GB	S&P_500	DJ_IMWI	S&P_GSCI	CRIX	S&P_BD	DJ_SUK	FRX	FROM others	Net spillovers	Conclusion
S&P_GB	48.56	2.23	2.6	2.29	4.77	3.81	2.81	32.92	51.44	-7.6	net-recipient
S&P_500	3.1	80.56	4.62	2.25	2.11	2.32	2.11	2.93	19.44	-3.47	net-recipient
DJ_IMWI	2.32	2.08	8.73	75.53	3.1	1.99	4.62	1.63	91.27	-65.37	net-recipient
S&P_GSCI	2.37	2.91	3.81	78.21	3.12	2.51	5.02	2.06	21.79	74.64	net-contributor
CRIX	4.51	2.95	3.81	5.24	72.38	4.47	2.45	4.19	27.62	-5.96	net-recipient
S&P_BD	3.32	1.38	3.15	4.47	2.01	69.04	13.69	2.95	30.96	-11.99	net-recipient
DJ_SUK	3.74	1.92	4.14	3.69	3.29	1.36	76.65	5.21	23.35	9.5	net-contributor
FRX	24.49	2.51	3.76	2.95	3.27	2.51	2.14	58.36	41.64	10.24	net-contributor
TO others	43.84	15.97	25.9	96.43	21.66	18.98	32.84	51.88	307.5	TSI=38.44%	

Note: This table shows net transmitter or receiver of spillovers among S&P_GB, S&P_500, DJ_IMWI, S&P_GSCI, CRIX, S&P_BD, DJ_SUK and FRX. The positive value in net spillovers column shows net transmitter or contributors while negative value shows net receivers.

In table 5.9, the diagonal elements represent the spillovers effect occurring within the own market, while the off-diagonal components reflect the spillovers effect from price volatility occurring across the market. In table 5.9, the column (name as from) displays the total amount received from other markets to the corresponding market. The second last column represents the net spillovers (subtracting the FROM others column from the last row (name as TO others) accordingly). Those with net positive values in the second last column are considered net contributors, while those with net negative values are considered net receivers.

The findings presented in Table 5.9 shows that S&P_GSCI is the largest net transmitter of spillovers followed by FRX and DJ_SUK. While, largest net receivers of spillovers are DJ_IMWI, S&P_BD, S&P_GB, CRIX and S&P_500. [Le et al. \(2021\)](#) also find green bonds as net volatility receivers. Interestingly, the largest receivers of spillover effects from other financial markets are DJ_IMWI, S&P_GB, FRX, S&P_BD, CRIX, DJ_SUK and S&P_500 respectively. S&P_GB positively influences the price volatilities in S&P_500, S&P_GSCI, CRIX, S&P_BD, DJ_SUK and FRX markets. The findings confirm that S&P_GB does not receive price volatility/volatility from any proposed financial market. Moreover, findings show that the spillover index (TSI) reaches 38.44% indicating a sizable degree of connectedness among the S&P_GB, S&P_500, DJ_IMWI, S&P_GSCI, CRIX, S&P_BD, DJ_SUK and FRX during the sample period. Furthermore, we discovered that own market spillovers accounted for the highest proportion of forecast error variance, owing to the fact that the diagonal elements got larger values when compared to the non-diagonal elements.

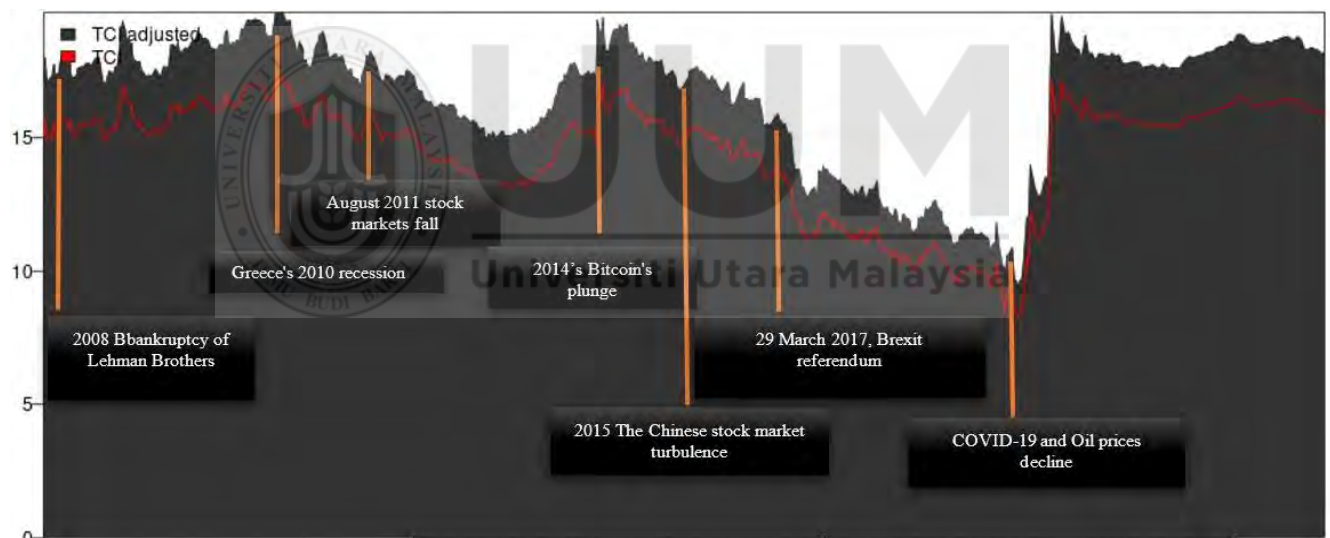
This result indicates that these financial markets are linked with each other, hence, connectedness is important for the policy makers and investors. Whether the major economies of the world are in expansion or recession, the green bonds and other selected markets tend to move in sync as they become more integrated. In other words, the more likely it is that positive

or negative return shocks will spread to other markets, the more the green bonds and other markets are integrated.

5.9.1.2. Dynamic-Connectedness Analysis

We have reported results of net connectedness between green bonds and other financial markets in table 5.9, however, these results do not account for the time-varying spillovers effect. Hence, to accommodate time-varying connectedness between green bonds and other financial markets we estimated dynamic volatility spillovers using 200-day rolling window samples. The fig 5.11 shows the time evolution of the total connectedness between green bonds and other financial markets over the sample period.

Figure 5.9: Dynamic Total Connectedness (DTC)



Note: The dynamic total connectedness index across green bonds and other financial markets is based on generalized variance decomposition associated with a VAR of order 2 with a 12-step ahead forecast horizon and a 200-day rolling window.

From a bird's-eye perspective, the total connectedness plot in Fig 5.11 has some revealing patterns, a large variation in this index (DTC) during the full sample period. The first such period is the global financial crisis, which was accompanied by many spectacular events, e.g. the bankruptcy of Lehman Brothers in August 2008. It lasted until the first half of 2009 when the global financial crisis deepened. It seems that the linkages between the analyzed financial

markets increased during the crisis, which is a characteristic phenomenon in times of turmoil. A similar effect was triggered in the summer of 2011 when there were drops in the stock exchanges across the United States, Europe and Asia due to the European sovereign debt crisis and concerns over the downgraded credit rating of the United States.

At the end of 2014, there was an interesting period of a huge fall in the Bitcoin prices and the connectedness index reach 20% from 15%, the highest level of DTC. Bitcoin experienced a meteoric rise in 2013, rising to about \$1,000 per coin as the year came to a close and raising excitement among fans about where the cryptocurrency would go in 2014? However, this year proved to be the worst year for the investment, with Bitcoin falling to \$300 by the end of December. Bitcoin's credibility took some serious hits as unregulated exchanges unravelled. The collapse of Mt. Gox, the Tokyo-based exchange that handled up to 70% of all Bitcoin trade in 2013, was perhaps the most serious threat to the cryptocurrency this year.

Another spectacular event that affected the level of the index was the referendum regarding the UK's exit from the European Union. The substantial shift in DTC demonstrates the high level of interconnectedness of these markets (green bonds and other financial markets), as well as the fact that the uncertainty surrounding the referendum result influenced all proposed markets.

It is most interesting to note, that around the beginning of 2019 the DTC index was reached 9% that shows a decrease in financial markets connectedness. However, around the mid or end of 2019 DTC index reached at 20% highest level, which shows high integration among the proposed financial markets. However, during the COVID-19 pandemic outbreak in the first quarter of 2020, overall connectedness reached new highs, with a level close to 22%.

These findings are confirmed by [Zhan et al. \(2020\)](#) and [Cepoi \(2020\)](#), who reported that financial markets dependence grew dramatically with the beginning of the health crisis. This outcome was not unexpected in the sense that it is generally known that the financial markets

are interconnected and interdependent on one another ([Morales & Andreosso-O'Callaghan, 2012](#)) and that crises enhance the interconnectedness of the global financial market ([Jondeau & Rockinger, 2006](#); [Mokni & Mansouri, 2017](#)). This outcome may be explained by the coronavirus pandemic and its fast-worldwide spread, which both slowed economic growth and induced unfavorable changes in investor sentiment, which had a significant impact on their investment decisions and, as a result, caused stock market price declines.

Similarly, [Wen et al. \(2019\)](#) found that investor attention negatively predicted future stock prices' crash risk. Investors throughout the world become more pessimistic about future returns as a result of such external and unanticipated shocks, and they subsequently prefer to take less risks. According to [Bai \(2014\)](#) and [Baker, Bloom, Davis, Kost, et al. \(2020\)](#), when an infectious illness epidemic occurs, investors may become pessimistic about the investment prospects in a particular market, resulting in the selling of that market's stocks.

Based on the results of this dynamic connectedness, it can be concluded that static TSI may conceal particular periods (e.g., economic, financial or political events etc.) which are likely to have differential effects on its interconnectedness. As a result, the time-varying behaviour of connectedness must be considered when evaluating the process of transmission spillovers among financial markets, in order to fully understand the characteristics of these spillovers, especially during critical times.

5.9.1.3. Directional Volatility Spillovers, FROM

Despite the fact that the total volatility spillovers index and its evolution are essential, however, it does not take into account directional information. To gain a better understanding of the interdependence between green bonds and other financial markets, it would be informative to continue with our analysis and concentrate on “directional connectedness,” which can be decomposed into “directional connectedness FROM others” (see Table 5.9 for its average

value) and “directional connectedness TO others” (see, Table 5.9 for its average value). Fig 5.12 and 5.13, respectively, depict a time-varying pattern of directional connectedness either FROM or TO others. Specifically, Fig 5.12 shows the directional volatility spillovers from each of the proposed markets to others (corresponding to the "Contribution to others" row in Table 5.9), whereas Figure 5.13 shows the directional volatility spillovers from other markets to each of the proposed markets (corresponding to the "Contribution from others" column in Table 5.9).

In accordance with these two figures 5.12 and 5.13, the directional connectedness from or to each financial market ranges between 5 and 98 percent. They change dramatically over time. Spillovers from each market are less than 60% during normal periods, but during volatile periods, directional spillovers reach around 98 percent. Among all proposed financial markets, gross volatility spillovers from the S&P_GSCI and S&P_500 to others are in general smaller than the spillovers from the other markets. However, spillovers from DJ_IMWI and S&P_GB is the largest to others.

5.9.1.4. Directional Volatility Spillovers, TO

In figure 5.13, we present directional volatility spillovers from others to each of the proposed financial markets (corresponds to the “directional from others” column in table 5.9). As with the directional spillovers to others, the spillovers from others vary noticeably over time. The relative variation pattern, however, is reversed, with directional volatility spillovers to S&P_500, S&P_GB and DJ_SUK increasing relatively more in turbulent times.

5.9.1.5. Net Total Directional Connectedness

It may also be of interest to determine who are the net recipients and who are the net contributors to the spillovers between the green bonds and other financial markets. The fig 5.14 shows net total volatility spillovers for each financial market. Net total volatility spillovers are

computed as the difference between spillover transmission and reception. The positive (negative) values at time t correspond to a net transmitter (receiver). It has been discovered that the pattern of volatility spillovers changes over time. For investors, it is important to study the connectedness of financial markets since it aids in portfolio diversification decision making. There are numerous studies that have explored connectedness between financial assets, and these studies have found that the degree of correlation or connectedness between these financial assets is dependent on financial crises, for example, the global financial crisis of 2008, the European debt crisis ([Mokni & Mansouri, 2017](#)), and the COVID-19 pandemic ([Azimli, 2020](#); [Cepoi, 2020](#); [Sharif et al., 2020](#); [Topcu & Gulal, 2020](#)).

The Fig 5.14 shows that S&P_GB is the net receiver of spillovers in the initial time period of the study. However, the pattern of connectedness does not remain the same but vary over time. Later in 2010 which is Greece recession-era S&P_GB act as a net transmitter of spillovers. However, from 2010 to 2019 S&P_GB acts as a net receiver of volatility spillovers but it is most important to note that as COVID-19 declares as a global pandemic, S&P_GB again act as a net transmitter of spillovers. The overall findings show that during the uncertainty or turbulence period S&P_GB acts as net transmitter of spillovers and one can see S&P_GB as a safe haven asset.

While focusing on S&P_GSCI, it is observed that S&P_GSCI is a net transmitter of spillovers throughout the sample of the study. However, it is also important to mention here that during the turbulence periods, the intensity of net connectedness of S&P_GSCI increases. In the DJ_SUK case, it is observed that overall DJ_SUK is a net transmitter of spillovers, however, sometimes it becomes the net receiver of spillovers. For example, at the beginning of the sample period (2008 and 2010) of the study DJ_SUK act as the net receiver of spillovers while the rest of the period of the sample acts as a net transmitter of spillovers. Let consider S&P_500, it is found that overall, it acts as a net receiver of spillovers, however during 2013 and 2015 it

acts as net volatility spillovers. In the case of CRIX, we find that during high financial crunch or turbulence CRIX act as a net transmitter of volatility and in the normal periods it acts as a net receiver of spillovers.

Considering FRX, it is found that it acts as a net transmitter of volatility throughout the sample period. It is important to note that DJ_IMWI acts as a net receiver of spillovers throughout the sample period. Finally, S&P_BD act as a net transmitter of spillovers during the financial crisis or turbulence period, while in the rest of the period (sample period) it acts as a net receiver of spillovers.

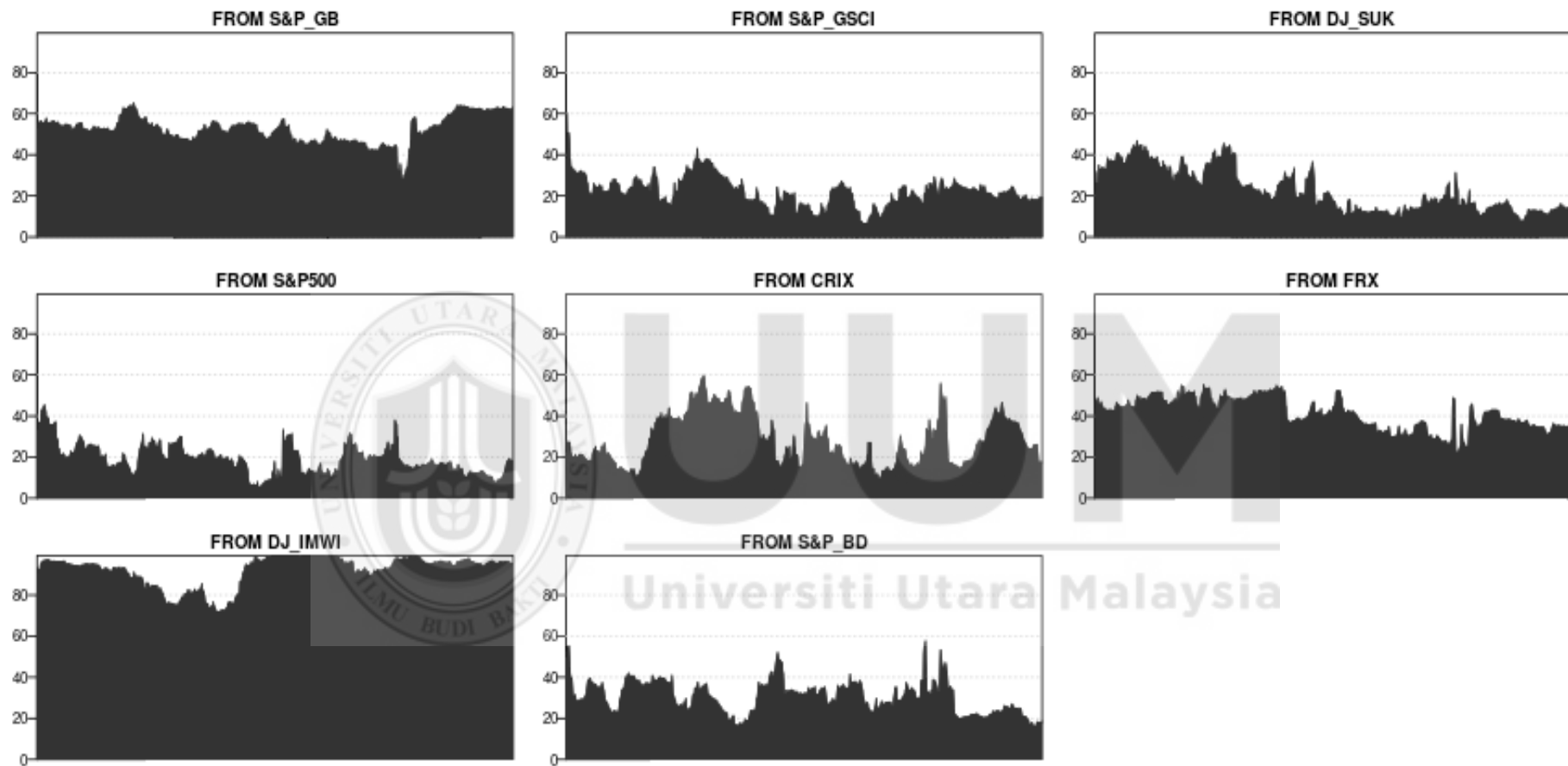
When we compared the dynamic spillovers findings, we discovered that all of the financial markets (with the exception of DJ_IMWI) transmitted net spillovers during the COVID-19 epidemic than they received. One probable reason is that the widespread announcement of the pandemic may have influenced the way market players assessed risk, leading them to anticipate high levels of adverse shock transmission. Because of this, investors are less confident in their ability to foresee risks during periods of market stress, which in turn enhances the spillovers from the bad news shocks ([Yousaf et al., 2021](#)).

Our findings provide policy implications for regulators, investors, and other market participants who should monitor how these financial markets shocks affect other selected financial markets. The findings confirm that S&P_GSCI, DJ_SUK, FRX become the main net transmitters, as a result of the volatility (risk) spillover analysis, we see S&P_GSCI, DJ_SUK, FRX as a safe haven asset. Simply, assets or financial markets that transmit positive high volatility spillovers to and from others are regarded as the best choice for portfolio diversification because these markets can improve the portfolio's risk-adjusted return. Similarly, assets or financial markets that experience negative high volatility spillovers to and from others should be excluded from the portfolio because these markets or assets can improve

returns and reduce portfolio risk ([Qarni & Gulzar, 2021](#)). Portfolio managers, individual investors, and speculators can use the findings or information to reduce portfolio risk by including S&P_GSCI, DJ_SUK, and FRX in their portfolios.

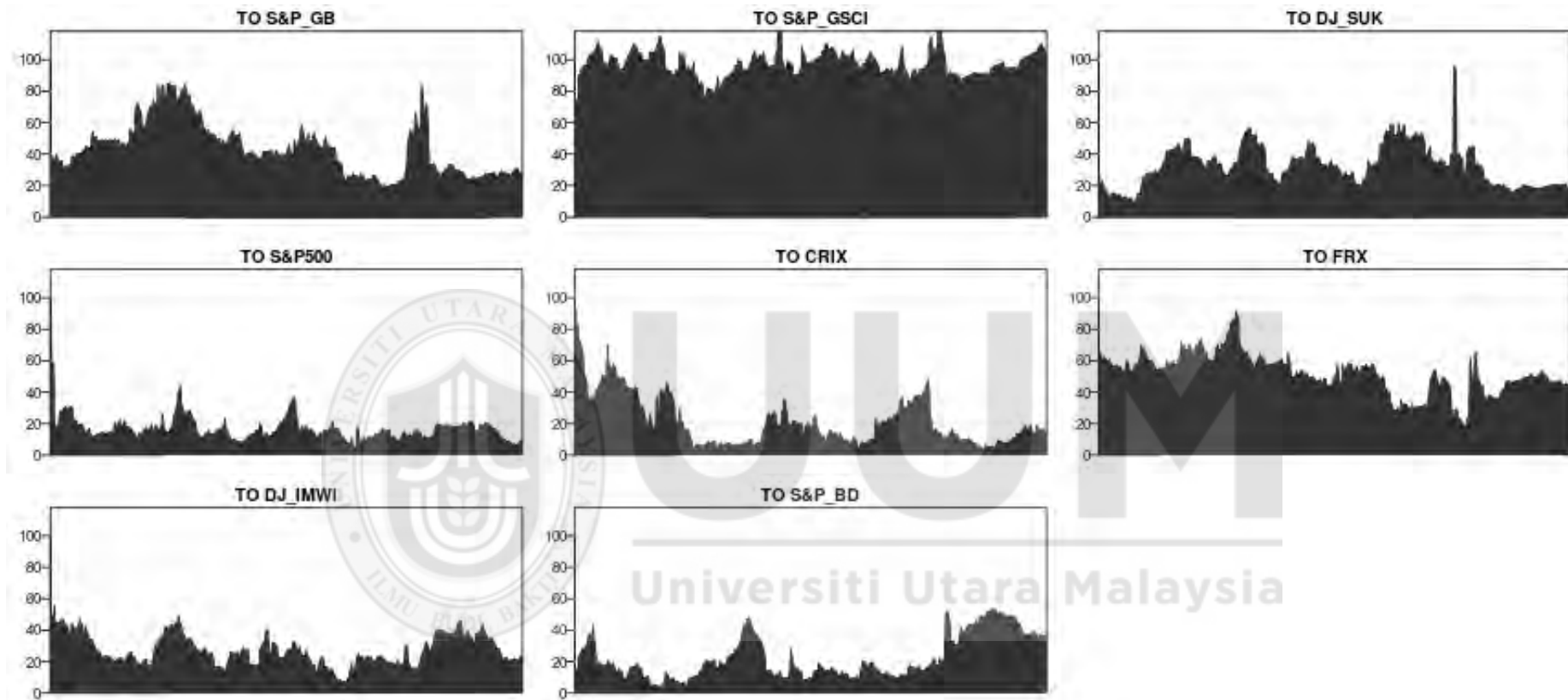


Figure 5.10: Directional Volatility Spillovers FROM



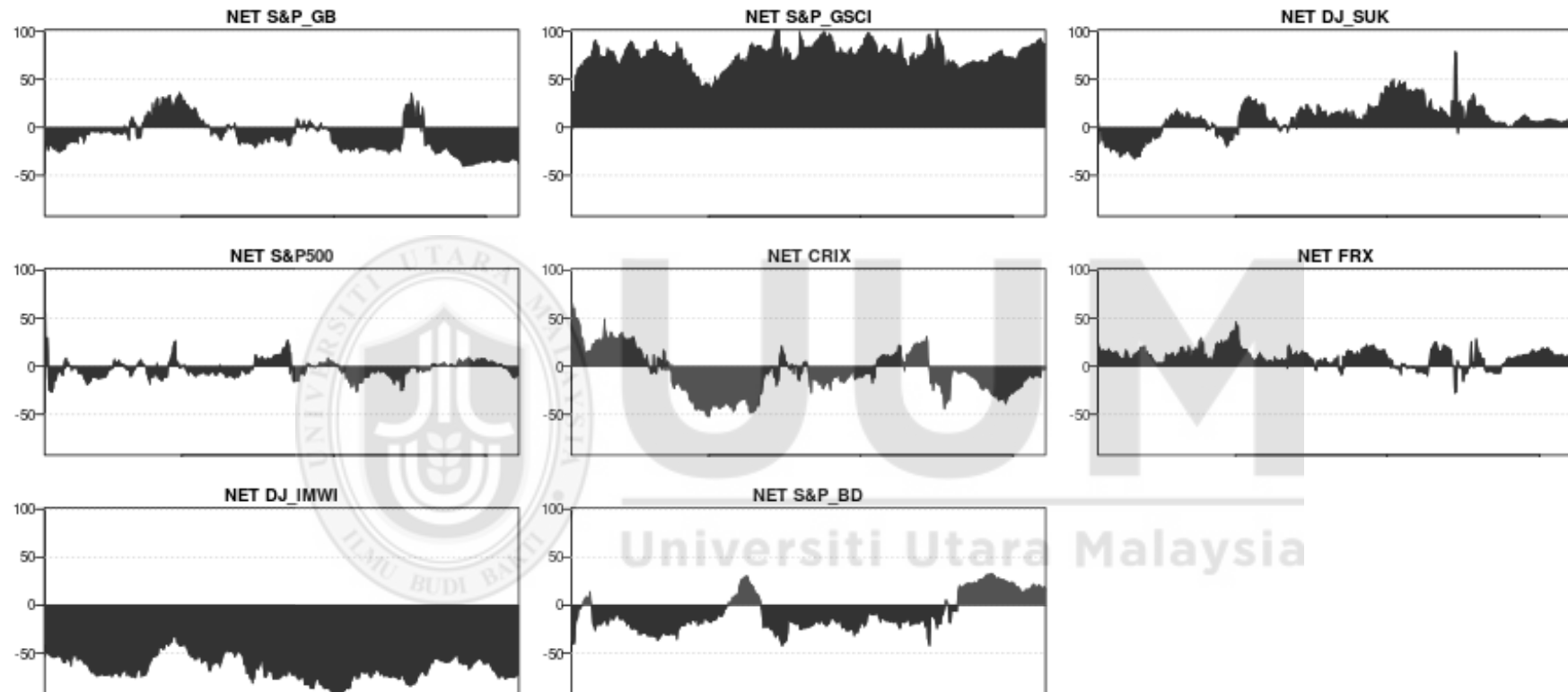
Note: Fig 5.12 depict a time-varying pattern of directional connectedness FROM others (see table 5.9 for its average value)

Figure 5.11: Directional Volatility Spillovers, TO



Note: Fig 5.13 depict a time-varying pattern of directional connectedness TO others (see table 5.9 for its average value)

Figure 5.12: Net Total Directional Connectedness



Note: Net directional spillovers Indexes are the differential between the volatility transmitted from one market to the system and the volatility received by that market from the system. As a result, when the index is positive, the market acts as a net transmitter of volatility, but when the index is negative, the market acts as a net recipient of volatility.

5.9.1.6. Net Pairwise Directional Connectedness

We now turn our attention to net pairwise directional connectedness obtained from the 200-days rolling window estimation presented in Fig 5.15, which bring further insights into the transmission process of financial market returns shocks across sample financial markets. The positive connectedness of the index shows that the first market is a net transmitter of spillovers and the negative connectedness of the index shows that second market is a net transmitter of spillovers. The Fig 5.15 shows that S&P_500 does not act as a net transmitter of spillovers to S&P_GB. However, it can be observed that S&P_GB act as a net transmitter of spillovers from 2015 to 2017. While for the rest of the period, there is no clue who transmit to whom for the rest of the sample period because there is no change in the index nor positive nor negative. In the case of S&P_GB- DJ_IMWI, one can find similar findings as for S&P_GB- S&P_500.

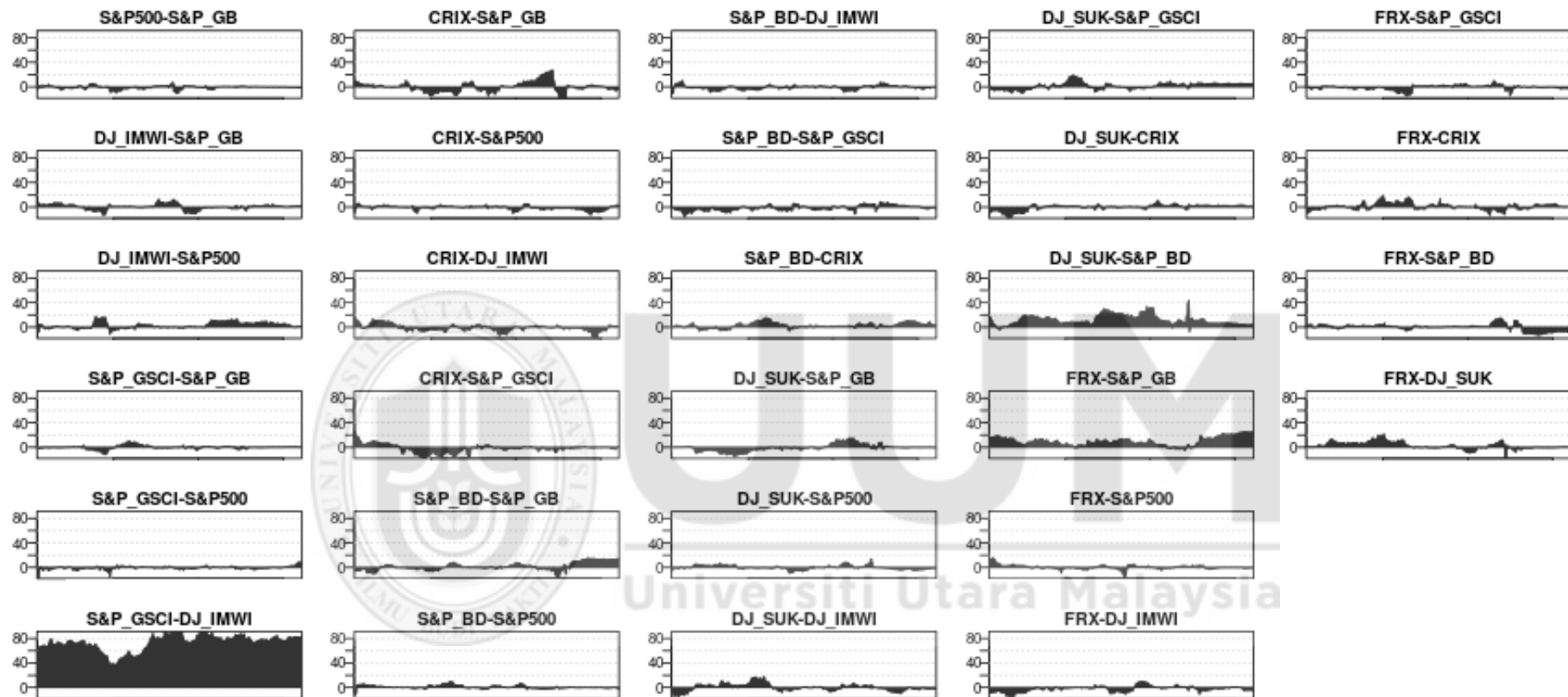
Moreover, we find some interesting findings for S&P_GB and S&P_GSCI. It is observed that from 2008 to 2010 it is difficult to find that S&P_GB transmit volatility shock to S&P_GSCI or S&P_GSCI to S&P_GB. However, around 2012 S&P_GB transmit net volatility spillovers to S&P_GSCI and around 2014 S&P_GSCI transmit net volatility spillovers to S&P_GB. While for the rest of the period, there is no clue who transmit to whom for the rest of the sample period because there is no change in the index nor positive nor negative. For the S&P_GB - CRIX, it is observed that initially, there is no clue who transmit to whom for the rest of the sample period because there is no change in the index nor positive nor negative. While during 2015 to 2017 S&P_GB transmit net volatility spillovers to CRIX but during 2018 CRIX transmit net volatility spillovers to S&P_GB. However, during 2019 S&P_GB transmit net volatility spillovers to CRIX and for the rest of the period, there is no clue who transmit to whom for the rest of the sample period because there is no change in the index nor positive nor negative.

For the S&P_GB and S&P_BD, it is found that initially S&P_BD transmit net volatility spillovers to S&P_GB. While during 2014 it can be seen that S&P_GB transmit net volatility spillovers to S&P_BD, however during 2019 S&P_GB transmit the volatility spillovers to S&P_BD and for the rest time of the period S&P_BD transmit volatility spillovers to S&P_GB. For the S&P_GB and DJ_SUK, it can be seen that in the initial period S&P_GB transmit the volatility while in the later period DJ_SUK transmit volatility spillovers to S&P_GB.

Finally, the most interesting findings emerge from S&P_GB and FRX, it can be seen that throughout the period FRX transmit volatility spillovers to S&P_GB. The findings that emerged from pairwise net volatility spillovers confirm that the pattern of volatility spillovers transmission varies over time hence we find an asymmetric pattern of volatility spillovers between pairs of markets. However, in most of the financial markets pairs, it is found that during the COVID-19 pandemic S&P_GB transmit volatility spillovers to other pairs of markets.

Overall findings show that during high uncertainty green bonds market transmit volatility spillovers to other selected markets. It is because, it is a fixed income asset, during high uncertainty investors sell their high volatile assets and purchase green bonds to save their investment and reduce portfolio risk ([Hamlin, 2021](#); [Naeem et al., 2021](#)).

Figure 5.13: Net Pairwise Directional Connectedness



Note: Pairwise spillovers indexes are the difference between the volatility transmitted from one market to another and the volatility received by that one market from the other. Hence when the index is positive the first market transmits more volatility to the second, whereas it is negative, the second markets send more volatility to the first one.

5.10. Dynamic Conditional Correlation GARCH Model (DCC-GARCH)

Based on AIC and BIC, we find the DCC (1,1)-GARCH (1,1) model estimated with t-distribution is the best fit with our sample and can capture the fat-tailed behaviour of the return distributions found in our sample.

5.10.1. Diversifier, Hedge and Safe-Haven Capabilities of Green Bond

We derived pairwise dynamic conditional correlations from Eq. (4.55) into separate time series and then used them to find green bonds' capabilities as diversifiers, hedges, or safe-haven following the estimation of the DCC-GARCH model. For example, the series of the DCC between green bonds and the S&P_500²⁰ is regressed on a constant (C_0) and three dummy variables (C_1, C_2, C_3) representing extreme movements in S&P_500 in the negative 10th, 5th and 1st quantiles of the return distribution. In table 5.10 the dynamic conditional correlation (DCC) of green bonds with other financial markets is estimated. A green bond is a diversifier against movements in the other asset if (C_0) is significantly positive. A green bond is a weak hedge against movements in the other asset if (C_0) is zero, or it is a strong hedge if (C_0) is negative. A green bond is a weak safe haven against movements in the other asset if the C_1, C_2 and C_3 coefficients are not significantly different from zero, or it is a strong safe haven if these coefficients are negative.

Table 5.10 indicates that green bonds cannot be regarded as a hedge against DJ_IMWI, because (C_0) is positive and significant. This implies that Green bond is only an effective diversifier for investors. Interestingly, we find that green bonds act as a strong hedge for investors against S&P_500, S&P_GSCI, CRIX, S&P_BD, DJ_SUK and FRX, because (C_0) is a significant negative. As such, it could be beneficial for investors to include green bonds in their portfolios for hedging purposes.

²⁰ Same for other selected financial markets (DJ_IMWI, S&P_GSCI, CRIX, S&P_BD, DJ_SUK and FRX)

As for the safe-haven capability of the green bond, it is found that the green bond act as a safe haven for S&P_500, DJ_IMWI, S&P_GSCI, CRIX, S&P_BD, DJ_SUK and FRX at 1% quantiles. It implies that, in times of extreme market turmoil and uncertainty, investors sell S&P_500, DJ_IMWI, S&P_GSCI, CRIX, S&P_BD, DJ_SUK and FRX and buy green bonds. The findings of the study are aligned with [\(Hamlin,2021\)](#). The findings confirm that during the COVID-19 pandemic, green bonds performed better than gold as a safe haven against various financial markets. As low volatility assets, green bonds are a fixed income asset class that reduces portfolio volatility. As a result, during periods of high uncertainty, investors sell highly volatile assets and buy green bonds to reduce portfolio risk.

Table 5-11: Diversifier, Hedge or Safe Haven Capabilities of green Bonds (S&P_GB)

	10% quantile (C1)	5% quantile (C2)	1% quantile (C3)	Hedge (C0)
S&P_500	-0.1308**	-0.125***	-0.017***	-0.021**
DJ_IMWI	-0.734**	-0.081***	-0.026***	0.022**
S&P_GSCI	-0.028***	-0.075***	-0.026***	-0.015***
CRIX	-0.184**	-0.029***	-0.017***	-0.143***
S&P_BD	-0.385**	-.007***	-0.005***	-0.049***
DJ_SUK	-0.635***	-0.035***	-0.396***	-0.021**
FRX	-0.208***	-0.125***	-0.017**	-0.541**

Note: This table presents estimated results on diversifier, hedge or safe-haven capabilities of green bond based on DCC-GARCH model. ***, **&*** denotes to level of significance at 1%, 5% and 10% respectively.

CHAPTER 6: CONCLUSION AND POLICY IMPLICATIONS

6.1. Introduction

This final chapter summarizes the primary findings of the study (conclusions), policy implications derived from the empirical findings, limitations, and future recommendations. This chapter is structured as follows. We begin by providing a brief overview of our main findings. Following that, we address policies from various perspectives based on our empirical findings. Finally, we discuss limitations and future research recommendations.

6.2. General Review of Findings

The primary issues addressed in this dissertation are the interactions between green bonds and other financial markets. More specifically, this dissertation examines these five issues (1) to examine dependency between green bonds and other financial markets under bearish, normal and bullish market states; (2) to examine whether COVID-19 changes correlation between green bonds and other financial markets; (3) to explore the dependency between green bonds and other financial markets across various investment horizons; (4) to find net volatility transmitter and receiver between green bonds and other financial markets and (5) to examining either green bonds market can act as a diversifier, a hedge or a safe haven against other financial markets. We use advanced econometrics models to test above mentioned issues using daily data from 11/28/2008 to 03/21/2021.

The first objective of the study is to examine the dependency between green bonds and other financial markets under bearish, normal and bullish market states. Therefore, to achieve this objective we employed quantile analysis (including quantile cointegration (QR), quantile on quantile regression (QQR) and quantile Granger-causality).

- The results based on quantiles cointegration suggest that S&P_GB has cointegration with other financial markets (S&P_500, DJ_IMWI, S&P_BD, DJ_SUK, and FRX) at low to medium quantiles, with the exception of S&P_GSCI.

- The findings demonstrate the existence of cointegration between S&P_GB and S&P_GSCI at low quantiles but the absence of cointegration at high quantiles. Overall findings show asymmetric cointegration between proposed financial markets.

Moreover, to examine quantiles dependency or entire dependency between green bonds and other financial markets before COVID-19 we applied QQR analysis. The QQR findings confirm an asymmetric relationship between proposed financial markets.

- Based on QQR findings it is confirmed that overall a negative relationship between S&P_GB and S&P_500 exists; however, this relationship does not remain the same but changes depending on market conditions (normal, bearish or bullish).
- When we analyzed comovement or correlation between S&P_GB and DJ_IMWI, it is confirmed that at the low quantiles (bearish markets state) a positive correlation exists between both financial markets. While in the normal and bullish market state both markets have a negative correlation.
- For the case of S&P_GB and S&P_GSCI, we find that in bearish market states both markets positively correlate with each other. While in normal and bullish market states both markets negatively correlate with each other.
- We also find asymmetric findings for S&P_GB and CRIX. It is found that in bearish and normal market states S&P_GB and CRIX both markets negatively correlate with each other. However, in a bullish market state, S&P_GB and CRIX positively correlate.
- The QQR analysis shows that when both S&P_GB and S&P_BD are in a bullish state have a strong positive correlation.
- For S&P_GB and DJ_SUK we find overall a weak positive correlation between S&P_GB and DJ_SUK.

- Finally, there is a strong negative correlation between S&P_GB and FRX (bearish, bullish, normal).

The second objective of the study is to examine whether COVID-19 changes correlation between green bonds and other financial markets. To achieve this objective, we applied quantile on quantile (QQR) analysis during the COVID-19.

- The findings during COVID-19 show that S&P_GB has a negative correlation with all of the proposed financial markets (S&P_500, DJ_IMWI, S&P_GSCI, CRIX, S&P_BD, DJ_SUK, and FRX).

The third objective of the study is to examine the lead-lag relationship between green bonds and other financial markets at different investment horizons. To achieve this objective of the study we applied continuous wavelet transformation (CWT).

- The findings based on continuous wavelet transformation confirm that coherence between green bonds and other financial markets is more evident up to the middle of the time frame of the study.

The fourth objective of the study is to examine who is the net volatility transmitter and receiver between S&P_GB, and other financial markets (including, S&P_500, DJ_IMWI, S&P_GSCI, CRIX, S&P_BD, DJ_SUK and FRX). While the fifth objective of the study is to find either the green bonds market can act as a diversifier, a hedge or a safe haven against other financial markets. To achieve these objectives, we applied [Diebold and Yilmaz \(2014\)](#) volatility spillovers index (including static connectedness analysis, dynamic connectedness analysis, directional volatility spillovers from, directional volatility spillovers to, net total directional connectedness, net pairwise directional connectedness) and the DCC-GARCH model.

- The findings based on volatility spillovers shows that S&P_GSCI is the largest net transmitter of spillover followed by FRX and DJ_SUK.
- While, largest net receivers of spillovers are DJ_IMWI, S&P_BD, S&P_GB, CRIX and S&P_500.
- In most of the financial market's pairs, it is found that during the COVID-19 pandemic S&P_GB transmit volatility spillovers to other pairs of markets.
- As for the safe-haven capability of the green bond, it is found that the green bond act as a safe haven for S&P_500, DJ_IMWI, S&P_GSCI, CRIX, S&P_BD, DJ_SUK and FRX.

6.3. Policy Implications

Because of the global pandemic crisis, the financial markets across the world are suffering historic downturns, prompting investors to seek alternative investments that offer diversification and hedging possibilities. Besides, governments across the globe are adopting stimulus packages to reboot their economies, which raises concern about the transition to a low-carbon economy. It has been discovered that during times of high uncertainty, investors in conventional assets and policymakers motivate green financial instruments due to their hedging and safe haven capabilities. Therefore, in the context of the pandemic crisis, this study investigates the possibility for diversification and hedging of green bonds investments in comparison with conventional financial assets (including stock, commodity, digital currency, bonds and foreign exchange markets).

Green bonds showed resilience throughout the epidemic, suggesting that they might be used to reboot the world economy. Hence, this financial instrument is one of the finest alternatives for achieving a low-carbon economy, and governments all over the world can reallocate financial resources to assist the green economy. The current study has some theoretical implications, such as the fact that some newly emerging financial asset classes,

such as green bonds and digital currency, have different fundamentals than traditional financial markets, and these financial markets have nonlinear properties. The current study's findings also have policy implications for governments, green bond issuers, investors, portfolio managers, and society.

6.3.1. Implications for Policy Makers

- The findings (objective 1 and 5) of the current research clearly show the hedging and safe-haven nature of the green bonds market against proposed other financial markets, particularly during the financial turbulences (such as COVID-19). Therefore, in terms of policymakers, having a bigger proportion of green bonds will unquestionably assist the transformation to a low carbon economy, keeping the promise of the Paris climate change agreement.
- The findings (objective 3) based on wavelet correlation and continuous wavelet transformation confirm that the coherence of each pair is more evident up to the middle of the time frame of the study. From the regulators and governments perspective, this result gives new evidence to see why the correlation and coherence are more vivid in the midterm investment horizon instead of the short and long-term investment horizon. The possible reason for this might be due to the inefficient for the taking prompt decision for the short-term period. Additionally, the dynamics and uncertainty of the market may make the long-term policy ineffective. That's why the policymakers should closely monitor the implementation of the policy through the regulatory body and vigilance team. Additionally, policymakers should take more comprehensive policies with considering more issues such as the geopolitical uncertainties and international trade policies. Finally, policymakers and investors should consider the greatest uncertainty of all time due to the COVID 19 pandemic in their decision making.

- It is necessary to implement appropriate regulations to promote the green bonds market in order to deliver both environmental and financial advantages. One of the most important aspects in the development of the green bonds market is the availability of an effective legislative framework for the functioning of green bonds ([Tu et al., 2020](#)).
- It is recommended that governments should take a more active role in promoting public understanding of the need for green financing for sustainable development.
- Finally, the progress of the green bond market has been outstanding in recent years, however, it needs to be further increased in the future. Indeed, the diversification advantage of green bonds boosts policymakers' trust in enlarging the green bond market for ecological commitment without compromising the growth of the economy and financial development. Hence the promotion of policies that encourage the growth of the green bonds market is therefore critical.

6.3.2. Implications for Green Bonds Issuers

- The bond issuers should improve their governance capacity and information disclosure to boost the investors' confidence.
- Furthermore, the rapid growth of the green bonds market shows that fund managers at the time of investment decision give full importance to the green properties of green bonds (means either green bonds are utilizing in environmentally friendly projects or not). Various studies show that the "green" in green bonds is a significant investment factor and that issuers should take steps to guarantee that their bonds provide the environmental advantages that investors are expecting. A survey was conducted to determine why investors purchase green bonds. According to the findings, the vast majority of respondents (79%) stated that they do not purchase green bonds if the benefits of these types of bonds are not clearly defined; furthermore, a majority of respondents stated that they would even sell green bonds if post-issuance reporting was

insufficient (55%) ([Sangiorgi & Schopohl, 2021](#)). Hence, if the issuer can provide full information related to the environment or environment-friendly projects supported by green bonds, then high demands for green bonds can open additional financing channels and this market can get high market capitalization.

6.3.3. Implications for Investors and Portfolio Managers

This research has several implications for investors.

- The first objective of this study is finding quantiles dependency between green bonds and other selected financial markets under bearish, normal and bullish market states. The QQR analysis confirms asymmetric dependency between green bonds and other financial markets subject to change in market conditions (normal, bearish or bullish). The estimation findings may thus be used to design the optimal risk-minimizing portfolio mix between green bonds and other selected financial markets (S&P_500, DJ_IMWI, S&P_GSCI, CRIX, S&P_BD, DJ_SUK and FRX). As the variability in the estimated correlation between the green bonds market and other selected financial markets indicates that the optimal portfolio mix requires frequent updating. Investors need to know about the mechanisms for the co-movements or correlation and their changes for appropriate investment decisions; otherwise, if they do not take these differences into account, they may do worse rather than better.
- It is confirmed that in bullish market conditions S&P_GB positively correlate with S&P_500. Hence, in bullish market conditions, investors should avoid investing in both market S&P_GB and S&P_500 because both markets can co-crash. While investors can invest in the green bonds market in normal conditions because it acts as a hedge against S&P_500. We find opposite outcomes for S&P_GB, DJ_IMWI and S&P_GSCI that in bullish market state S&P_GB positively correlate with both markets and in normal and bearish market conditions negatively. It is recommended to investors

that in a bullish market state investor should avoid investing in both markets S&P_GB-DJ_IMWI and S&P_GB - S&P_GSCI. However, in normal and bullish market conditions S&P_GB acts as a hedge against DJ_IMWI and S&P_GSCI. For, S&P_GB and CRIX in bearish and normal market conditions, investment should be encouraged in S&P_GB because it acts as hedging against CRIX while in a bullish market state investor should avoid investing in these two markets. based on QQR findings investors should also avoid investing in S&P_GB and S&P_BD due to positive correlation in bullish market states but in normal market conditions, S&P_GB act as a diversifier. A weak positive correlation between S&P_GB and DJ_SUK suggests that S&P_GB act as diversifiers during normal to bullish market conditions. Finally, the relationship between S&P_GB and FRX is negative across all the quantiles of both markets which suggest investors must have both financial markets in portfolio selections.

- The second objective of the study is to examine either COVID-19 changes correlation between green bonds and other selected financial markets. The findings during COVID-19 confirm a very strong negative correlation between S&P_GB and other financial markets (including S&P_500, DJ_IMWI, S&P_GSCI, CRIX, S&P_BD, DJ_SUK, and FRX). It shows that during high uncertainty investor moves toward green bonds market to save their investment. Based on findings it is recommended for the investors that during high uncertainty or volatility S&P_GB act as a safe haven, which highly reduces portfolio risk.
- Moreover, our results (see findings of objectives 2 and 5) also show that green bond holders and issuers may fulfil their low-carbon investment goals while simultaneously avoiding financial market turmoil because of hedging and safe have qualities of green bonds.

- The findings based on wavelet correlation and continuous wavelet transformation (objective 3) confirm that the coherence of each pair is more evident up to the middle of the time frame of the study, other than the coherence between S&P_GB and FRX. With regards to the policy, this pairwise wavelet coherence can give insightful information for all stakeholders including the investors and government. For example, the investors can easily find that the pairwise lead-lag relationship expires at the long investment horizon. It implies that the long-term investors (who has a holding period of more than 256 or above) are not affected by their lead-lag relationship. A similar case happens for the short-term investors (those who are holding the investment horizon for less than 16 periods). However, the interesting results found for the midterm investors (holding period 16-256 periods) where they find the lead-lag relationship is more vivid especially between 16-128-time scale periods. This result helps the midterm investors to see how their targeted assets correlated and changes with one another. The possible reason for this high lead-lag relationship is because the government policy or regulatory decision takes a moderation time frame to affect the market. That's why; our study did not find any significant impact on the short- and long-term investment horizon. So, this is very important for the risk management midterm investors to see when and how the government policy has been undertaken. Due to the lower coherence and interdependency between the assets in the short- and long-term investments, the investors can diversify their investment. However, the midterm investors should consider all the assets carefully.
- Finally, the findings of our 4th objective show that when there is a lot of uncertainty or turbulence in the market, the green bonds market transmits volatility to other selected financial markets. As a result, investors and fund managers should think about these findings, and the green bonds market should be their best option for portfolio

diversification during financial turbulence. The study's 5th objective also demonstrates that green bonds act as a safe haven during financial turbulences. During times of financial turmoil, this encourages investors and fund managers to invest in green bond markets.

6.3.4. Implications for Society

The favorable impact of green bonds on investors portfolio diversification gives an alternative assets class to the existing investors and fund managers. However, the benefits of green bonds are not only limited to investors portfolio diversification but this financial instrument is equally important for society as well. According to various studies, corporations' environmental performance improves after issuing green bonds in the market. According to Thomson Reuters' ASSET4 scale, which includes more than 250 indicators (related to environmental sustainability), companies that issue green bonds have a 6.1% increase in their environmental score. They reduced their emissions by 17 tons of CO₂ per \$1 million of assets ([Flammer, 2018](#)).

6.4. Limitations and Recommendations for the Future Research

The current study is based on a global dataset, which explores the comovement between green bonds and other selected financial markets. Hence, this study's findings are limited from various perspectives. For example, (1) this study ignores, country-specific comovement between proposed financial markets, (2) this study uses only specific financial markets and (3) this study employed bivariate quantiles on quantiles approach and bivariate wavelet approaches.

As this study only examines the relationship between green bonds and other selected financial markets in terms of portfolio diversification; however, it will be very interesting to see how green bond-funded projects affect environmental performance in order to

improve this market. Moreover, to know the detailed information about the green bonds market's diversification benefits country-specific research is required. In future studies, other financial markets comovement should be checked with the green bonds market. Finally, for a better understanding of the comovement between green bonds and other selected financial markets multivariate econometrics should be used.



REFERENCES

- Abdel-Khaleq, A. H., & Richardson, C. F. (2006). New horizons for Islamic securities: emerging trends in sukuk offerings. *Chi. J. Int'l L.*, 7, 409.
- African Development Bank. (2016). *Why Africa needs green bonds*. Retrieved from <https://www.afdb.org/fileadmin/uploads/afdb/Documents/Publications>
- African Development Bank. (2017). *The AfDB's Annual Green Bond Newsletter*. Retrieved from
- Agliardi, E., & Agliardi, R. (2019). Financing environmentally-sustainable projects with green bonds. *Environment and development economics*, 24(6), 608-623.
- Ahmed, H., & Elsayed, A. H. (2019). Are Islamic and conventional capital markets decoupled? Evidence from stock and bonds/sukuk markets in Malaysia. *The Quarterly Review of Economics and Finance*, 74, 56-66.
- Albulescu, C. (2020). Coronavirus and financial volatility: 40 days of fasting and fear. *arXiv preprint arXiv:2003.04005*.
- Allen, F., & Carletti, E. (2010). An overview of the crisis: Causes, consequences, and solutions. *International Review of Finance*, 10(1), 1-26.
- Aloui, Aïssa, M. S. B., & Nguyen, D. K. (2011). Global financial crisis, extreme interdependencies, and contagion effects: The role of economic structure? *Journal of Banking & Finance*, 35(1), 130-141.
- Aloui, Hammoudeh, S., & Hamida, H. B. (2015). Co-movement between sharia stocks and sukuk in the GCC markets: A time-frequency analysis. *Journal of International Financial Markets, Institutions and Money*, 34, 69-79.
- Aloui, Jammazi, R., & Hamida, H. B. (2018). Multivariate co-movement between Islamic stock and bond markets among the GCC: a wavelet-based view. *Computational Economics*, 52(2), 603-626.

- Andersson, M., Krylova, E., & Vähämaa, S. (2008). Why does the correlation between stock and bond returns vary over time? *Applied Financial Economics*, 18(2), 139-151.
- Andrieş, A. M., Ihnatov, I., & Tiwari, A. K. (2014). Analyzing time–frequency relationship between interest rate, stock price and exchange rate through continuous wavelet. *Economic Modelling*, 41, 227-238.
- Apergis, N., Bonato, M., Gupta, R., & Kyei, C. (2018). Does geopolitical risks predict stock returns and volatility of leading defense companies? Evidence from a nonparametric approach. *Defence and Peace Economics*, 29(6), 684-696.
- Arif, M., Naeem, M. A., Farid, S., Nepal, R., & Jamasb, T. (2021). Diversifier or more? Hedge and safe haven properties of green bonds during COVID-19.
- Ariff, M., Safari, M., & Mohamed, S. (2012). Sukuk securities, their definitions, classification and pricing issues *The Islamic Debt Market for Sukuk Securities*: Edward Elgar Publishing.
- Azimli, A. (2020). The impact of COVID-19 on the degree of dependence and structure of risk-return relationship: A quantile regression approach. *Finance Research Letters*, 36, 101648.
- Bachelet, M. J., Becchetti, L., & Manfredonia, S. (2019). The green bonds premium puzzle: The role of issuer characteristics and third-party verification. *Sustainability*, 11(4), 1098.
- Baek, C., & Elbeck, M. (2015). Bitcoins as an investment or speculative vehicle? A first look. *Applied Economics Letters*, 22(1), 30-34.
- Baele, L., Bekaert, G., & Inghelbrecht, K. (2010). The determinants of stock and bond return comovements. *The Review of Financial Studies*, 23(6), 2374-2428.

- Bai, Y. (2014). Cross-border sentiment: an empirical analysis on EU stock markets. *Applied Financial Economics*, 24(4), 259-290.
- Baillie, R. T., & Bollerslev, T. (1989). Common stochastic trends in a system of exchange rates. *The Journal of Finance*, 44(1), 167-181.
- Baker, Bloom, N., Davis, S. J., Kost, K. J., Sammon, M. C., & Viratyosin, T. (2020). *The unprecedented stock market impact of COVID-19*. Retrieved from
- Baker, Bloom, N., Davis, S. J., & Terry, S. (2020). *Covid-induced economic uncertainty*. Retrieved from
- Baker, S. R., Bergstresser, D., Serafeim, G., & Wurgler, J. (2018). *Financing the response to climate change: The pricing and ownership of US green bonds*. Retrieved from
- Balcilar, M., Bouri, E., Gupta, R., & Roubaud, D. (2017). Can volume predict Bitcoin returns and volatility? A quantiles-based approach. *Economic Modelling*, 64, 74-81.
- Banz, R. W. (1981). The relationship between return and market value of common stocks. *Journal of Financial Economics*, 9(1), 3-18.
- Barsky, B. (1989). Why Don't the Prices of Stocks and Bonds.
- Baruník, J., Vácha, L., & Krištoufek, L. (2011). *Comovement of Central European stock markets using wavelet coherence: Evidence from high-frequency data*. Retrieved from
- Basu, S. (1977). Investment performance of common stocks in relation to their price-earnings ratios: A test of the efficient market hypothesis. *The Journal of Finance*, 32(3), 663-682.
- Baur, Hong, K., & Lee, A. D. (2016). Virtual Currencies: Media of Exchange or Speculative Asset?

- Baur, Hong, K., & Lee, A. D. (2018). Bitcoin: Medium of exchange or speculative assets? *Journal of International Financial Markets, Institutions and Money*, 54, 177-189.
- Baur, Lee, A. D., & Hong, K. (2015). Bitcoin: currency or investment? *Available at SSRN*, 2561183.
- Baur, & Lucey, B. M. (2006). Flight-to-quality or Contagion? An Empirical Analysis of Stock-bond correlations. *Institute for International Integration Studies Discussion Paper*, 122.
- Baur, & Lucey, B. M. (2009). Flights and contagion—An empirical analysis of stock–bond correlations. *Journal of Financial stability*, 5(4), 339-352.
- Baur, & Lucey, B. M. (2010). Is gold a hedge or a safe haven? An analysis of stocks, bonds and gold. *Financial Review*, 45(2), 217-229.
- Bayraci, S., Demiralay, S., & Gencer, H. G. (2018). Stock-Bond Co-Movements and Flight-To-Quality in G7 Countries: A Time-Frequency Analysis. *Bulletin of Economic Research*, 70(1), E29-E49.
- Beaulieu, M. C., Gagnon, M. H., & Khalaf, L. (2009). A cross-section analysis of financial market integration in North America using a four factor model. *International Journal of Managerial Finance*.
- Bekaert, G., Ehrmann, M., Fratzscher, M., & Mehli, A. (2014). The global crisis and equity market contagion. *The Journal of Finance*, 69(6), 2597-2649.
- Bentolila, S., Jansen, M., & Jiménez, G. (2018). When credit dries up: Job losses in the great recession. *Journal of the European Economic Association*, 16(3), 650-695.
- Bezemer, D. J. (2011). The credit crisis and recession as a paradigm test. *Journal of Economic Issues*, 45(1), 1-18.
- Black, F. (1972). Capital market equilibrium with restricted borrowing. *The journal of Business*, 45(3), 444-455.

- Böhringer, C., Rutherford, T. F., & Springmann, M. (2015). Clean-development investments: An incentive-compatible CGE modelling framework. *Environmental and Resource Economics*, 60(4), 633-651.
- Boubaker, S., & Jouini, J. (2014). Linkages between emerging and developed equity markets: Empirical evidence in the PMG framework. *The North American Journal of Economics and Finance*, 29, 322-335.
- Bouri, E., Gupta, R., Tiwari, A. K., & Roubaud, D. (2017). Does Bitcoin hedge global uncertainty? Evidence from wavelet-based quantile-in-quantile regressions. *Finance Research Letters*, 23, 87-95.
- Bouri, E., Shahzad, S. J. H., Roubaud, D., Kristoufek, L., & Lucey, B. (2020). Bitcoin, gold, and commodities as safe havens for stocks: New insight through wavelet analysis. *The Quarterly Review of Economics and Finance*, 77, 156-164.
- Boyer, B. H., Kumagai, T., & Yuan, K. (2006). How do crises spread? Evidence from accessible and inaccessible stock indices. *The Journal of Finance*, 61(2), 957-1003.
- Briere, M., Oosterlinck, K., & Szafarz, A. (2015). Virtual currency, tangible return: Portfolio diversification with bitcoin. *Journal of Asset Management*, 16(6), 365-373.
- Broadstock, D. C., & Cheng, L. T. (2019). Time-varying relation between black and green bond price benchmarks: Macroeconomic determinants for the first decade. *Finance Research Letters*, 29, 17-22.
- Cakir, S., & Raei, F. (2007). Sukuk vs. Eurobonds: Is there a difference in Value-at-Risk?
- Campbell, & Ammer, J. (1993). What moves the stock and bond markets? A variance decomposition for long-term asset returns. *The Journal of Finance*, 48(1), 3-37.
- Campbell, Koedijk, K., & Kofman, P. (2002). Increased correlation in bear markets. *Financial Analysts Journal*, 58(1), 87-94.

- Campiglio, E. (2016). Beyond carbon pricing: The role of banking and monetary policy in financing the transition to a low-carbon economy. *Ecological economics*, 121, 220-230.
- Candelon, B., Piplack, J., & Straetmans, S. (2008). On measuring synchronization of bulls and bears: The case of East Asia. *Journal of Banking & Finance*, 32(6), 1022-1035.
- Cao, J., Liang, H., & Zhan, X. (2019). Peer effects of corporate social responsibility. *Management Science*, 65(12), 5487-5503.
- Capobianco, E. (2004). Multiscale analysis of stock index return volatility. *Computational Economics*, 23(3), 219-237.
- Cappiello, L., Engle, R. F., & Sheppard, K. (2006). Asymmetric dynamics in the correlations of global equity and bond returns. *Journal of Financial econometrics*, 4(4), 537-572.
- Cenedese, G., Payne, R., Sarno, L., & Valente, G. (2016). What do stock markets tell us about exchange rates? *Review of Finance*, 20(3), 1045-1080.
- Cepoi, C.-O. (2020). Asymmetric dependence between stock market returns and news during COVID-19 financial turmoil. *Finance Research Letters*, 36, 101658.
- Chan, S., Chu, J., Nadarajah, S., & Osterrieder, J. (2017). A statistical analysis of cryptocurrencies. *Journal of Risk and Financial Management*, 10(2), 12.
- Chatzitheodorou, K., Skouloudis, A., Evangelinos, K., & Nikolaou, I. (2019). Exploring socially responsible investment perspectives: A literature mapping and an investor classification. *Sustainable production and consumption*, 19, 117-129.
- Chiang, T. C., Jeon, B. N., & Li, H. (2007). Dynamic correlation analysis of financial contagion: Evidence from Asian markets. *Journal of International Money and Finance*, 26(7), 1206-1228.

- Chiang, T. C., Li, J., & Yang, S.-Y. (2015). Dynamic stock–bond return correlations and financial market uncertainty. *Review of Quantitative Finance and Accounting*, 45(1), 59-88.
- Cho, J. H., & Parhizgari, A. M. (2009). East Asian financial contagion under DCC-GARCH. *International Journal of Banking and Finance*, 6(1), 17-30.
- Chui, C. M., & Yang, J. (2012). Extreme correlation of stock and bond futures markets: international evidence. *Financial Review*, 47(3), 565-587.
- Ciaian, P., & Rajcaniova, M. (2018). Virtual relationships: Short-and long-run evidence from BitCoin and altcoin markets. *Journal of International Financial Markets, Institutions and Money*, 52, 173-195.
- Ciaian, P., Rajcaniova, M., & Kancs, d. A. (2016). The economics of BitCoin price formation. *Applied Economics*, 48(19), 1799-1815.
- Ciner, C., Gurdgiev, C., & Lucey, B. M. (2013). Hedges and safe havens: An examination of stocks, bonds, gold, oil and exchange rates. *International Review of Financial Analysis*, 29, 202-211.
- Clapp, C., Alfsen, K. H., Lund, H. F., & Pillay, K. (2015). Green bonds and environmental integrity: Insights from cicero second opinions. *Nature Climate Change*, 5.
- Clare, A. D., Maras, M., & Thomas, S. H. (1995). The integration and efficiency of international bond markets. *Journal of Business Finance & Accounting*, 22(2), 313-322.
- Clark, T. E., & West, K. D. (2007). Approximately normal tests for equal predictive accuracy in nested models. *Journal of econometrics*, 138(1), 291-311.
- Climate Bonds Initiative. (2015). *Support for Green Bonds in Climate Finance Policy & Market Mix*. Retrieved from

- Climate Bonds Initiative (2018). *Bonds and climate change: State of the market*. Retrieved from https://www.climatebonds.net/files/files/CBI-SotM_2017-Bonds%26ClimateChange.pdf
- Connolly, R., Stivers, C., & Sun, L. (2005). Stock market uncertainty and the stock-bond return relation. *Journal of Financial and Quantitative Analysis*, 40(1), 161-194.
- Constantinides, G. M., & Malliaris, A. G. (1995). Portfolio theory. *Handbooks in operations research and management science*, 9, 1-30.
- Corbet, S., Lucey, B., Urquhart, A., & Yarovaya, L. (2019). Cryptocurrencies as a financial asset: A systematic analysis. *International Review of Financial Analysis*, 62, 182-199.
- Crowley, P. M., & Lee, J. (2005). Decomposing the co-movement of the business cycle: a time-frequency analysis of growth cycles in the euro area. *Bank of Finland Research Discussion Paper*(12).
- Curley, M. (2014). *Finance policy for renewable energy and a sustainable environment*: CRC Press.
- Dai, Q., & Singleton, K. J. (2002). Expectation puzzles, time-varying risk premia, and affine models of the term structure. *Journal of Financial Economics*, 63(3), 415-441.
- Dajcman, S., Festic, M., & Kavkler, A. (2012). European stock market comovement dynamics during some major financial market turmoils in the period 1997 to 2010—a comparative DCC-GARCH and wavelet correlation analysis. *Applied Economics Letters*, 19(13), 1249-1256.
- Daskalaki, C., & Skiadopoulos, G. (2011). Should investors include commodities in their portfolios after all? New evidence. *Journal of Banking & Finance*, 35(10), 2606-2626.

- Daubechies, I. (1992). *Ten lectures on wavelets*: SIAM.
- DeCanio, S. J. (2009). The political economy of global carbon emissions reductions. *Ecological Economics*, 68(3), 915-924.
- Demir, E., Gozgor, G., Lau, C. K. M., & Vigne, S. A. (2018). Does economic policy uncertainty predict the Bitcoin returns? An empirical investigation. *Finance Research Letters*, 26, 145-149.
- Dickey, D. A., & Fuller, W. A. (1979). Distribution of the estimators for autoregressive time series with a unit root. *Journal of the American Statistical Association*, 74(366a), 427-431.
- Diebold, F. X., & Yilmaz, K. (2009). Measuring financial asset return and volatility spillovers, with application to global equity markets. *The Economic Journal*, 119(534), 158-171.
- Diebold, F. X., & Yilmaz, K. (2014). On the network topology of variance decompositions: Measuring the connectedness of financial firms. *Journal of econometrics*, 182(1), 119-134.
- Durand, R. B., Junker, M., & Szimayer, A. (2010). The flight-to-quality effect: a copula-based analysis. *Accounting & Finance*, 50(2), 281-299.
- Dyhrberg, A. H. (2016). Hedging capabilities of bitcoin. Is it the virtual gold? *Finance Research Letters*, 16, 139-144.
- Ehlers, T., & Packer, F. (2017). Green bond finance and certification. *BIS Quarterly Review September*.
- Eisl, A., Gasser, S. M., & Weinmayer, K. (2015). Caveat emptor: Does Bitcoin improve portfolio diversification? *Available at SSRN 2408997*.
- El Mosaid, F., & Boutti, R. (2014). Sukuk and bond performance in Malaysia. *International Journal of Economics and Finance*, 6(2), 226-234.

- Elton, E. J., & Gruber, M. J. (1997). Modern portfolio theory, 1950 to date. *Journal of Banking & Finance*, 21(11-12), 1743-1759.
- Engle. (2002). Dynamic conditional correlation: A simple class of multivariate generalized autoregressive conditional heteroskedasticity models. *Journal of Business & Economic Statistics*, 20(3), 339-350.
- Engle, & Granger, C. W. (1987). Co-integration and error correction: representation, estimation, and testing. *Econometrica: journal of the Econometric Society*, 251-276.
- Erb, C. B., & Harvey, C. R. (2006). The strategic and tactical value of commodity futures. *Financial Analysts Journal*, 62(2), 69-97.
- Evans, J. D. (1996). *Straightforward statistics for the behavioral sciences*: Thomson Brooks/Cole Publishing Co.
- EY. (2016). Green bonds - a fresh look at financing green projects. *Technical report*.
- Fama, E. F. (1965). The behavior of stock-market prices. *The journal of Business*, 38(1), 34-105.
- Fama, E. F. (1970). Session topic: stock market price behavior. *The Journal of Finance*, 25(2), 383-417.
- Fama, E. F. (1981). Stock returns, real activity, inflation, and money. *The American economic review*, 71(4), 545-565.
- Fang, L., Bouri, E., Gupta, R., & Roubaud, D. (2019). Does global economic uncertainty matter for the volatility and hedging effectiveness of Bitcoin? *International Review of Financial Analysis*, 61, 29-36.
- Fathurahman, H., & Fitriati, R. (2013). Comparative analysis of return on sukuk and conventional bonds. *American Journal of Economics*, 3(3), 159-163.

- Febi, W., Schäfer, D., Stephan, A., & Sun, C. (2018). The impact of liquidity risk on the yield spread of green bonds. *Finance Research Letters*, 27, 53-59.
- Fender, I., McMorrow, M., Sahakyan, V., & Zulaica, O. (2019). Green bonds: the reserve management perspective.
- Firouzi, S., & Wang, X. (2019). A comparative study of exchange rates and order flow based on wavelet transform coherence and cross wavelet transform. *Economic Modelling*, 82, 42-56.
- Flaherty, M., Gevorkyan, A., Radpour, S., & Semmler, W. (2017). Financing climate policies through climate bonds—A three stage model and empirics. *Research in International Business and Finance*, 42, 468-479.
- Flammer, C. (2018). green bonds Benefit Companies, Investors, and the Planet. *Harvard Business Review*, 7.
- Foley, S., Karlsen, J. R., & Putniņš, T. J. (2019). Sex, drugs, and bitcoin: How much illegal activity is financed through cryptocurrencies? *The Review of Financial Studies*, 32(5), 1798-1853.
- Forbes, K. J., & Rigobon, R. (2002). No contagion, only interdependence: measuring stock market comovements. *The journal of Finance*, 57(5), 2223-2261.
- Francis, J. C., & Kim, D. (2013). *Modern portfolio theory: Foundations, analysis, and new developments* (Vol. 795): John Wiley & Sons.
- Fratzscher, M. (2002). Financial market integration in Europe: on the effects of EMU on stock markets. *International Journal of Finance & Economics*, 7(3), 165-193.
- Gabaix, X., & Maggiori, M. (2015). International liquidity and exchange rate dynamics. *The Quarterly Journal of Economics*, 130(3), 1369-1420.
- Gaiotti, E. (2013). Credit availability and investment: Lessons from the “great recession”. *European Economic Review*, 59, 212-227.

- Gallegati, M., Gallegati, M., Ramsey, J. B., & Semmler, W. (2011). The US wage Phillips curve across frequencies and over time. *Oxford Bulletin of Economics and Statistics*, 73(4), 489-508.
- Galvao Jr, A. F. (2009). Unit root quantile autoregression testing using covariates. *Journal of econometrics*, 152(2), 165-178.
- Gandal, N., Hamrick, J., Moore, T., & Oberman, T. (2018). Price manipulation in the Bitcoin ecosystem. *Journal of Monetary Economics*, 95, 86-96.
- Gao, X., & Nardari, F. (2018). Do commodities add economic value in asset allocation? New evidence from time-varying moments. *Journal of Financial and Quantitative Analysis*, 53(1), 365-393.
- Gençay, R., Ballocci, G., Dacorogna, M., Olsen, R., & Pictet, O. (2002). Real-time trading models and the statistical properties of foreign exchange rates. *International Economic Review*, 463-491.
- Gençay, R., Selçuk, F., & Whitcher, B. J. (2001). *An introduction to wavelets and other filtering methods in finance and economics*: Elsevier.
- Gençay, R., Dacorogna, M., Muller, U. A., Pictet, O., & Olsen, R. (2001). *An introduction to high-frequency finance*. Elsevier.
- Geske, R., & Roll, R. (1983). The fiscal and monetary linkage between stock returns and inflation. *The Journal of Finance*, 38(1), 1-33.
- Gianfrate, G., & Peri, M. (2019). The green advantage: Exploring the convenience of issuing green bonds. *Journal of Cleaner Production*, 219, 127-135.
- Giudici, P., & Abu-Hashish, I. (2019). What determines bitcoin exchange prices? A network VAR approach. *Finance Research Letters*, 28, 309-318.
- Gkillas, K., & Katsiampa, P. (2018). An application of extreme value theory to cryptocurrencies. *Economics letters*, 164, 109-111.

- Glavas, D. (2018). How do stock prices react to green bond issuance announcements?
Available at SSRN 3279069.
- Glomsrød, S., & Wei, T. (2018). Business as unusual: the implications of fossil divestment and green bonds for financial flows, economic growth and energy market. *Energy for sustainable development*, 44, 1-10.
- Godlewski, C. J., Turk-Ariss, R., & Weill, L. (2013). Sukuk vs. conventional bonds: A stock market perspective. *Journal of Comparative Economics*, 41(3), 745-761.
- Gokmenoglu, K. K., & Hadood, A. A. A. (2019). Volatility spillovers and time varying correlation for Chinese tourism firms. *Asia Pacific Journal of Tourism Research*, 24(6), 584-596.
- Gorton, G., & Rouwenhorst, K. G. (2006). Facts and fantasies about commodity futures. *Financial Analysts Journal*, 62(2), 47-68.
- Granger. (1986). *Developments in the study of cointegrated economic variables*. Paper presented at the Oxford Bulletin of Economics and Statistics.
- Granger, C. W. (1969). Investigating causal relations by econometric models and cross-spectral methods. *Econometrica: journal of the Econometric Society*, 424-438.
- Group, G. F. S. (2016). *G20 green finance synthesis report*. Retrieved from http://unepinquiry.org/wp-content/uploads/2016/09/Synthesis_Report_Full_EN.pdf.
- Grubel, H. G., & Fadner, K. (1971). The interdependence of international equity markets. *The Journal of Finance*, 26(1), 89-94.
- Guidolin, M., & La Ferrara, E. (2010). The economic effects of violent conflict: Evidence from asset market reactions. *Journal of Peace Research*, 47(6), 671-684.
- Gulko, L. (2002). Decoupling. *The Journal of Portfolio Management*, 28(3), 59-66.

- Gupta, R., Kollias, C., Papadamou, S., & Wohar, M. E. (2018). News implied volatility and the stock-bond nexus: Evidence from historical data for the USA and the UK markets. *Journal of Multinational Financial Management*, 47, 76-90.
- Hachenberg, B., & Schiereck, D. (2018). Are green bonds priced differently from conventional bonds? *Journal of Asset Management*, 19(6), 371-383.
- Hakkio, C. S., & Rush, M. (1989). Market efficiency and cointegration: an application to the sterling and deutschemark exchange markets. *Journal of International Money and Finance*, 8(1), 75-88.
- Hamburner, M., & Kochin, L. A. (1972). Money and stock prices: The channels of influences. *Journal of Finance*, 27(2), 231-249.
- Hamlin, J. (2021). Green bonds were a better safe haven than gold during the pandemic. *Portfolio*. Retrieved from <https://www.institutionalinvestor.com/article/bls5yxtf3gdxfk/Green-Bonds-Were-a-Better-Safe-Haven-Than-Gold-During-the-Pandemic>
- Haque, M. M., Chowdhury, M. A. F., Buriev, A. A., Bacha, O. I., & Masih, M. (2017). Who drives whom-sukuk or bond? A new evidence from granger causality and wavelet approach. *Review of Financial Economics*.
- Hart, O., & Zingales, L. (2017). Companies should maximize shareholder welfare not market value. *ECGI-Finance Working Paper*(521).
- Hu, Y., Valera, H. G. A., & Oxley, L. (2019). Market efficiency of the top market-cap cryptocurrencies: Further evidence from a panel framework. *Finance Research Letters*, 31, 138-145.
- Hung, S.-Y., Liang, T.-P., & Liu, V. W.-C. (1996). Integrating arbitrage pricing theory and artificial neural networks to support portfolio management. *Decision support systems*, 18(3-4), 301-316.

- Ilmanen, A. (2003). Stock-bond correlations. *The Journal of Fixed Income*, 13(2), 55-66.
- Iqbal, J., & Haider, A. (2005). Arbitrage pricing theory: evidence from an emerging stock market.
- Jammazi, R., Tiwari, A. K., Ferrer, R., & Moya, P. (2015). Time-varying dependence between stock and government bond returns: International evidence with dynamic copulas. *The North American Journal of Economics and Finance*, 33, 74-93.
- Ji, Q., Bouri, E., Gupta, R., & Roubaud, D. (2018). Network causality structures among Bitcoin and other financial assets: A directed acyclic graph approach. *The Quarterly Review of Economics and Finance*, 70, 203-213.
- Jiguang, L., & Zhiquan, S. (2011). Low carbon finance: Present situation and future development in China. *Energy Procedia*, 5, 214-218.
- Jivraj, F. T. (2013). Stock-bond correlation: time variation, predictability & hedging.
- Jondeau, E., & Rockinger, M. (2006). The copula-garch model of conditional dependencies: An international stock market application. *Journal of International Money and Finance*, 25(5), 827-853.
- Kang, Maitra, D., Dash, S. R., & Brooks, R. (2019). Dynamic spillovers and connectedness between stock, commodities, bonds, and VIX markets. *Pacific-Basin Finance Journal*, 58(C).
- Kang, Ratti, R. A., & Yoon, K. H. (2014). The impact of oil price shocks on US bond market returns. *Energy economics*, 44, 248-258.
- Kapraun, J., Latino, C., Scheins, C., & Schlag, C. (2021). *(In)-Credibly Green: Which Bonds Trade at a Green Bond Premium?* Paper presented at the Proceedings of Paris December 2019 Finance Meeting EUROFIDAI-ESSEC.
- Karpf, A., & Mandel, A. (2017). Does it pay to be green? Available at SSRN 2923484.

- Karpf, A., & Mandel, A. (2018). The changing value of the 'green' label on the US municipal bond market. *Nature Climate Change*, 8(2), 161-165.
- Keim, D. B., & Stambaugh, R. F. (1986). Predicting returns in the stock and bond markets. *Journal of Financial Economics*, 17(2), 357-390.
- Kettell, B. (2001). *Financial economics: making sense of information in financial markets*: Ft Press.
- Killeen, W. P., Lyons, R. K., & Moore, M. J. (2006). Fixed versus flexible: Lessons from EMS order flow. *Journal of International Money and Finance*, 25(4), 551-579.
- Kim, H. B., & Kang, S. H. (2012). Volatility transmission between the sharia stock and sukuk GII markets in Malaysia. *한국금융공학회/ 학술발표논문집*, 2012(1), 1-17.
- Kochetygova, J., & Jauhari, A. (2014). Climate change, green bonds and index investing: the new frontier. *Retrieved*, 20, 2017.
- Koenker, R. (2005). Quantile Regression. *Econometric Society Monographs*, 38
- Koenker, R., & Bassett Jr, G. (1978). Regression quantiles. *Econometrica: journal of the Econometric Society*, 33-50.
- Koenker, R., & Xiao, Z. (2004). Unit root quantile autoregression inference. *Journal of the American Statistical Association*, 99(467), 775-787.
- Koop, G., Pesaran, M. H., & Potter, S. M. (1996). Impulse response analysis in nonlinear multivariate models. *Journal of econometrics*, 74(1), 119-147.
- Koutoulas, G., & Kryzanowski, L. (1994). Integration or segmentation of the Canadian stock market: Evidence based on the APT. *Canadian Journal of Economics*, 329-351.
- Kristian, K., Carl, L., & Jakob, P. (2006). Practical Application of Modern Portfolio Theory: Jonkoping International Business School, Jonkoping University.

- Kristoufek, L. (2015). What are the main drivers of the Bitcoin price? Evidence from wavelet coherence analysis. *PloS one*, 10(4), e0123923.
- Le, T.-L., Abakah, E. J. A., & Tiwari, A. K. (2021). Time and frequency domain connectedness and spill-over among fintech, green bonds and cryptocurrencies in the age of the fourth industrial revolution. *Technological Forecasting and Social Change*, 162, 120382.
- Le Tran, V., & Leirvik, T. (2019). A simple but powerful measure of market efficiency. *Finance Research Letters*, 29, 141-151.
- Lee, Lee, K., & Zhang, X. (2019). Time-varying comovement of Chinese stock and government bond markets: Flight to safe haven. *Emerging Markets Finance and Trade*, 55(13), 3058-3068.
- Lee, & Stevenson, S. (2005). Real estate portfolio construction and estimation risk. *Journal of Property Investment & Finance*.
- Lee, Tsong, C.-C., & Lee, C.-F. (2014). Testing for the efficient market hypothesis in stock prices: International evidence from nonlinear heterogeneous panels. *Macroeconomic Dynamics*, 18(4), 943-958.
- Levy, H., & Lerman, Z. (1988). The benefits of international diversification in bonds. *Financial Analysts Journal*, 44(5), 56-64.
- Li, W., & Jia, Z. (2017). Carbon tax, emission trading, or the mixed policy: which is the most effective strategy for climate change mitigation in China? *Mitigation and Adaptation Strategies for Global Change*, 22(6), 973-992.
- Lin, F.-L., Yang, S.-Y., Marsh, T., & Chen, Y.-F. (2018). Stock and bond return relations and stock market uncertainty: Evidence from wavelet analysis. *International Review of Economics & Finance*, 55, 285-294.

- Linter, J. (1965). The Valuation of Risk Assets and The Selection of Risk Investments: Review of.
- Liu, Q., Tse, Y., & Zhang, L. (2018). Including commodity futures in asset allocation in China. *Quantitative Finance*, 18(9), 1487-1499.
- Ma, L., & Koenker, R. (2006). Quantile regression methods for recursive structural equation models. *Journal of econometrics*, 134(2), 471-506.
- Madaleno, M., & Pinho, C. (2012). International stock market indices comovements: A new look. *International Journal of Finance & Economics*, 17(1), 89-102.
- Magill, M., Quinzii, M., & Rochet, J. C. (2015). A theory of the stakeholder corporation. *Econometrica*, 83(5), 1685-1725.
- Makarov, I., & Schoar, A. (2020). Trading and arbitrage in cryptocurrency markets. *Journal of Financial Economics*, 135(2), 293-319.
- Malkiel, B. G. (1962). Expectations, bond prices, and the term structure of interest rates. *The Quarterly Journal of Economics*, 197-218.
- Malkiel, B. G. (2003). The efficient market hypothesis and its critics. *Journal of economic perspectives*, 17(1), 59-82.
- Mallat, S. G., & Zhang, Z. (1993). Matching pursuits with time-frequency dictionaries. *IEEE Transactions on signal processing*, 41(12), 3397-3415.
- Maritz, G. (2002). *Assessing risk in the Paarl/Berg River region by means of various portfolio diversification models*. Stellenbosch: Stellenbosch University.
- Markowitz, H. (1952). The utility of wealth. *Journal of political Economy*, 60(2), 151-158.
- Markowitz, H. (1959). *Portfolio Selection*, New Haven & London: Yale University Press.
- Mensah, J. O., & Alagidede, P. (2017). How are Africa's emerging stock markets related to advanced markets? Evidence from copulas. *Economic Modelling*, 60, 1-10.

- Meo, M. S., & Karim, M. Z. A. (2021). The role of green finance in reducing CO2 emissions: An empirical analysis. *Borsa Istanbul Review*.
- Mian, A., & Sufi, A. (2010). The great recession: Lessons from microeconomic data. *American Economic Review*, 100(2), 51-56.
- Mishra, S., Sharif, A., Khuntia, S., Meo, M. S., & Khan, S. A. R. (2019). Does oil prices impede Islamic stock indices? Fresh insights from wavelet-based quantile-on-quantile approach. *Resources Policy*, 62, 292-304.
- Mokni, K., & Mansouri, F. (2017). Conditional dependence between international stock markets: A long memory GARCH-copula model approach. *Journal of Multinational Financial Management*, 42, 116-131.
- 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.
- Morales, L., & Andreosso-O'Callaghan, B. (2012). The current global financial crisis: Do Asian stock markets show contagion or interdependence effects? *Journal of Asian Economics*, 23(6), 616-626.
- Mullan, P. C. (2014). What Is Digital Currency? *The Digital Currency Challenge: Shaping Online Payment Systems through US Financial Regulations* (pp. 4-12): Springer.
- Naeem, M. A., Mbarki, I., Alharthi, M., Omri, A., & Shahzad, S. J. H. (2021). Did COVID-19 Impact the Connectedness Between Green Bonds and Other Financial Markets? Evidence From Time-Frequency Domain With Portfolio Implications. *Frontiers in Environmental Science*, 9, 180.
- Naifar, N. (2016). Modeling dependence structure between stock market volatility and sukuk yields: A nonlinear study in the case of Saudi Arabia. *Borsa Istanbul Review*, 16(3), 157-166.

- Naifar, N. (2018). Exploring the dynamic links between gcc sukuk and commodity market volatility. *International Journal of Financial Studies*, 6(3), 72.
- Najeeb, S. F., Bacha, O., & Masih, M. (2017). Does a held-to-maturity strategy impede effective portfolio diversification for Islamic bond (sukuk) portfolios? A multi-scale continuous wavelet correlation analysis. *Emerging Markets Finance and Trade*, 53(10), 2377-2393.
- Nakamoto, S. (2008). Bitcoin: A peer-to-peer electronic cash system. *Decentralized Business Review*, 21260.
- Nanayakkara, M., & Colombage, S. (2019). Do investors in green bond market pay a premium? Global evidence. *Applied Economics*, 51(40), 4425-4437.
- Narayan, P. K., & Gupta, R. (2015). Has oil price predicted stock returns for over a century? *Energy economics*, 48, 18-23.
- Nasreen, S., Naqvi, S. A. A., Tiwari, A. K., Hammoudeh, S., & Shah, S. A. R. (2020). A wavelet-based analysis of the Co-movement between sukuk bonds and shariah stock indices in the GCC region: implications for risk diversification. *Journal of Risk and Financial Management*, 13(4), 63.
- Ng, A. W. (2018). From sustainability accounting to a green financing system: Institutional legitimacy and market heterogeneity in a global financial centre. *Journal of Cleaner Production*, 195, 585-592.
- Nguyen, T. T. H., Naeem, M. A., Balli, F., Balli, H. O., & Vo, X. V. (2021). Time-frequency comovement among green bonds, stocks, commodities, clean energy, and conventional bonds. *Finance Research Letters*, 40, 101739.
- Odier, P., & Solnik, B. (1993). Lessons for international asset allocation. *Financial Analysts Journal*, 49(2), 63-77.
- OECD. (2012). *OECD Green Growth Studies Energy*. Retrieved from

- Orlov, S., Rovenskaya, E., Puauschunder, J. M., & Semmler, W. (2017). Green bonds, transition to a low-carbon economy, and intergenerational fairness: Evidence from an extended DICE model. *Transition to a Low-Carbon Economy, and Intergenerational Fairness: Evidence from an Extended DICE Model (December 12, 2017)*.
- Ozili, P. K., & Arun, T. (2020). Spillover of COVID-19: impact on the Global Economy. *Available at SSRN 3562570*.
- Pagliari, J., Webb, J., & Del Casino, J. (1995). Applying MPT to institutional real estate portfolios: the good, the bad and the uncertain. *Journal of Real Estate Portfolio Management, 1*(1), 67-88.
- Park, D., Park, J., & Ryu, D. (2020). Volatility spillovers between equity and green bond markets. *Sustainability, 12*(9), 3722.
- Pearce, D. K., & Roley, V. V. (1983). The reaction of stock prices to unanticipated changes in money: A note. *The Journal of Finance, 38*(4), 1323-1333.
- Percival, D. B., & Walden, A. T. (2000). *Wavelet methods for time series analysis* (Vol. 4): Cambridge university press.
- Pesaran, & Timmermann, A. (2002). Market timing and return prediction under model instability. *Journal of Empirical Finance, 9*(5), 495-510.
- Pesaran, H. H., & Shin, Y. (1998). Generalized impulse response analysis in linear multivariate models. *Economics letters, 58*(1), 17-29.
- Pham, L. (2016). Is it risky to go green? A volatility analysis of the green bond market. *Journal of Sustainable Finance & Investment, 6*(4), 263-291.
- Pham, L., & Huynh, T. L. D. (2020). How does investor attention influence the green bond market? *Finance Research Letters, 35*, 101533.

- Phillip, A., Chan, J., & Peiris, S. (2019). On long memory effects in the volatility measure of cryptocurrencies. *Finance Research Letters*, 28, 95-100.
- Phillips, P. C., & Perron, P. (1988). Testing for a unit root in time series regression. *Biometrika*, 75(2), 335-346.
- Phiri, A. (2015). Efficient market hypothesis in South Africa: Evidence from linear and nonlinear unit root tests.
- Platanakis, E., & Urquhart, A. (2019). Portfolio management with cryptocurrencies: The role of estimation risk. *Economics letters*, 177, 76-80.
- Platanakis, E., & Urquhart, A. (2020). Should investors include bitcoin in their portfolios? A portfolio theory approach. *The British Accounting Review*, 52(4), 100837.
- Polasik, M., Piotrowska, A. I., Wisniewski, T. P., Kotkowski, R., & Lightfoot, G. (2015). Price fluctuations and the use of bitcoin: An empirical inquiry. *International Journal of Electronic Commerce*, 20(1), 9-49.
- Qarni, M. O., & Gulzar, S. (2021). Portfolio diversification benefits of alternative currency investment in Bitcoin and foreign exchange markets. *Financial Innovation*, 7(1), 1-37.
- Radelet, S., Sachs, J. D., Cooper, R. N., & Bosworth, B. P. (1998). The East Asian financial crisis: diagnosis, remedies, prospects. *Brookings papers on Economic activity*, 1998(1), 1-90.
- Rady, D. A. M. (2012). Greece debt crisis: Causes, implications and policy options. *Academy of Accounting and Financial Studies Journal*, 16, 87.
- Rahim, A. M., & Masih, M. (2016). Portfolio diversification benefits of Islamic investors with their major trading partners: Evidence from Malaysia based on MGARCH-DCC and wavelet approaches. *Economic Modelling*, 54, 425-438.

- Ramsey, J. B. (1999). The contribution of wavelets to the analysis of economic and financial data. *Philosophical Transactions of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences*, 357(1760), 2593-2606.
- Ramsey, J. B. (2002). Wavelets in economics and finance: Past and future. *Studies in Nonlinear Dynamics & Econometrics*, 6(3).
- Ratner, M., & Chiu, C.-C. J. (2013). Hedging stock sector risk with credit default swaps. *International Review of Financial Analysis*, 30, 18-25.
- Raza, H., & Wu, W. (2018). Quantile dependence between the stock, bond and foreign exchange markets—Evidence from the UK. *The Quarterly Review of Economics and Finance*, 69, 286-296.
- 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. (2016). Quantile dependence of oil price movements and stock returns. *Energy economics*, 54, 33-49.
- 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.
- Rigobon, R. (2016). Contagion, spillover and interdependence. European Central Bank. *Working paper 1975*.
- Rjoub, H., Türsoy, T., & Günsel, N. (2009). The effects of macroeconomic factors on stock returns: Istanbul Stock Market. *Studies in Economics and Finance*.
- Röll, K. (1976). Analysis of stress and strain distribution in thin films and substrates. *Journal of Applied Physics*, 47(7), 3224-3229.

- Roll, R., & Ross, S. A. (1980). An empirical investigation of the arbitrage pricing theory. *The Journal of Finance*, 35(5), 1073-1103.
- Rosenberg, B., Reid, K., & Lanstein, R. (1985). Persuasive evidence of market inefficiency. *The Journal of Portfolio Management*, 11(3), 9-16.
- Ross, S. (1976). The arbitrage theory of capital asset pricing, 'Journal of Economic Theory': Elsevier, Amsterdam.
- Sachs, J. D. (2014). Climate change and intergenerational well-being. *The Oxford handbook of the macroeconomics of global warming*, 248-259.
- Sachs, J. D. (2015). *The age of sustainable development*: Columbia University Press.
- Saikkonen, P. (1991). Asymptotically efficient estimation of cointegration regressions. *Econometric theory*, 7(1), 1-21.
- Saiti, B., & Noordin, N. H. (2018). Does Islamic equity investment provide diversification benefits to conventional investors? Evidence from the multivariate GARCH analysis. *International Journal of Emerging Markets*.
- Sangiorgi, I., & Schopohl, L. (2021). Why do institutional investors buy green bonds: Evidence from a survey of European asset managers. *International Review of Financial Analysis*, 75, 101738.
- Scholtens, B. (2017). Why finance should care about ecology. *Trends in Ecology & Evolution*, 32(7), 500-505.
- Sclip, A., Dreassi, A., Miani, S., & Paltrinieri, A. (2016). Dynamic correlations and volatility linkages between stocks and sukuk: Evidence from international markets. *Review of Financial Economics*, 31, 34-44.
- Selgin, G. (2015). Synthetic commodity money. *Journal of Financial stability*, 17, 92-99.

- Selmi, R., Gupta, R., Kollias, C., & Papadamou, S. (2019). The stock-bond nexus and investors' behavior in mature and emerging markets: Evidence from long-term historical data. *Studies in Economics and Finance*.
- Selmi, R., Kollias, C., Papadamou, S., & Gupta, R. (2017). *A Copula-Based Quantile-on-Quantile Regression Approach to Modeling Dependence Structure between Stock and Bond Returns: Evidence from Historical Data of India, South Africa, UK and US*. Retrieved from
- Selmi, R., Mensi, W., Hammoudeh, S., & Bouoiyour, J. (2018). Is Bitcoin a hedge, a safe haven or a diversifier for oil price movements? A comparison with gold. *Energy economics*, 74, 787-801.
- Shahzad, S. J. H., Aloui, C., Jammazi, R., & Shahbaz, M. (2019). Are Islamic bonds a good safe haven for stocks? Implications for portfolio management in a time-varying regime-switching copula framework. *Applied Economics*, 51(3), 219-238.
- Shankleman, J. (2016). *Green bond will grow to \$158 billion in 2016*. Retrieved from <https://www.bloomberg.com/authors/ASoVYP9ojQ0/jess-shankleman>
- Sharif, A., Aloui, C., & Yarovaya, L. (2020). COVID-19 pandemic, oil prices, stock market, geopolitical risk and policy uncertainty nexus in the US economy: Fresh evidence from the wavelet-based approach. *International Review of Financial Analysis*, 70, 101496.
- Sharpe, W. F. (1964). Capital asset prices: A theory of market equilibrium under conditions of risk. *The Journal of Finance*, 19(3), 425-442.
- Shiller, R. J., & Beltratti, A. E. (1992). Stock prices and bond yields: Can their comovements be explained in terms of present value models? *Journal of Monetary Economics*, 30(1), 25-46.

- Sim, N., & Zhou, H. (2015). Oil prices, US stock return, and the dependence between their quantiles. *Journal of Banking & Finance*, 55, 1-8.
- Sims, C. A. (1980). Macroeconomics and reality. *Econometrica: journal of the Econometric Society*, 1-48.
- Širůček, M., & Křen, L. (2017). Application of Markowitz portfolio theory by building optimal portfolio on the US stock market *Tools and Techniques for Economic Decision Analysis* (pp. 24-42): IGI Global.
- Smith, K. L. (2002). Government bond market seasonality, diversification, and cointegration: international evidence. *Journal of Financial Research*, 25(2), 203-221.
- Solnik, B., Boucrelle, C., & Le Fur, Y. (1996). International market correlation and volatility. *Financial Analysts Journal*, 52(5), 17-34.
- Stanley, M. (2017). Behind the green bond boom. *Forbes*. November, 6, 187.
- Street, M. (2014). Green bonds are the answer to Africa's investment need. *Financial Times*, 23.
- Suciningtias, S. A. (2019). Macroeconomic Impacts on Sukuk Performance in Indonesia: Co-integration and Vector Error Correction Model Approach. *Journal of Islamic Finance*, 8, 117-130.
- Syllignakis, M. N., & Kouretas, G. P. (2011). Dynamic correlation analysis of financial contagion: Evidence from the Central and Eastern European markets. *International Review of Economics & Finance*, 20(4), 717-732.
- Taghizadeh-Hesary, F., & Yoshino, N. (2019). The way to induce private participation in green finance and investment. *Finance Research Letters*, 31, 98-103.
- Tang, D. Y., & Zhang, Y. (2020). Do shareholders benefit from green bonds? *Journal of Corporate Finance*, 61, 101427.

- Tariq, A. A., & Dar, H. (2007). Risks of Sukuk structures: Implications for resource mobilization. *Thunderbird International Business Review*, 49(2), 203-223.
- Tolikas, K. (2018). The lead-lag relation between the stock and the bond markets. *The European Journal of Finance*, 24(10), 849-866.
- Tolliver, C., Keeley, A. R., & Managi, S. (2019). Green bonds for the Paris agreement and sustainable development goals. *Environmental Research Letters*, 14(6), 064009.
- Topcu, M., & Gulal, O. S. (2020). The impact of COVID-19 on emerging stock markets. *Finance Research Letters*, 36, 101691.
- Trilla, A., Trilla, G., & Daer, C. (2008). The 1918 “spanish flu” in spain. *Clinical infectious diseases*, 47(5), 668-673.
- Troster, V. (2018). Testing for Granger-causality in quantiles. *Econometric Reviews*, 37(8), 850-866.
- Troster, V., Shahbaz, M., & Uddin, G. S. (2018). Renewable energy, oil prices, and economic activity: A Granger-causality in quantiles analysis. *Energy economics*, 70, 440-452.
- Tsai, I.-C. (2012). The relationship between stock price index and exchange rate in Asian markets: A quantile regression approach. *Journal of International Financial Markets, Institutions and Money*, 22(3), 609-621.
- Tu, C. A., Rasoulinezhad, E., & Sarker, T. (2020). Investigating solutions for the development of a green bond market: Evidence from analytic hierarchy process. *Finance Research Letters*, 34, 101457.
- VanEck. (2017). *Income with Impact: A Guide to Green Bonds*. Retrieved from <https://www.vaneck.com/vaneck-green-bond-etf-guide-source.pdf>
- Veys, A. (2010). The Sterling Bond Markets and Low Carbon or Green Bonds. *E3G, UK*.

- Vishwanath, S., & Azmi, S. (2009). An overview of Islamic sukuk bonds. *The Journal of Structured Finance*, 14(4), 58-67.
- Wagner, A. F. (2020). What the stock market tells us about the post-COVID-19 world. *Nature Human Behaviour*, 4(5), 440-440.
- Wang, Y., & Zhi, Q. (2016). The role of green finance in environmental protection: Two aspects of market mechanism and policies. *Energy Procedia*, 104, 311-316.
- Wen, F., Xu, L., Ouyang, G., & Kou, G. (2019). Retail investor attention and stock price crash risk: evidence from China. *International Review of Financial Analysis*, 65, 101376.
- Wickremasinghe, G. B. (2016). Efficiency of foreign exchange market of Sri Lanka: some empirical evidence. *Economics, Management, and Financial Markets*, 11(4), 49-60.
- Widad, M., & Hadjer, B. (2018). Causal relationship between Islamic bonds, oil price and precious metals: evidence from Asia pacific. *Al-Iqtishad Journal of Islamic Economics*, 10(2), 285-298.
- Wilson, R. (2008). Innovation in the structuring of Islamic sukuk securities. *Humanomics*.
- Wisniewski, T. P. (2016). Is there a link between politics and stock returns? A literature survey. *International Review of Financial Analysis*, 47, 15-23.
- Wong, H. T. (2017). Real exchange rate returns and real stock price returns. *International Review of Economics & Finance*, 49, 340-352.
- World Bank. (2015). *Innovative Finance for Development Solutions*. Retrieved from Washington, DC: World Bank Treasury Department: Accessed 1 July 2016. <http://siteresources.worldbank.org/CFPEXT/Resources/IF-for-Development-Solutions.pdf>
- World Bank. (2017). *Green Bond Impact Report*. Retrieved from

- Wu, & Liang, S.-S. (2011). The economic value of range-based covariance between stock and bond returns with dynamic copulas. *Journal of Empirical Finance*, 18(4), 711-727.
- Wu, Pandey, V. K., & Dba, C. (2014). The value of Bitcoin in enhancing the efficiency of an investor's portfolio. *Journal of financial planning*, 27(9), 44-52.
- Xiao, & Dhesi, G. (2010). Volatility spillover and time-varying conditional correlation between the European and US stock markets. *Global Economy and Finance Journal*, 3(2), 148-164.
- Xiao, Z. (2009). Quantile cointegrating regression. *Journal of econometrics*, 150(2), 248-260.
- Yang, J., Zhou, Y., & Wang, Z. (2009). The stock–bond correlation and macroeconomic conditions: One and a half centuries of evidence. *Journal of Banking & Finance*, 33(4), 670-680.
- Yang, J., Zhou, Y., & Wang, Z. (2010). Conditional coskewness in stock and bond markets: time-series evidence. *Management Science*, 56(11), 2031-2049.
- Yermack, D. (2013). Is Bitcoin a real currency? An economic appraisal (No. w19747). *National Bureau of Economic Research*, 36(2), 843-850.
- Yoshino, N., Taghizadeh-Hesary, F., & Otsuka, M. (2021). Covid-19 and optimal portfolio selection for investment in sustainable development goals. *Finance Research Letters*, 38, 101695.
- Yousaf, I., Suleman, T., & Demirer, R. (2021). Green investments: A luxury good or a financial necessity? Available at SSRN 3855125.
- Zerbib, O. D. (2019). The effect of pro-environmental preferences on bond prices: Evidence from green bonds. *Journal of Banking & Finance*, 98, 39-60.

Zhan, M., Qin, Y., Xue, X., & Zhu, S. (2020). Death from Covid-19 of 23 health care workers in China. *New England Journal of Medicine*, 382(23), 2267-2268.

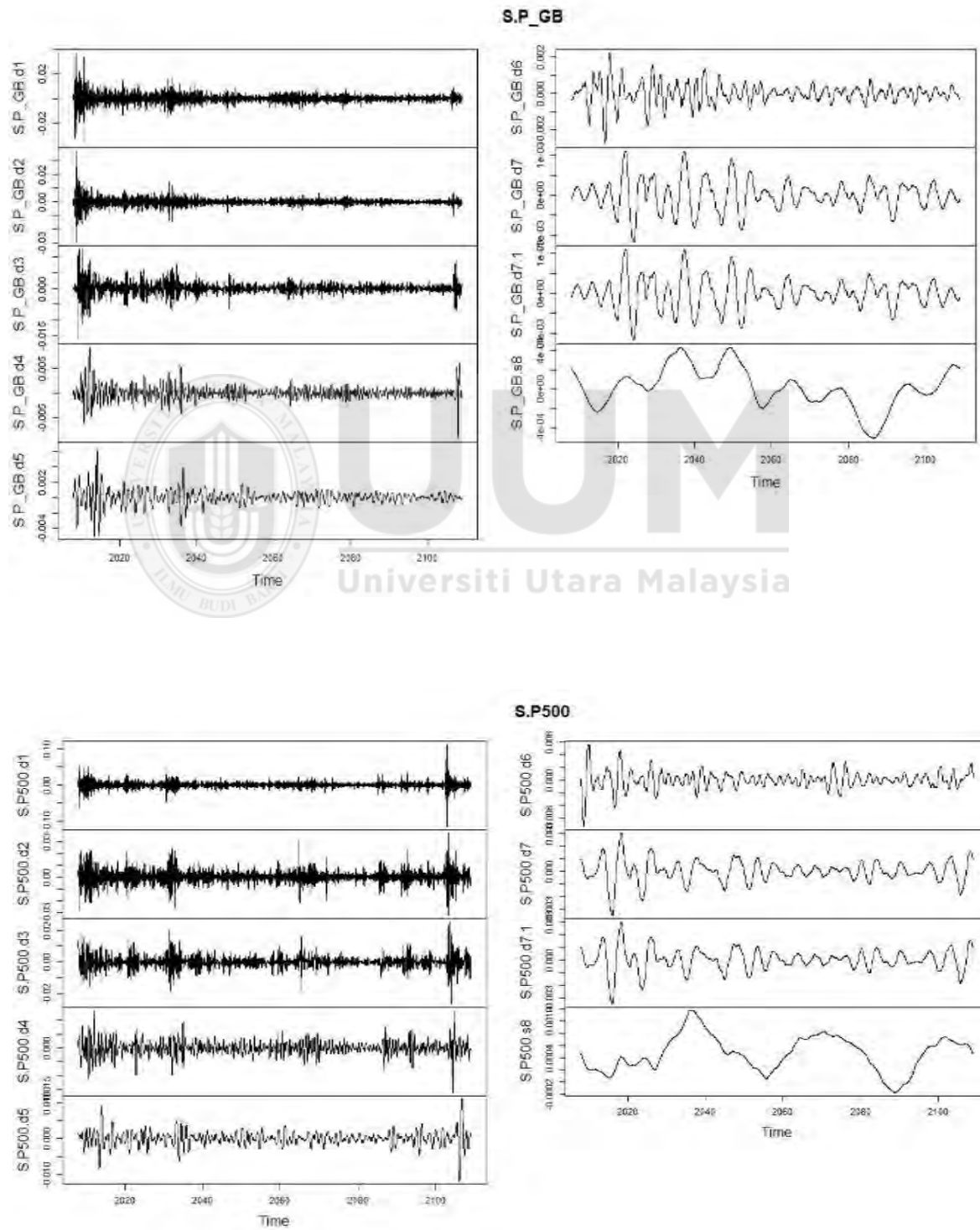
Zin, M. Z. M., Sakat, A. A., Ahmad, N. A., Nor, M. R. M., Bhari, A., Ishak, S., & Jamain, M. S. (2011). The effectiveness of Sukuk in Islamic finance market. *Australian Journal of Basic and Applied Sciences*, 5(12), 472-478.

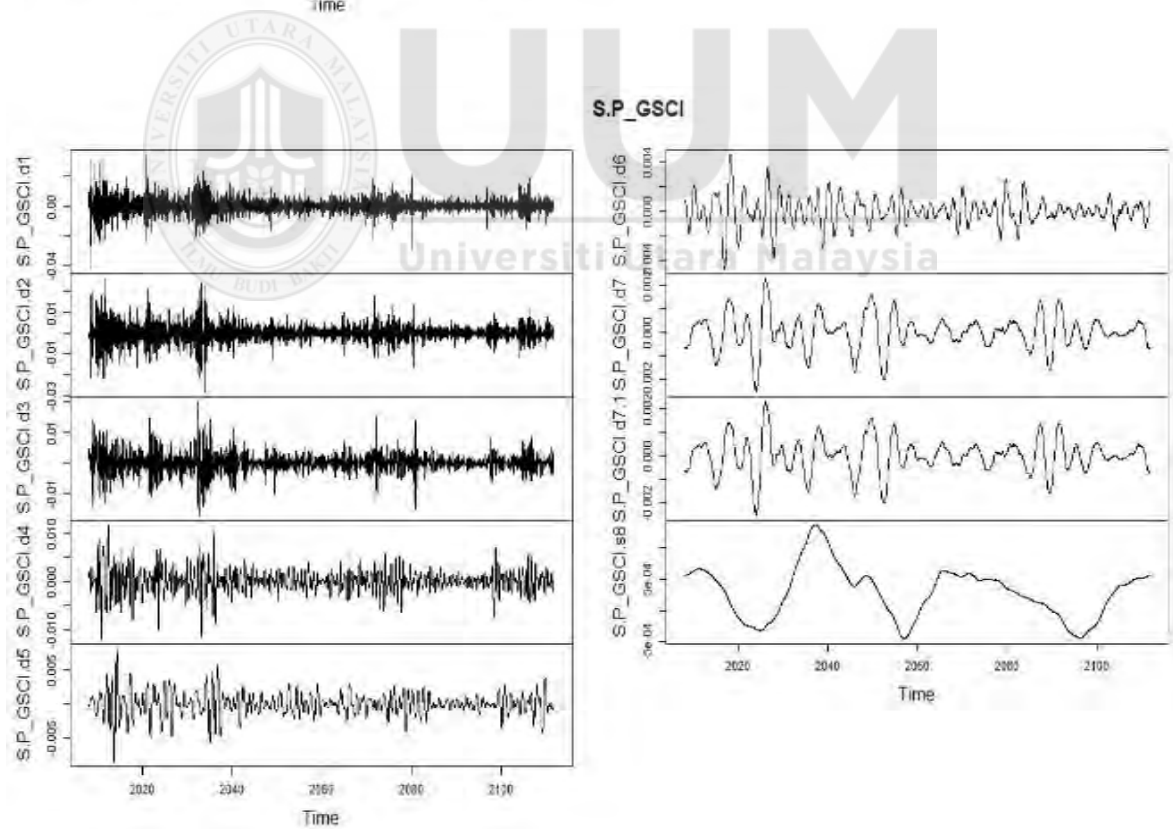
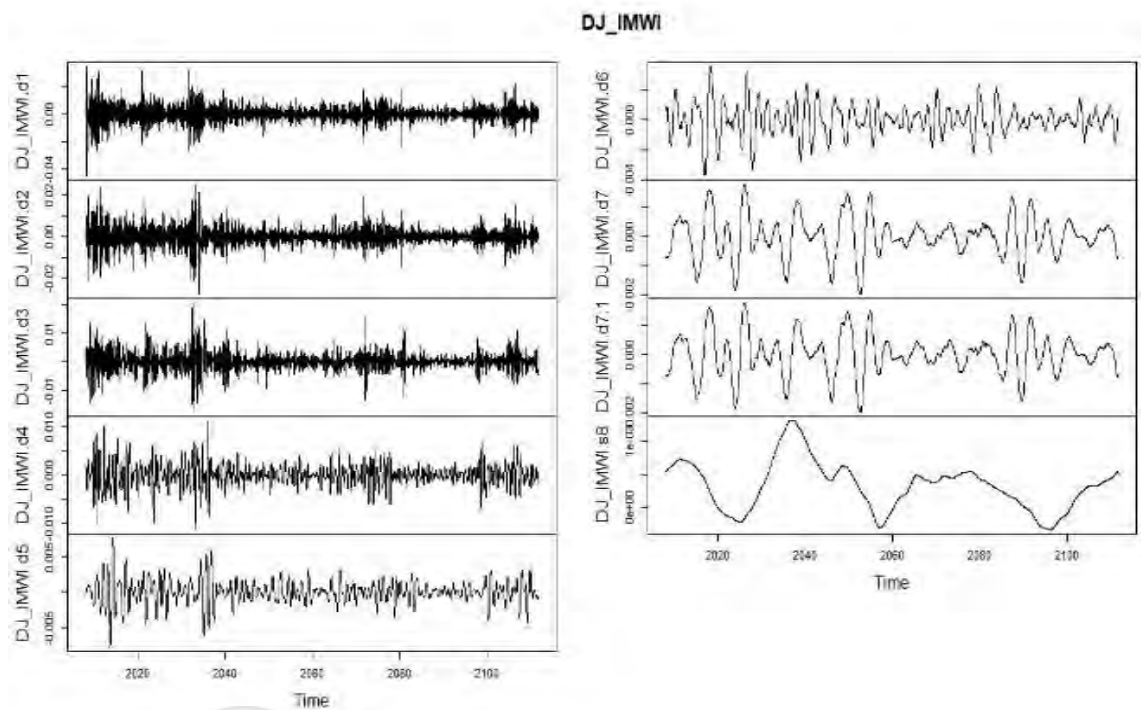


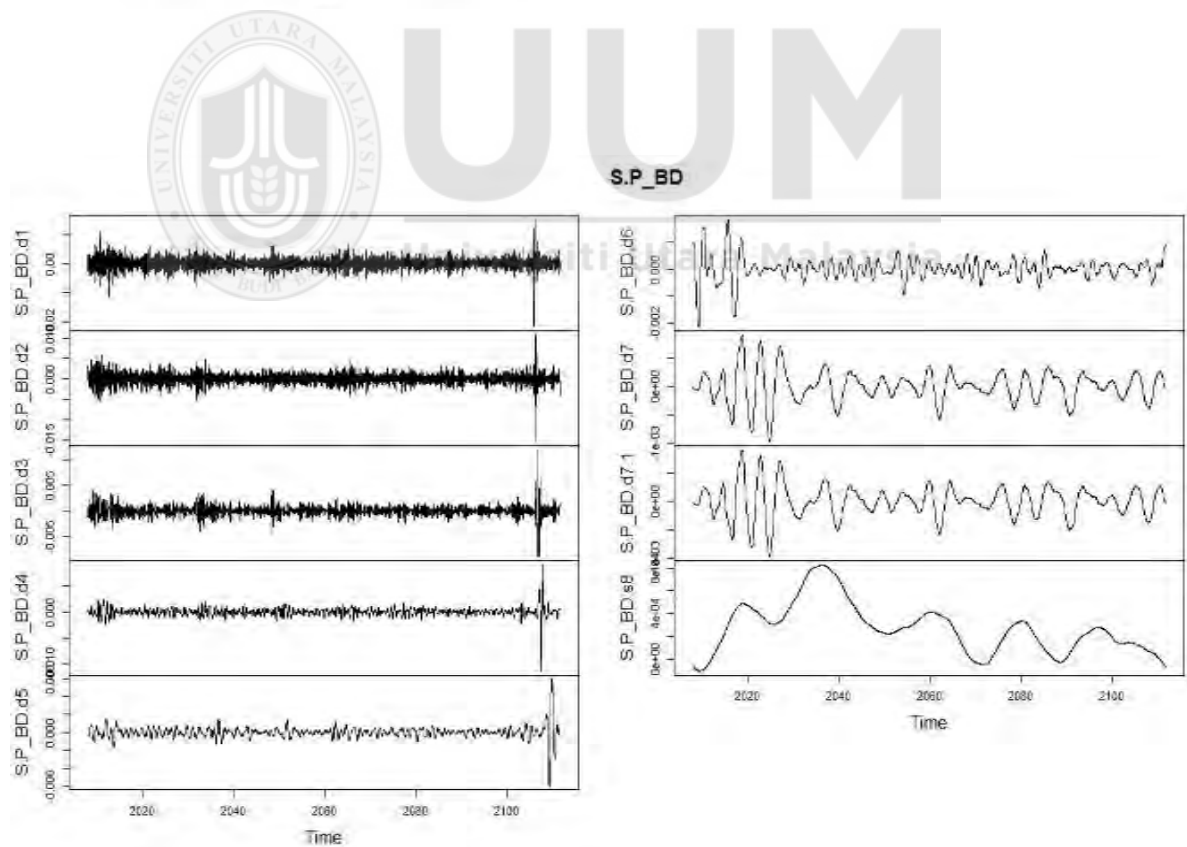
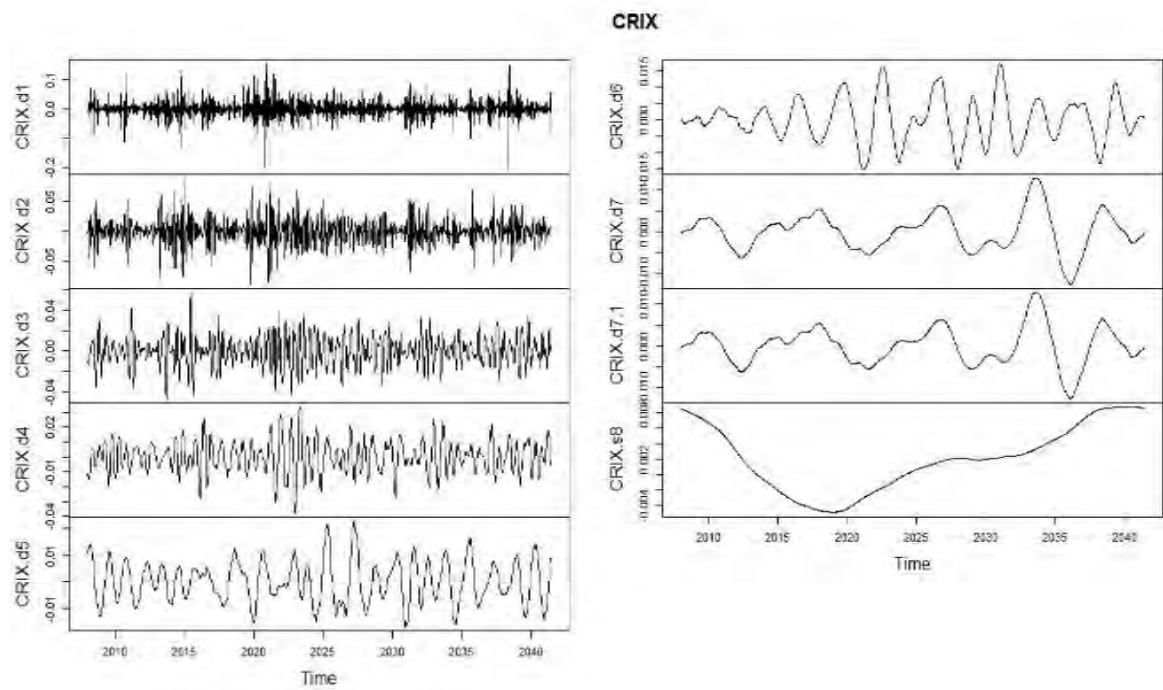
Appendix

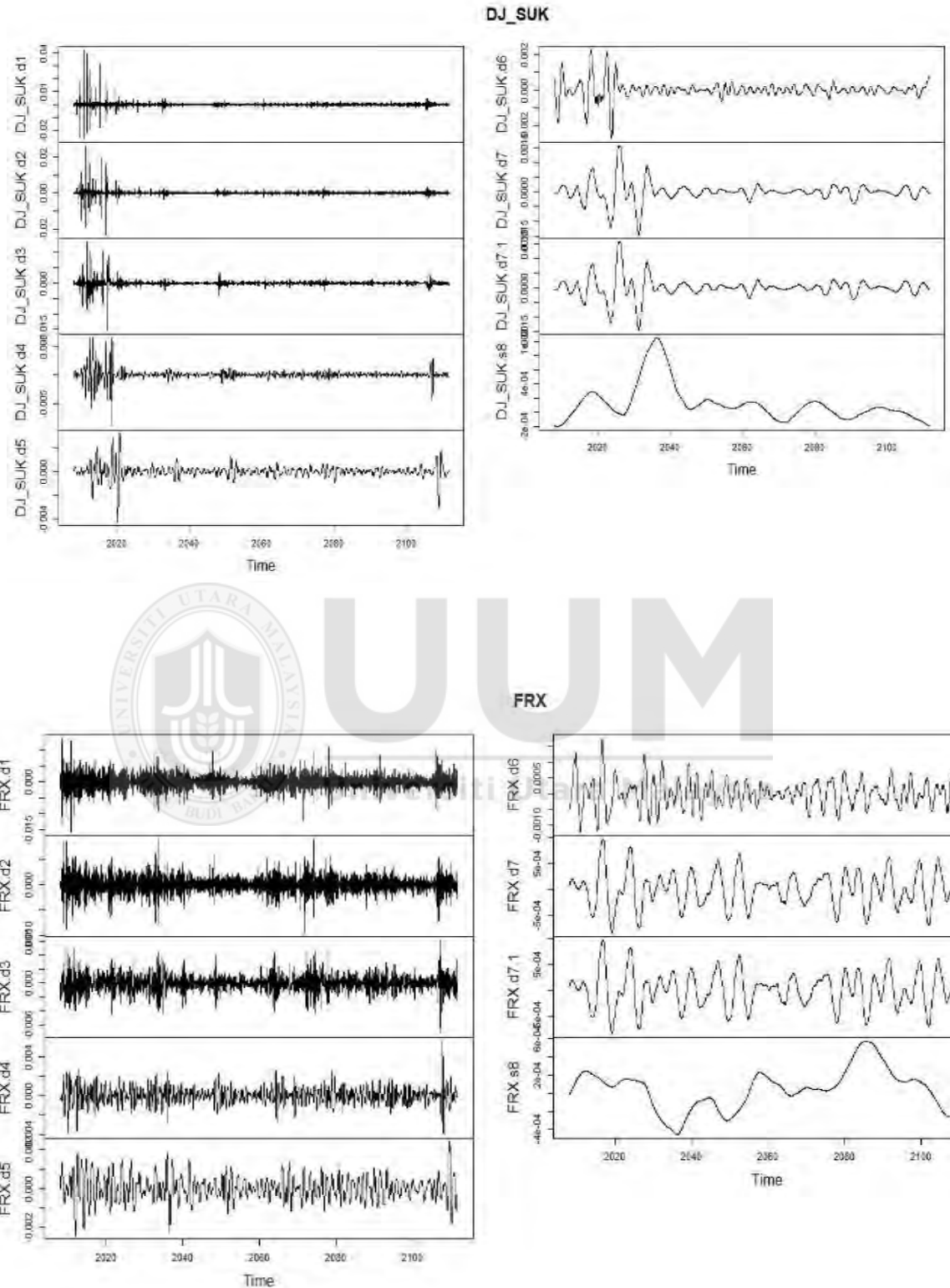
Fig 5.5

Figure 6.1: Maximal Overlap Discrete Wavelet Transform (MODWT)





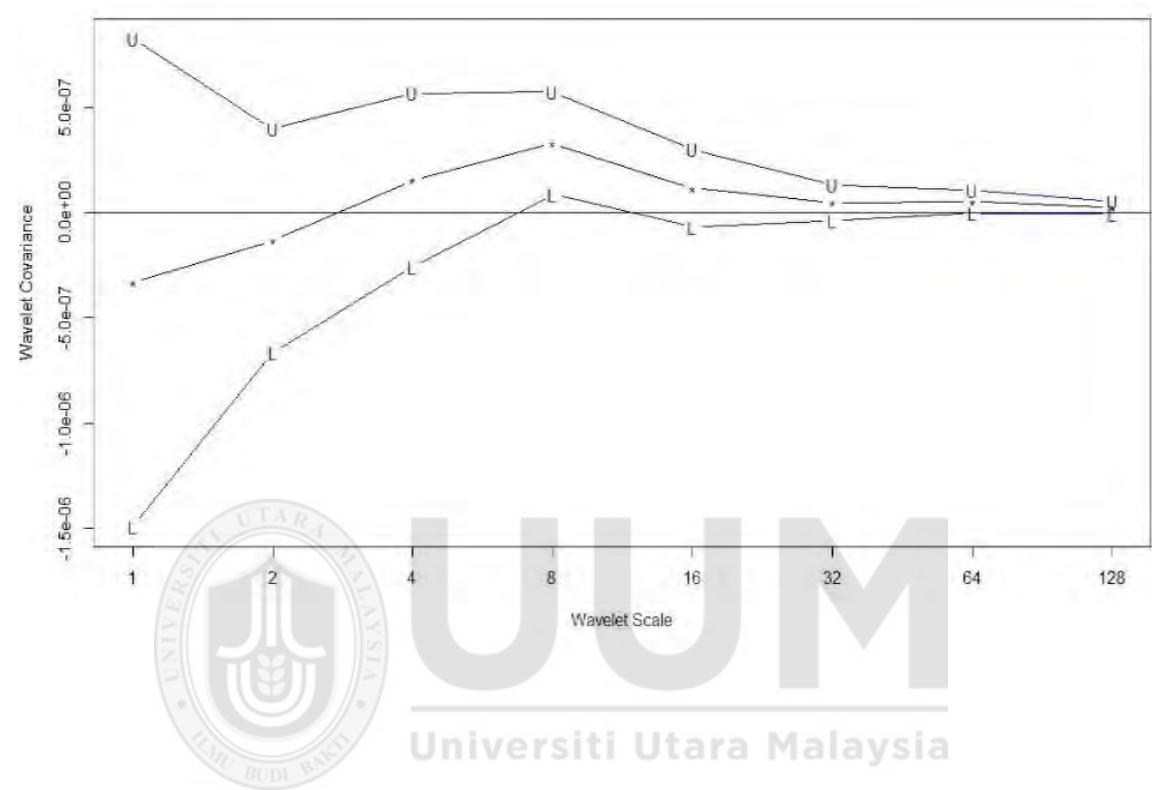




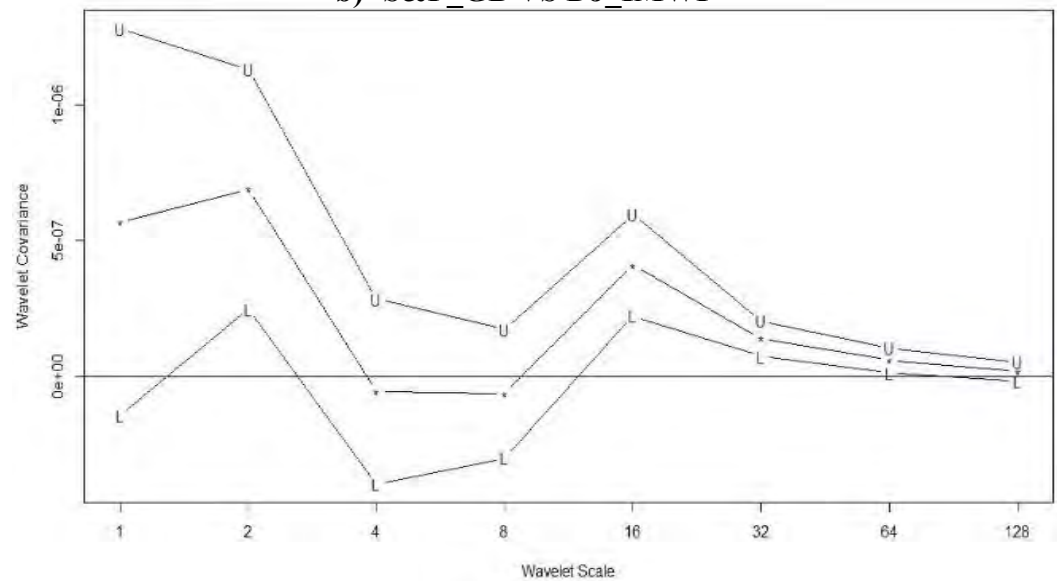
Note: MODWT decomposition of variables on $J = 8$ Wavelet Levels. While, S&P_GB, S&P_500, DJ_IMWI, S&P_GSCI, CRIX, S&P_BD, DJ_SUK and FRX is S&P green bond index, S&P 500 index, Dow Jones Islamic market world index, S&P GSCI index, Crypto index, S&P 500 bond index, Dow Jones Sukuk index and Foreign exchange index respectively.

Figure 6.2: Wavelet Covariance

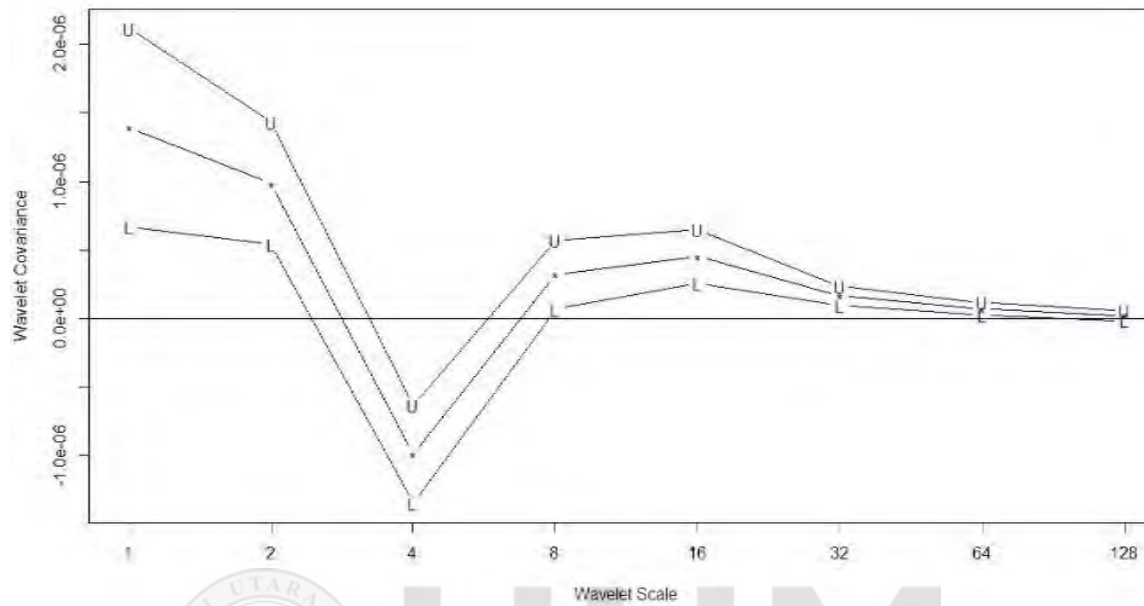
a) S&P_GB VS S&P_500



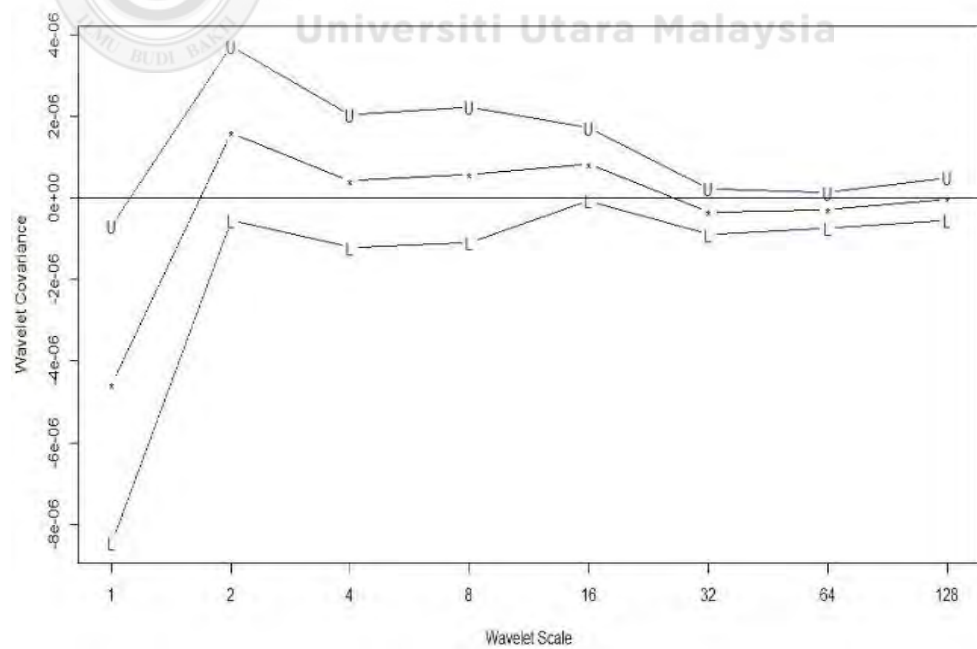
b) S&P_GB VS DJ_IMWI



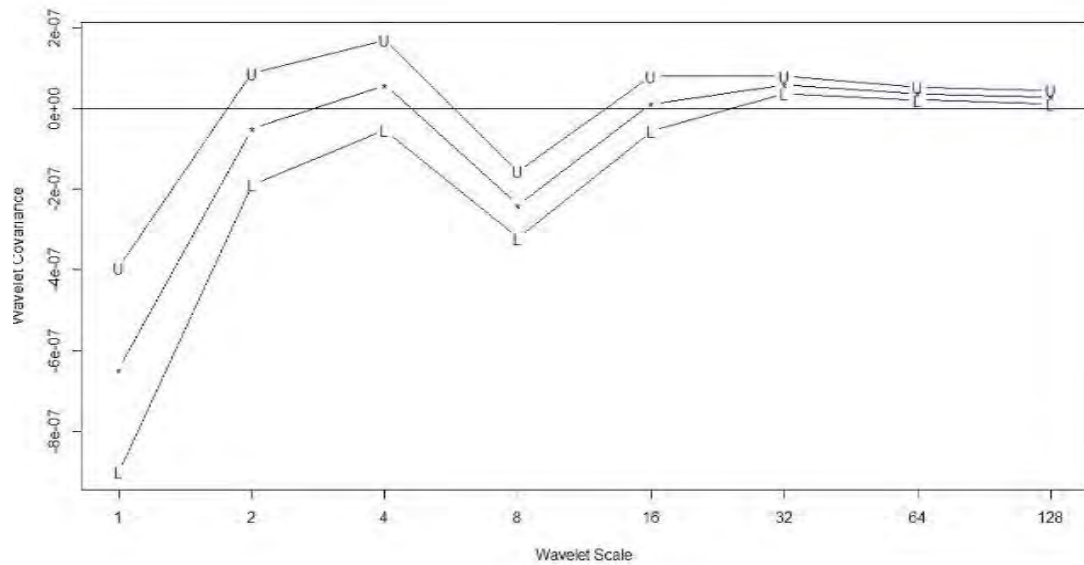
c) S&P_GB VS S&P_GSCI



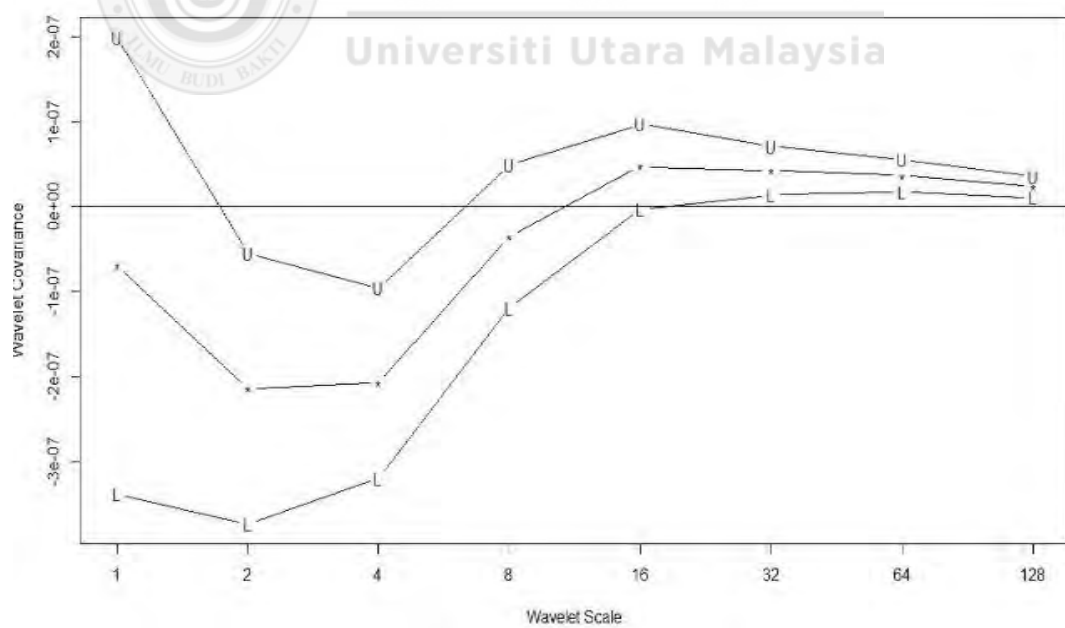
d) S&P_GB VS CRIX

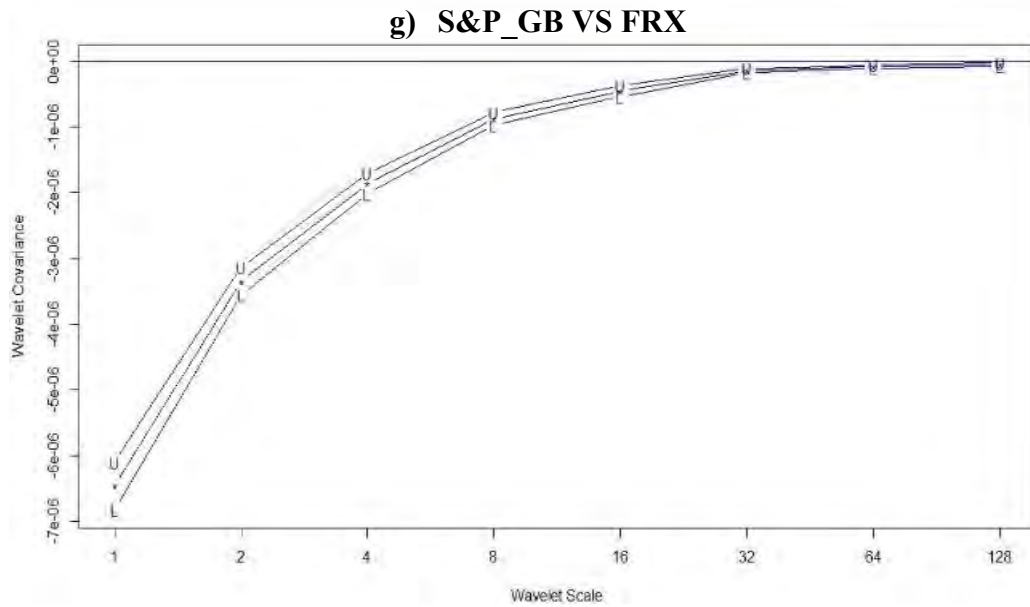


e) S&P_GB VS S&P_BD



f) S&P_GB VS DJ_SUK





Note: Fig 5.6 estimated wavelet covariance of S&P_GB with other financial markets. The “U” and “L” lines correspond to the upper and lower bounds of the corresponding 95% confidence interval. While, S&P_GB, S&P_500, DJ_IMWI, S&P_GSCI, CRIX, S&P_BD, DJ_SUK and FRX is the log-difference of S&P green bond index, S&P 500 index, Dow Jones Islamic market world index, S&P GSCI index, Crypto index, S&P 500 bond index, Dow Jones Sukuk index and Foreign exchange index respectively.