MARKET RISK AND GREEN INVESTMENT: AN EMPIRICAL ANALYSIS OF INDIAN SCENARIO

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By

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DECLARATION

I, hereby declare that the presented work in the thesis entitled **"Market risk and Green investment: An empirical analysis of Indian Scenario"** in fulfillment of degree of **Doctor of Philosophy (Ph. D.)** is outcome of research work carried out by me under the supervision of Dr. Rupinder Katoch, working as Professor, in the Mittal School of Business of Lovely Professional University, Punjab, India. In keeping with general practice of reporting scientific observations, due acknowledgements have been made whenever work described here has been based on findings of other investigator. This work has not been submitted in part or full to any other University or Institute for the award of any degree.

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CERTIFICATE

This is to certify that the work reported in the Ph. D. thesis entitled "Market risk and Green investment: An empirical analysis of Indian scenario" submitted in fulfilment of the requirement for the award of degree of **Doctor of Philosophy (Ph.D.)** in Commerce, is a research work carried out Ubaid Ahmad Peer Registration No. 12021100, is bonafide record of his original work carried out under my supervision and that no part of thesis has been submitted for any other degree, diploma or equivalent course.

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Abstract

The Indian government is now engaging in quite a few large-scale initiatives that are designed to reduce carbon dioxide emissions, and these attempts involve a range of environmentally friendly projects and infrastructural green schemes. As a result, the issue of green investment has been actively raised in India. The stock prices of Indian green companies are extremely volatile and are prone to being associated with the infestation of risk from other financial assets. This is quite natural at present, as the investment in environmentally friendly projects are still relatively new. Within the scope of this study, a comprehensive study on the volatility dynamics of Indian green companies is carried out. The purpose of this investigation is to determine whether or not it is feasible to anticipate the volatility of these stocks by utilizing data from the commodities market, the equity market, the foreign currency market, and interest rates. We analyze daily data from April 2014 to December 2023. The model that we ultimately decided to use to achieve this objective is known as a Dynamic Conditional Correlation Generalized Autoregressive Conditional Heteroskedasticity (DCC-GARCH) model and TVP-VAR. Utilizing these two techniques allows us to capture the ever-changing links and volatility spillovers that occur between these markets and green stocks. This allows us to better understand the relationship between the two. Additionally, by examining daily data with Wavelet Coherence and Partial Wavelet Coherence, we explore the mechanisms that are responsible for the discovery of prices inside these marketplaces. This is done to better understand how prices are discovered and we can realize the co-movement and causal ties that exist across the markets over a variety of periods. This is possible because of the fact that we can understand the markets. Furthermore, as a consequence of this, we have a more in-depth comprehension of how information originating from one market influences information originating from another market.

According to the findings of our research, the ARCH effects, which are instances of disruptions to short-term volatility, do not have a substantial effect on any of the four markets when they are combined with Indian green stocks. This is the conclusion that can be drawn from the findings of our study. In light of the fact that this is the circumstance, it is evident that the immediate influence of disruptions that have place

in the past on the volatility of the present is very insignificant. GARCH effects, which imply the persistence of long-term volatility, are resilient, with values constantly over 0.90 throughout all pairs. This is even though the GARCH effects have been seen. The high level of persistence that has been seen regarding the volatility of these stocks is indicative of the persistent and long-lasting influence that volatility in the commodities market, equities market, foreign currency market, and interest rates plays on the volatility of Indian green stocks. This effect has been observed for a considerable amount of time. Our comprehension of these linkages is further strengthened by the findings of the Wavelet Coherence and Partial Wavelet Coherence investigations. Except gold, silver, aluminum, copper, and natural gas, which did not exhibit a lead-lag relationship with Greenex, we found that all commodities during the COVID-19 period demonstrated lead correlations with Carbonex and Greenex. Major indices in the equities market, including the Russell 2000, NASDAQ 100, and S&P 500, all showed a lead relationship with green stocks in the same time frame. On the other hand, no meaningful lead-lag correlations were discovered between green stocks and the currency market. In conclusion, there was a positive correlation between interest rates and green stocks, especially during the peak of the COVID-19 pandemic. The DCC-GARCH model uncovers a significant GARCH effect of 0.9, indicating enduring volatility linkages across all financial instruments with Indian green stocks. Despite the absence of significant Autoregressive Conditional Heteroskedasticity (ARCH) effects, the findings underscore persistent impacts of volatility from diverse financial markets on Indian green stocks. In contrast, the TVP-VAR and QVAR models emphasize short-term volatility spillovers. The TVP-VAR's frequency connectedness framework reveals substantial short-term return spillovers, with the S&P BSE CARBONEX and GREENEX indices demonstrating mutual spillovers of approximately 37% and 41%, respectively. These findings collectively suggest a nuanced understanding of volatility dynamics. While the DCC-GARCH model highlights persistent long-term spillovers, the TVP-VAR model underscores pronounced short-term volatility interactions among financial markets and Indian green stocks. This dual perspective underscores the importance of integrating both short-term fluctuations and long-term impacts in assessing volatility spillovers, offering valuable insights for risk management and portfolio diversification strategies in green finance and broader financial markets.The intermarket volatility connectivity is mainly driven by volatility transmission in the short term (48.54 percent), compared with uncertainty transmission in the long term (12.30 percent). Furthermore, the level of connection is mainly driven by advancements, namely the transmission of shocks, in the short period, which accounts for around 48.54% of the entire impact.

The application of Wavelet coherence and partial wavelet analysis to investigate price discovery has provided insightful results into which markets are leading and lagging. Our analysis, specifically focusing on periods of significant market disruptions such as the Chinese financial crisis and the COVID-19 pandemic, reveals critical dynamics in market behavior during these turbulent times. The graphical representations of our results highlight predominantly red areas during the Chinese financial crisis and the COVID-19 pandemic, indicating strong correlations and significant lead-lag relationships during these periods. This suggests that during these crises, certain markets exhibited pronounced leadership or lagging behavior, significantly influencing the price discovery process. Understanding these dynamics is crucial for investors, fund managers, and policymakers who seek to support the growth and stability of green investments in India.

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INTRODUCTION

1.1 An Overview

The concept of sustainable development was first proposed by the "Brundtland Commission 1987", which also offered solutions to the serious environmental problems caused by globalization and economic growth. It is possible to develop and manage Brundtland Commission technology and social institutions to open the door to a new era of economic progress. Because it poses a threat to all 17 of the Sustainable Development Goals as climate change is a "code red" issue. The foundation of sustainability is a close relationship between the requirements of the present and the needs of the future. Discussions regarding environmental difficulties during United Nations meetings in the 1970s and 1980s gave rise to this idea. It has now been used in financial and economic studies. Adherence to internationally accepted norms, an openness to tackle new challenges, and adopting cutting-edge goods and technologies form the cornerstone of sustainable development. The theory has gradually found its way into the financial and economic research domains, demonstrating the importance of this field for scholarly investigation (Kates et al., 2001; Dresner, 2012; Ahi et al., 2018; Hussain et al., 2018; Tseng et al., 2018).

The financial sector is the foundation of every economy, and dramatically affects a country's capacity for economic expansion. However, to ensure sustainable economic growth, environmental considerations must be considered. The financial sector must take these issues seriously because of the growing national and worldwide ecological worries. Thus, the financial sector witnessed the emergence of a new concept known as "green investment." Green investment refers to allocating financial resources to projects or activities with positive environmental outcomes or promoting sustainable development. These initiatives focus on controlling waste disposal, reducing or eliminating greenhouse gas emissions, improving water quality, cutting back on industrial pollution, and protecting biodiversity in general. Investments in exchange-traded funds, mutual funds, and stocks of Companies whose mission is to improve the environment through business operations are also included. Bringing environmentally friendly practices into the financial and commercial domains is the primary goal of green investing. A wide range of stakeholders, including financial institutions, producers, investors, and individual and corporate clients, use it as a venue. One problem is that there needs to be a commonly agreed-upon definition of green finance. Individual viewpoints, frequently shaped by financial incentives, dictate how green investments are seen. This strategy emphasizes the benefits to the environment while concentrating on growing the environmental protection industry (Goel, 2016; wang & Zhi, 2016).

As mentioned, green investments include various financial products, including equities, bonds, mutual funds, exchange-traded funds, and loans. In addition to promoting institutional investors' participation in tandem with markets, banks are essential in helping to create project financing structures Wehinger and Nassr (2016). When compared to conventional financial instruments, green financial products are more sophisticated. Because green assets, in contrast to their non-green counterparts, need to be evaluated using Environmental, Social, and Governance (ESG) criteria, the complexity comes from this. This measurement is crucial for investors to feel confident that the assets they purchase align with ecologically sustainable methods. The increasing concern and awareness among asset managers and investors about ESG investing highlight its growing acceptance. During the past 20 years, researchers have continuously explored how socially responsible, or "S.R.," firms are operating in the stock market. The scholarly interest in the area of socially conscious investing has been extreme, particularly in the area of green investing, which is expected to be the endowment industry's quickest and most dynamic division and which "increases the positive attributes of your portfolio and decreases the negative ones" (Sadrosky, 2014). Research is increasingly turning to the examination of environmental, social, and governance, or "ESG," issues in its attempts to examine ESG trends for evidence of the extent to which the population is doing the same— the reasons behind why sustainable and responsible investment, or "SRI," is increasingly becoming important.

The global financial crisis had widespread consequences that still linger, alongside ever-growing worries relating to climate change and environmental ruin wrought by unchecked industrialization. Several large corporations had also shaken faith in ethical business practices through brazen acts of deception that prioritized profits over people—in nations like America and Britain, conscious consumerism and socially-minded investment progressed significantly as an alternative. However, the notion of directing capital toward companies embracing corporate social responsibility remained novel in India, though pockets of interest were emerging. Changing tides were foreseeable on the subcontinent as a younger generation of investors increasingly insisted that their values be respected in economic decisions. This delayed development could be attributed to investor illiteracy and the need for more publicly available Environmental, Social, and Governance (ESG) data on firms. Due to its restricted accessibility, investors cannot base their well-informed financial judgments on sustainable standards. The institutional and individual investors are starting to embrace ESG investing more and more on a global scale. Sustainable investment is still relatively new in India, even if few options are available to individual investors interested in Socially Responsible Investment (SRI) and ESG funds, which has made a substantial financial contribution to the S&P ESG India Index, a collaborative effort founded in January 2008 by Standard and Poor's, CRISIL, and KLS. The 2014 Global Sustainable Investment Review predicts that impact investing will gain increased importance in influencing the sustainable investment landscape in India. For instance, more than $1.6 billion is thought to have been invested in more than 220 impact firms throughout India, according to Intellecap, an Indian advising firm specializing in social entrepreneurs. Concern over environmental problems and responsible governance has grown dramatically globally in recent decades. These days, a company's success indicators are closely linked to several environmental factors, including using ecological resources, releasing harmful pollutants into the atmosphere, and efforts to slow down environmental degradation. Furthermore, societal considerations impact organizations, such as maintaining health standards for employees and the general public. In the corporate world, sustainability has become a ubiquitous subject. Most businesses want to develop a sustainable brand for long-term success (Tripati & Bhandari, 2014; Tripati & Bhandari, 2015; Tripati & Bhandari, 2016).

Hence, a move toward green investments has been accelerated, primarily in the clean energy field. These investments began to be in increasing demand and became famous as the majority of investors attempted to reduce the carbon footprint of their portfolios. The driving factor of this tendency is rising carbon prices. The Indian stock market is one of the components of the financial system of the country, the most important goal of which is economic development, highlighting the function of facilitating capital accumulation and provision of investment opportunities. The increasing awareness of the whole world's environmental problems forces the interest in so-called green stocks, which are shares of enterprises that are environmentally safe or produce green technologies (Kyritsis & Serletis, 2019; Mohammed & Mellit, 2023; Karkowska & Urjasz, 2023). The study explores the dynamics and performance of green technologies stocks in the Indian equity market, an area that has been under-researched when it comes to financial studies in India. The stock market is considered to be an issue of most significant importance when analyzing how the economy grows and how economic resources are accumulated within the country. RMA et al. (2021) stated that the stock market is the most critical indicator of the economy's conditions at any given moment. Changes in the stock market prices can be ascribed to several factors, including social, economic, cultural, and environmental ones. Each of these has its impact on the market, while crises are significant due to their effect on the stock market downturns.

In the wake of the global financial crisis, several studies have been carried out to assess the degree of integration between the various financial markets due to the transmission of the crisis. Consequently, the origin and nature of the crisis continue to be issues that have been necessary to investigate that aspect of the function that contributes to the transmission of the crisis. With the assistance of other regulatory bodies, international organizations such as the International Monetary Fund (IMF), the Bank of International Settlement (BIS), and the World Bank have conducted investigations into the connection between stock markets and systematic risk, which was previously disregarded before the occurrence of the financial crisis. According to the findings of these investigations, the fundamental cause of the crisis was the instability in the local markets. The preliminary roots of the crisis were revealed to be the transfer of volatility resulting from integrations between the local markets.

The Indian stock market showed several distinct patterns before and after the crisis. These patterns can be noticed in both periods. Several economic problems have surfaced due to the crisis and pandemic's influence on the pattern of the Indian stock market. This comparable to the situation described above. A tremendous amount of pressure is being imposed on the financial and currency markets as a direct result of the crisis the world is currently experiencing. The global gross domestic product (GDP) dropped to 2.1% in 2008 due to the financial crisis in 2008 and 2009. This was only one of the many adverse effects of the crisis. Most of the previous studies revealed the loss caused by the financial crisis. Additionally, these studies explored the level of interconnectedness between developed markets with a reduced potential for diversification. In addition, an interest in researching emerging markets is growing as a result of globalization and diversification.

Over the past few years, there has been a significant increase in attention paid to integrating environmental sustainability with financial markets. This study aims to investigate the phenomenon of green equity markets, with a particular emphasis on the Indian context, to investigate the effects of volatility spillover from important international equities markets, commodities markets, foreign exchange markets, and interest rate markets. It aims to provide a comprehensive knowledge of how these many factors influence the volatility of green stocks, specifically in India.

Green investing is achieved by integrating environmental, social responsibility, and governance considerations. This a process that entails incorporating environmental, social, and governance (ESG) factors into investment initiatives to enhance the portfolio's risk profile and return. Sustainable asset investments are viable across all asset classes. Various situations require ESG considerations. For example, environmental concerns may involve initiatives to mitigate climate change, reduce pollution, or optimize energy efficiency. A constituent element, social responsibility comprises labor conditions, human rights, and working conditions. Governance concerns encompass a wide range of issues, such as the board of directors' independence, tax compliance, and anti-corruption initiatives. Various financial crises and corresponding regulatory measures have occurred throughout the globe in recent decades. However, regarding detrimental effects on society, the 2008-2009 global economic crisis is considered the most significant (Stiglitz, 2010). A consequence of the situation was the downfall of an investment banking institution that was among the most sizable, established, and lucrative. Following the worldwide financial crisis, an extensive range of stakeholders began to scrutinize the functioning of financial markets as an essential element of capitalism concerning the world's sustainability, focusing on social and environmental dimensions (Stiglitz, 2017).

To address the growing challenges linked to sustainable development, public and private financial and business institutions must incorporate sustainability considerations into their decision-making procedures (Hopwood et al., 2010). On occasion, however, insufficient resource allocation and the lack of a systematic approach to strategy implementation impede the success of commendable endeavours. Without a supplementary financial system that promotes green finance and sustainability, this is a significant cause for concern. In line with monetary policy initiatives, it is promising to observe the incorporation of strategies that promote sustainability into the strategic development of global financial centres (Boubaker & Nguyen, 2019; Ng Law, 2019).

1.2 Stock Market of India

The Indian stock market is an integral part and parcel of the country's economy and financial environment. In India, it consists of two prominent exchanges: the Bombay Stock Exchange – one of the oldest in Asia – and the National Stock Exchange, which is one of the largest in the world in terms of trading volume. These exchanges allow investors to participate in a variety of financial instruments: stocks and options, fixed-income securities, and exchange-traded funds. Over the last shift, the stock market in India has undergone numerous expansions, indicative of its growing involvement and the country's economic development. One of the key indicators of industry size is industry capitalization, which has shown significant increases as several Indian companies' boasted gargantuan valuations. The I.T., pharmaceutical, banking, and consumer goods industries contributed to the rise.

One of the striking aspects that can be observed in the Indian stock market is its ability to overcome various issues and recover from them. Despite the fact that some market corrections and global economic concerns may occur from time to time, the situation in the Indian economy has always been stable by showing signs of resiliency. The country's economic recovery is explained by various reasons, such as domestic demands, reforms implemented by the government, and the growing entrepreneurial energies of Indian companies. At the same time, a new review was conducted of the overall regulatory structure that governs the Indian stock market to improve transparency and protect investors' interests. The importance of the role played by the Securities and Exchange Board of India in monitoring the market, ascertaining whether the system is fair, and protecting the market cannot be exaggerated to do the above issues. Therefore, the entities regulated concerning transparency, corporate governance requirements, instead market surveillance tools have been reviewed as a result of the actions taken by the Securities and Exchange Board of India. Moreover, there is one other point that attracts attention—yet another way in which this market reflects India's economic diversity. The Indian stock market not only serves as an indicator of opportunities for growth among large corporations but also reflects the possibilities for expansion among small and mid-cap corporations. Finally, investors also see socially and environmentally responsible investments gaining more attention in the market. This is evidenced by the increasing number of green bonds and ESG factors used when making investments.

Currently, the Indian stock market is ranked as the fifth largest in the world, and it is anticipated that by the year 2030, the market value of the Indian stock market will reach a total of ten trillion dollars. The Indian stock market has accomplished a great deal with this success. According to Jefferies, the corporate sector offers many investment options, most of which emphasize return on equity (RoE). These opportunities can be found in a variety of business sectors. A projection of future growth can also be made based on the success of the country's stock market from January 2023 up until the current day. India became the world's fourth-largest equity market for the first time, briefly surpassing Hong Kong. This is a noteworthy development that occurred. The total value of shares listed on Indian exchanges was reported to be $4.33 trillion, according to Bloomberg in January 2024. This figure was higher than the value of shares listed in Hong Kong, which was $4.29 trillion.

For the first time, India's economy surpassed US$1 trillion on May 28, 2007. On the other hand, the nation took ten years to reach the milestone of US$2 trillion in financial assets. After a gap of only four years from the previous big milestone, the next significant milestone, which was attained on May 24, 2021, was the amount of US$3 trillion. India has emerged as a competitor to China due to its quick growth in equity share. As a result, India has attracted new investments from foreign firms and investors. Several additional factors, including the nation's stable political structure and consumption-oriented economy, which continues to be one of the fastest-growing among major countries, are likely to have contributed to this remarkable accomplishment. With a particular emphasis on midcaps and small-caps, foreign portfolio investors and mutual funds invested more than US$21 billion in Indian equities in 2023. It has helped boost the S&P BSE Sensex Index, which serves as the benchmark for the country, to a record eight straight years of growth.

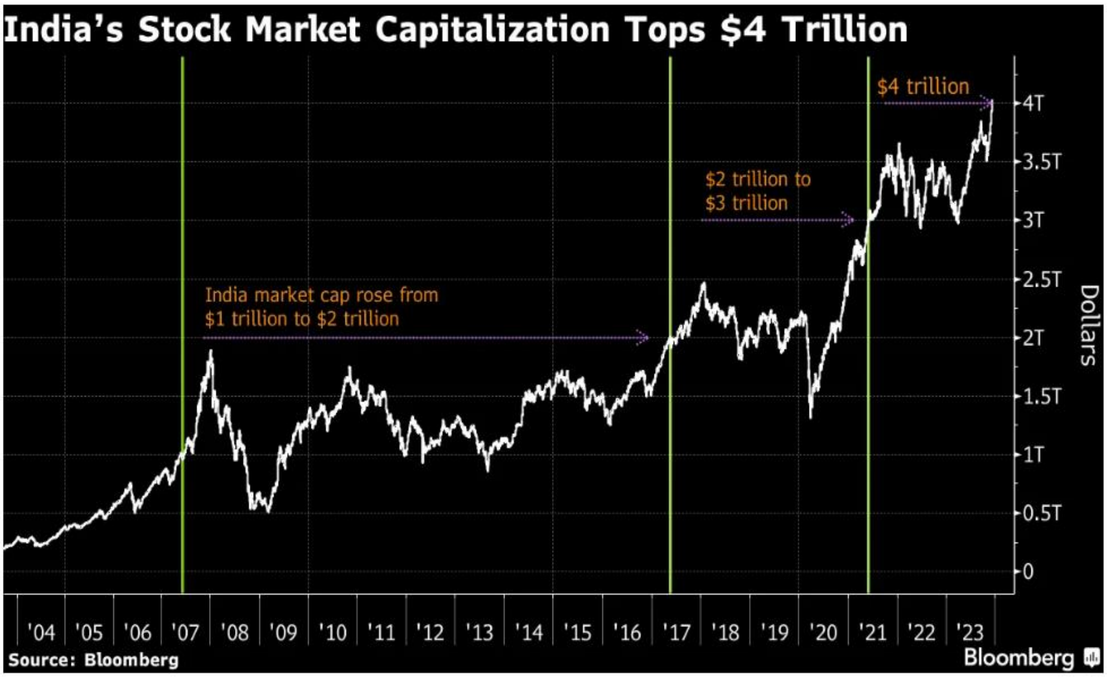


Fig 1.1 Trend in Indian Stock Market

An essential historical milestone has been reached by the Indian stock market, which has now surpassed a market capitalization of $4 trillion for the very first time. As a result of this accomplishment, India is now the fifth-largest equity market in the world. The market value of companies listed on Indian markets has increased by one trillion dollars in less than three years, as reported by Bloomberg International. The critical stock benchmarks in India have reached all-time highs, reflecting an increase of more than 13% from the beginning of the year to the present. On a net basis, foreign investors have contributed more than $15 billion to India's stock market, while domestic funds have contributed more than $20 billion to the stock market. Several steps India has undertaken to increase investment in its capital markets and industrial production have attracted much interest from investors from other countries.

1.3 Green Investment

As environmental concerns continue to escalate, the integration of green, sustainable, and responsible investments has become a critical focus for organizations. Beyond the traditional goal of profit maximization, companies are now increasingly prioritizing the alignment of their operations with environmental sustainability. Recent environmental and climate shifts have significantly heightened investor interest in resource efficiency and environmental responsibility. Since 1924, corporate social responsibility (CSR) has been recognized as a key factor influencing organizational activities, encompassing environmental, social, and economic dimensions. This broader view suggests that companies bear a responsibility not only for generating profits but also for fostering societal and economic development in harmony with the natural environment. This has led to the rise of socially responsible investments, rooted in ethical and religious movements, which have evolved into what we now recognize as green investments. The overarching goal of green investment is to achieve sustainable development. The motivation behind exploring this theme lies in the need to identify the drivers that promote green investments, as they offer substantial benefits to the economy, the environment, and private organizations alike (Han et al., 2020).

"Green investment" is a term with a wide-ranging meaning. It can be viewed as a distinct concept, a component of a larger investment strategy, or as being closely intertwined with other investment approaches. The term gained prominence as global concern for the green economy and sustainable growth surged, particularly following the 2008 financial crisis. This shift in focus was especially evident in 2010-2011, when green growth strategies were widely recognized as tools to address the crisis. The green economy was also a central theme at the United Nations Conference on Sustainable

Development in 2012. This growing emphasis has sparked a wealth of literature, with numerous publications emerging from international organizations, national governments, think tanks, experts, and non-governmental organizations, all exploring various aspects of the green economy (Allen & Clouth, 2012).

Green investments, often referred to as eco-friendly investments, ESG (Environmental, Social, and Governance) investing, socially responsible investing (SRI), sustainable investing, or responsible investing (RI), encompass a wide range of investment activities aimed at fostering environmental stewardship. These investments are driven by the objective of safeguarding the environment by reducing pollution, lowering carbon emissions, embracing alternative energy sources, and conserving natural resources. The core idea is that companies involved in green investments are not only focused on financial returns but also on making a positive impact on the planet (Inderst et al., 2012). In today's rapidly evolving market landscape, businesses are under increasing pressure from various stakeholders, including customers, regulators, and investors, to adopt more sustainable practices. This pressure, combined with the growing complexity of products and services, requires organizations to develop new capabilities and management practices to remain competitive and efficient. As a result, many companies are turning to green investments as a way to align their operations with broader environmental goals while also enhancing their market position.

The concept of green investments has been the subject of extensive research. Scholars have explored the definition of green investments, seeking to clarify what constitutes eco-friendly or responsible investment practices. This research has also delved into the numerous benefits that green investments can bring, not only for sustainable development but also for the financial performance of companies. By reducing environmental risks and improving resource efficiency, green investments can lead to cost savings, enhanced brand reputation, and increased investor confidence. Moreover, researchers have examined the factors that drive green investments. These factors include regulatory frameworks, market demand for sustainable products, technological advancements, and the growing awareness among consumers and investors about the importance of environmental sustainability. Understanding these drivers is crucial for companies and investors looking to capitalize on the opportunities presented by green investments (Han et al., 2020; Falcone, 2018; Zhang et al., 2015; Xing et al., 2019; Pekovic et al., 2018; Mokhov et al., 2018; Rauter et al., 2019).

Overall, green investments represent a strategic approach to balancing financial returns with environmental responsibility. As the world continues to face significant environmental challenges, the importance of these investments is likely to grow, making them a key component of corporate strategies aimed at achieving long-term sustainability and profitability. A relevant study delves into the varying definitions of "green" investments across different asset classes, such as stocks, bonds, and alternative investments, and offers estimates of the size of these investments under different approaches. The study finds that, due to the lack of consensus on the term "green," adopting a flexible and evolving approach to definitions and standards may be the most effective strategy. Broadly speaking, sustainable investments encompass ESG (Environmental, Social, and Governance), responsible, and socially responsible investments (Utz, 2015; Escrig-Olmedo et al., 2017; Zhang & Yousaf, 2020).

Government-regulated environmental policies often focus on reducing businesses' carbon emissions. Consequently, when governments invest in environmental protection, it may reduce the need for private sector investments in these areas. However, without robust government regulations on environmental practices, supply chain participants may not implement sufficient environmental improvements. Additionally, environmental policy actions can bolster social responsibility and promote resource conservation. The concept of green governance has gained significant traction both in academic circles and in practice. It involves measures to support ecological environments, such as resource conservation, and the development of mechanisms to regulate companies' ecological practices green investments are also viewed as environmental investments, referring to social investments aimed at improving the environment, such as individual environmental donations or the activities of socially responsible enterprises. These investments align with the concept of ecological civilization. Other researchers define green investments as those aimed at reducing greenhouse gas emissions and air pollutants, while not significantly diminishing the production and consumption of non-energy products (Costa, 2021; Wang et al., 2018; Du et al., 2019; Eyraud et al., 2013; Shi et al., 2016; Han, 2020)

In terms of impact, enhancing green systems and constructing ecological mechanisms are crucial for ensuring the sustainable development of the economy. An increase in green investments can also indirectly spur the growth of industries related to environmental protection and lead to the creation of environmental protection funds. Given the critical role that green investments and environmental practices play in various sectors, companies must address the growing concerns and challenges posed by stakeholders. Research conducted on 63 CDP (Carbon Disclosure Project) companies in South Africa revealed that organizations integrating green investments designed to reduce carbon emissions can effectively manage financial performance (Yen, 2018; Ganda & Milondzo, 2018; Ghosh et al., 2020).

1.4 Evolution of the Sustainable Stock Exchange (SSE) of Indian Prospective

Stock exchanges and evolving market structures are essential for economic growth and development. Stock exchanges, in particular, wield significant influence in formulating sustainable indices. These indices empower investors to transition their investments from environmentally unfriendly enterprises to those committed to green practices. The engagement approach further amplifies this shift towards green investment by establishing favourable practices that prioritize environmental sustainability. The World Economic Forum Report 2005 states that "making decisions that consider how decisions will affect the environment and larger society over time is generally considered part of investing responsibly." Consequently, investing in environmentally aware firms, buying clean technologies, and leaving highly hazardous corporations behind are all examples of investing in a socially responsible manner (Patel & Kumari, 2020). This multifaceted approach aligns with the broader goal of integrating responsible practices into investment strategies, reflecting an awareness of the impact investments can have on society and the environment.

The U.N. Global Compact's first ray into the financial world entailed the participation of several international stock markets. This event occurred in 2004 at U.N. Headquarters in New York. After the discussion, the Global Compact published a joint statement with ten exchanges, all "committing to exploring further areas for substantive cooperation." Based on this experience, in 2008, UNCTAD and the Principles for Responsible Investment organized two seminars held at U.N. Headquarters in Geneva.

The events gathered investors, stock exchanges, financial information providers, and public policymakers focused on promoting responsible practices of investment in developing countries and the associated regulatory system.

The Sustainable Stock Exchanges initiative emerged from collaborative efforts between crucial United Nations organizations to promote sustainability within financial markets. Established in 2009 under Secretary-General Ban Ki-Moon, the first SSE Global Dialogue convened in New York City brought together leaders from intergovernmental bodies, including the International Organisation of Securities Commissions and the World Federation of Exchanges. Also in attendance were delegates representing stock exchanges and institutional investors worldwide. The dialogue underscored the importance of examining the influence of fluctuating commodity prices on socially responsible equities in India during periods of high and low economic uncertainty. Hold three years later in 2012, the subsequent Sustainable Stock Exchange Global Dialogue further analyzed the pivotal role global exchanges play in encouraging long-term, environmentally-conscious investment and cultivating markets committed to sustainability. During this dialogue, participants likely engaged in discussions, presentations, and collaborative efforts to address the challenges and opportunities associated with integrating sustainability into financial markets. The SSE 2012 Global Dialogue played a role in advancing the mission of the SSE initiative, contributing to the ongoing global conversation on sustainable investment and development. These countries are recognized as founding members of SSE Partner Exchanges for their commitment to promoting sustainability in their markets (Brazil, Egypt, South Africa, Turkey, United States, and India). They were crucial in establishing the SSE Initiative's core principles and goals.

1.5 India's Sustainable Stock Exchange

Sustainability refers to the capacity to fulfil current requirements without compromising the ability of future generations to meet their own needs. E environmentalists have continuously warned about the harmful consequences of our current economic growth and use of resources on the Earth's ability to sustain life, causing concerns about the potential for ecological collapse. This a collaborative endeavour that aims to improve the long-term profitability of businesses and advocate for investment strategies that align with ethical standards. After recognizing the proactive initiatives of BSE, UNCTAD strongly encouraged the exchange to become a part of the Sustainable Stock Exchange Initiative. As a result, BSE has become the first stock exchange in Asia to comply with this worldwide initiative, demonstrating its dedication to promoting sustainable investing and improving transparency in environmental, social, and corporate governance.

BSE, recognizing its responsibilities as an ethical stock exchange, has undertaken numerous sustainability and corporate social responsibility initiatives. A significant effort is the introduction of theme-based indices, such as the S&P BSE Carbonex and S&P BSE Greenex. A proactive participant in the sustainable stock exchanges project, BSE has demonstrated its commitment by establishing a formal agreement with the Ministry of Corporate Affairs and creating a corporate social responsibility index.

The S&P BSE GREENEX and S&P BSE CARBONEX indices meticulously track the stock prices of businesses dedicated to environmental preservation in India. This is a surveillance system for GREENEX mainly monitors corporations emphasizing ecological sustainability across their enterprises, in precisely gauging the functioning of the top twenty-five companies displaying excellence in this domain. Selection relies upon particular qualifications, like atmospheric carbon volume, corporate scale, and liquid assets. Companies dynamically investing in planet-friendly ventures or technologies ameliorating nature constitute "green stocks." Such areas involve sustainable energy creation, energy efficiency advances, material reprocessing, waste administration, and water administration. To be incorporated, these corporations must rigorously enact extensive steps to preclude unmediated environmental harm in everyday functioning.

Additionally, the S&P BSE CARBONEX index appraises firms listed on the S&P BSE 100 and emphasizes their dedication to reducing climate risks. The objective is to accurately portray enterprises in the broader market, motivating an active approach to climate issues. It offers investors a valuable tool to align their portfolios with environmentally aware and climate-conscious businesses. Tracking these indexes gives insights into the financial performance of companies prioritizing sustainability and mitigating climate risks. These benchmarks contribute to cultivating a greener and more ecologically conscious investment landscape across India. The formation of Carbonex and Greenex can be seen in Table 1.1 with varying levels of commitment to sustainability by companies and their exposures to environmental risks.

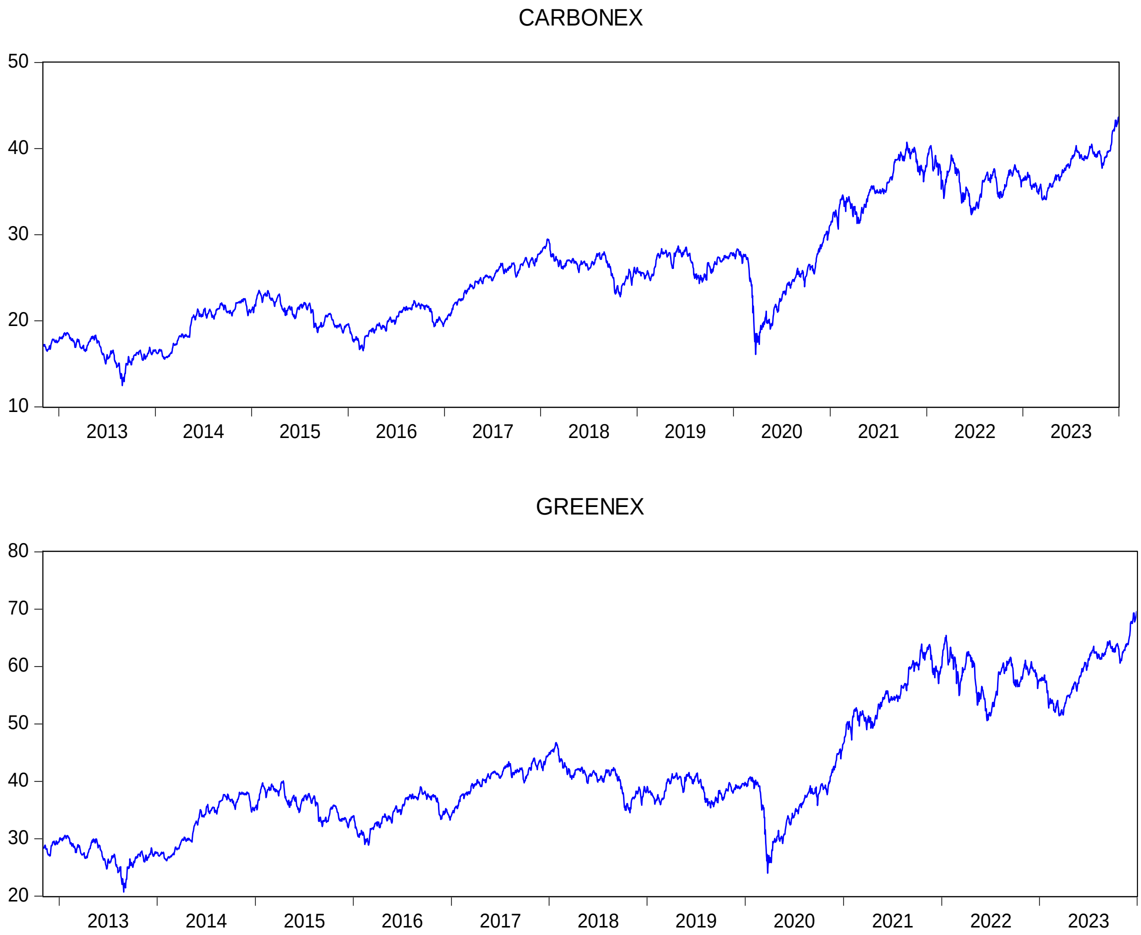


Fig 1.2 Trend in Carbonex and Greenex index

Before the global financial crisis of 2008-2009, the Principles for Responsible Investment (PRI) and Socially Responsible Investment (SRI) were formulated (Krosinsky & Robins, 2008; Blowfield & Murray, 2014). The cross-disciplinary movement towards green and sustainable finance and investment has developed in response to the growing concern of stakeholders regarding social and environmental sustainability, climate change-related issues and hazards, and the like. In addition to its traditional purpose of generating financial returns for shareholders and stimulating economic growth, corporate financial activities have been recognized as crucial drivers in establishing a sustainable society and environment (Waygood, 2011). Decades ago, financial regulators in developed economies made substantial progress in convincing private sector financial institutions to incorporate broader social and environmental concerns into their business operations, especially in light of the threat posed by climate change (TCFD 2017). Beyond merely advocating for financial institutions to generate value for investors, these endeavours have expanded.

The significance of sustainable finance and investment on the global agenda has been elevated due to international consensus on climate change's intergenerational consequences and dangers. Both developed and developing nations have garnered significant support for the United Nations Sustainable Development Goals (SDGs). The organization established these objectives in 2030 and seeks to tackle many challenges associated with sustainable development. Despite divergent governmental ideologies, distinguished global economies like the United States and China have endorsed the Paris Agreement to reduce greenhouse gas emissions expeditiously. Emerging global initiatives of this nature have provided momentum for the continued development of a green finance ecosystem by private-sector financial institutions (Carney, 2012).

The association between green stocks and other financial assets in developing nations like India remains ambiguous despite projections suggesting that up to US$ 686 billion will be allocated to green enterprises by 2033. Following the implementation of the United Nations Framework Convention on Climate Change (UNFCCC) Paris Agreement in 2016, there has been a substantial increase in global green investment. India has also observed a commensurate rise in this trend. The Indian government has established ambitious targets, seeking to reduce CO2 emissions by 35% compared to 2005 levels and raise the share of power capacity generated from renewable sources to 40% by 2030. To achieve this goal, the Indian government has introduced measures to fund a diverse array of environmentally sustainable enterprises and infrastructure.

The interconnections between different assets or stock markets, regardless of whether they are developed or emerging, have been the subject of many theories that have been used to provide insight into the connections between these stock markets. An earlier study demonstrated the association between the Indian stock market and other markets. This correlation was shown through the utilization of contemporary financial and geographical diversification ideas. A further benefit of the theory of international portfolio diversification is that it offers valuable insights into the theoretical connections between various stock markets. This will be followed by the subsequent sections, which will provide a detailed overview of these instructive scholarly connections. Furthermore, the Keynesian theory explains how the government plays a role in the growth of the financial sectors of economies such as India and other nations. The way in which the precision of the literature is pertinent to these inquiries is by making use of this theoretical framework.

1.6 Basic Theories on Financial Market

The Capital Asset Pricing Model (CAPM) and the Black Swan Theory are considered fundamental pillars of contemporary financial theories with enduring relevance. At the same time, both models' foundational assumptions are deemed essential. With its conceptual framework, the Efficient Market Hypothesis (EMH) is the foundation upon which these theories are built. The EMH is based on logical Analysis. As a result of the rise of behavioral finance theory in the 1980s, however, the landscape of financial theory started to move in a different direction. Even though there has been a significant increase in the amount of research conducted over the past few years, there still needs to be more consensus within the particular subject, which makes it challenging to build a coherent theoretical framework. Shiller (1999) asserts that behavioral finance can be characterized on several different levels, further exemplifying this research field's complexity.

There are numerous popular theories concerning the stock market and the behavior of investors, all of which assert that there is a connection between the two elements, such as the following:

1.6.1 Efficient Capital Market Theory

In the theory of efficient capital markets, the most widely accepted theory is the Efficient Market Hypothesis or EMH, developed by E. Fama in 1970. This theory suggests that because stock prices reflect all the pertinent information that is currently available, equities are being traded at their actual value. The efficient market hypothesis or EMH is a critical concept, with researchers claiming that no investor in financial markets may receive a higher rate of return than the market. In today's world, the majority of abnormalities are anticipated to be eliminated. According to E. Fama (1970), when a market event occurs, the current prices will accurately reflect all of the relevant information regarding the actual value of assets. The effective market can consolidate data by utilizing this method, raising buyers' freedoms while simultaneously providing sellers protection. A controversial debate is taking place among academics, and at the same time, they have also addressed the production level. This debate is taking place regardless of whether or not the markets are acceptable. Even though there are a significant number of researchers who provide evidence in favor of EMH, there are also a considerable number of researchers who are against it. Based on their findings, these researchers believe it is unnecessary to make predictions about the market by conducting fundamental or technology studies.

According to E. Fama (1970), allocating responsibility for the stock of capital in the economy is the most fundamental transaction in any market. He was under the impression that an ideal market would provide clear signs of asset allocation. With this clarification, it was clear that corporations consented to decisions regarding formation and investment in a market, and investors selected hedges that appealed to responsibility. Using theory, Apiyeva (2007) and Fama (2021) claimed that a competent market is one in which the values of securities fully represent all of the accessible data. Jensen (1968) states that it is impossible to outperform the market, and he alludes to the fact that investors cannot derive extraordinary gains from the pattern of price movements in the stock market.

Nevertheless, stock values tend to vary unpredictably; hence, it is impossible to effectively forecast future prices depending on historical patterns (Tursoy et al., 2008). The hypotheses demonstrate three distinct types of market adequacy, which categorize markets according to the degree of efficiency they possess. Examples of poor market types include a productivity rating in which prices reflect all of the accessible data from the past. This is an example of a market type. On the other hand, investors cannot outperform the market by examining stock data that can be independently confirmed. This is the case that investors face.

A similar concept is semi-solid efficiency, which refers to the degree of efficiency at which stock prices are represented in a significant amount of readily available data for a specific period. According to Fama (1970), this level is mainly connected to the pace of change in the stock prices of the variables. According to Handa and Khan (2008), the stringent qualification type is the third and most advanced level of implicit efficiency. This efficiency occurs when stock market prices meet both fragile and semi-rigid states and expansion criteria, which demand stock prices to reflect future data. To this degree of efficiency, there is no insider exchange, and the company's internal auditors need access to fundamental data about future investment decisions that would enable them to produce profits more significant than the average returns on the market.

The foundation of the EMH is comprised of three basic kinds, each of which represents a different level of market efficiency:

Weak Form Efficiency: According to this theory, current stock prices already consider all past price and volume information. Technical Analysis is, therefore, considered unproductive since it uses historical market data to forecast future price changes. It is not feasible for buyers to consistently outperform the overall market by studying past trading trends or patterns.

Moderate Form Efficiency: The mild form of EMH postulates that stock prices effectively incorporate into consideration everything that is publicly accessible, including headlines, accounting records, and indicators of the economy, along with previous data. As such, it is impossible to consistently get higher returns using either fundamental Analysis or the utilization of publicly available information. New knowledge is immediately and correctly reflected in prices, making any attempt to profit from it pointless.

Strong Form Efficiency: The EMH's strong form goes one step further and asserts that the prices of the shares accurately show all information, both private and public. It suggests that obtaining a long-term competitive advantage in the market is impossible, even with insider knowledge. Investors can only regularly beat Marketplace in a well-organized, effective market.

1.6.2 Capital Asset Pricing Model (CAPM)

The purpose of the Capital Asset Pricing Model, more commonly referred to as CAPM, is to ascertain the degree to which risk and anticipated returns mutually depend on one another. On the other hand, one interpretation of this is that the Beta of an investment is what determines its expected return, or the degree to which the investment is volatile compared to the market. C PM, on the other hand, has been exposed to criticism due to the simplifying assumptions that it makes. Even though we are presented with an overwhelming amount of information in the modern world, we only have a limited amount of time and resources to deal with it acceptably. According to Cohen (1979), investors must decide where to concentrate their limited attention. This indicates that not every piece of information receives the same amount of attention for the same reason. Using the term "recognition of investor," which suggests that investors place a substantial level of attention on stock markets, Merton (1987) was the first person to use the word. The asset pricing theory proposes that while assessing a stock's value, investors should consider all of the information that draws their attention. This based on the findings presented by Peng et al. (2006).

For this reason, it is essential to have an awareness of the dynamics of investor attention to have a complete comprehension of the behavior of the financial market. It is also conceivable to refer to the stock markets as the stock exchanges because of their similarities. The idea of a stock exchange has existed for quite some time; the first known exchange was created in Antwerp, Belgium, in the sixteenth century. As a result of changes in technology and market dynamics, stock markets have evolved and become more complicated over time. This is because the market has become more complex. In today's world, there are many operational stock exchanges, and each of these markets has its own individual set of rules and regulations that govern themselves. Having at least one stock market owned and operated by a nation is typical.

1.6.3 Keynesian theory

The Keynesian theory, developed by Keynes in 1936, greatly influenced the formulation of monetary policy in addressing economic recessions (Kim et al., 2009). In line with Keynesian principles, inflation occurs when aggregate demand exceeds available supply, increasing the general price. Keynes argued that in a well-functioning economy, increases in government spending and higher levels of private consumption and investment might boost the overall demand for goods and services (Dymski & Kaltenbrunner, 2021; Reddy, 2012). the excessive pressure and a broad increase in price levels result from an economy running at total capacity and utilizing its resources to their limitations. This results in the economy being unable to raise its total supply to meet the rising aggregate demand. Additionally, this theory demonstrates that the influence of the government may be seen in the variations of stock values and the shifts in the market for goods and services within the economy.

The Keynesian Economic Theory argument is that in the case of an economic recession, the government should intervene to avoid further economic downturn. A free-market economy is characterized by boom and bust cycles, and the government can control the magnitudes of these cycles. The boom and bust cycles characterize free market economies. Because these cycles are already expected, this occurs. A British economist named John Maynard Keynes was the first person to put forth the idea in the 1940s. Kynes is most renowned for his works on the economics of war, as well as his involvement in setting up the International Monetary Fund and the World Bank. As per the Keynesian Economic Theory, the government should continuously observe three key indicators. Suppose you understood the Keynesian Economic Theory to know the relationship among interest rates, tax rates, and social programs. At a time when there was a period of economic expansion, the Keynesian Economic Theory suggests that a central bank should raise interest rates. At the same time, it is vital to restrict the extent of financial booms, but it is also essential to avoid a severe recession from arising. This is because excessive investment in both the public and private sectors can lower the amount of money accessible to the government. According to the Keynesian economic theory, to be prepared for probable economic downturns in the future, commercial banks and central banks should increase their cash reserves in reaction to increases in interest rates. The Keynesian theory says this will help them be better prepared.

1.6.4 International Portfolio Diversification Theory

An investor's portfolio can contain various gold securities, bonds, and worldwide equity markets, depending on the investor's preferences. Portfolio investors who have a variety of equity from a variety of foreign stock markets that are negatively correlated with one another are the ones who benefit from greater diversification of their holdings. The unfavourable and uncorrelated link that exists between stocks that are located on foreign stock exchanges is something that must be taken into mind in the case of a financial crisis. This a significant factor to take into account. Since the beginning of time, gold and other assets have been regarded as a haven asset. Even in times of war, recession, or catastrophe, having some of these things is desirable.

Due to the liquidity risk, Baur and Lucey (2010) find that during times of crisis, certain forms of stock markets, such as the gold market, are seen to be more secure than stock markets. This is because gold markets are more liquid than stock markets. There is a negative association between the stock market and the gold market, particularly during times of crisis or recession, according to Anand, Tulin, and Kumar (2014). This is especially true during times of economic instability. Thus, the two markets move in different directions; investors may diversify their risk by establishing a portfolio that includes gold and equities. This is done if the two markets do not move jointly. The relationship between gold and stocks can be described using two characteristics: diversification and safety. These characteristics can be used to explain the relationship more accurately. So, the influence of gold on the stock market was explored in their studies both before and after the crisis era. This was done to understand the situation better.

Researchers found in previous research that the risk associated with a portfolio may be defined by comparing the return variance of the portfolio to the return variance of the market. This was done to determine the value of the portfolio's risk. This ratio is usually referred to as the beta coefficient when it is discussed in the context of mathematics. As a result of this, the risk that is connected with a portfolio falls at a quick rate as the number of assets that are associated with the portfolio increases. Finally, it approaches the level of systematic risk. Thus, both systematic and unsystematic risks are present in the portfolio. In the context of a fully diversified domestic portfolio with a beta (β) value of 1, the market risk is regarded as precisely one.

If we consciously decide to invest in multiple countries, what are the possibilities we face? As a consequence of this, there has been an increase in the percentage of investors. A wide range of asset classes and financial instruments can be utilized at any given location globally. Solnik (1974) investigates how investing in foreign stock can significantly increase profits. This accomplished with the assistance of diversification tactics. It has been suggested by Huang, X., & Wang, X. (2021) that a global portfolio that incorporates assets from the United States can be of assistance in reducing the overall risk of the portfolio.

The benefits of international diversification have been diminished over the past several years due to the globalization of financial markets and the cointegration of economies worldwide. The presence of multinational corporations and organizations, the growth of information technology, investments that cross international borders, and the capacity of major currencies to be translated into one another all contribute to the interconnectedness of national economies in the modern world. Because economies worldwide are interconnected, international variety is less valuable than in other circumstances.

An analysis conducted by (Miziołek et al., 2020) indicates that the benefits obtained due to globalization have not undergone any substantial modifications. When there is a regional influence brought about by globalization, as is the case in the European Union (E.U.), there is an increase in the variance composition. The advantages of global diversification will probably be diminished if the economic ties within a specific economic zone become more closely intertwined. Because certain regions are primarily autonomous, investors from other nations can diversify their interests. Because of the different business cycles and levels of economic growth, it is possible that even countries that are physically next to one another do not have a strong link. This is because their economies are growing at different rates. Despite the current circumstances, the region's diversification still has a feasible potential. A global stock market or correlation coefficients of economic areas need to be found to ascertain if the stock prices of nations and regions move in the same direction or whether they move in opposing ways and are disconnected from one another. This is necessary to evaluate whether or not financial markets are connected. The ability of major currencies to be converted into one another, the development of new technologies, and investments that cross international borders are all examples of this phenomenon. Because economies worldwide are intertwined in many ways, the value of global diversity is likely lower than it would be under different conditions.

In India, investment in environmentally sustainable initiatives is still developing despite its significant growth potential. The stock prices of environmentally conscious companies in India are susceptible to heightened volatility and risk transference from other asset classes owing to the prevailing market uncertainties. There is a plethora of dynamic interactions that affect the precision of volatility prediction and the complexity of asset price swings. For the stakeholders in the market, such as portfolio managers and investors, there are several opportunities and challenges. An opportunity is that precise environmental awareness raises the rise of the green investing sector. The government is also committed to promoting green investments. An investor can thus come up with specific environment-friendly stocks and benefit from the escalating demand. Therefore, investors will be associated with the inchoate growth of the sector, thereby increasing the complexity and risk. Such rates affect the asset pricing dynamics and the investment strategies. Thus, the relationship between green stocks and traditional financial assets in India is crucial, and investors need to strive to understand the correlation. For instance, it would enable them to understand the drivers of volatility and risks and how they are linked to different asset classes, hence coming up with superior investment strategies. Additionally, it is crucial to conduct more research and studies to help understand how investing patterns change over time. This will also help to make informed decisions.

Bank of America predicts that India's green energy sector will receive a one-off investment of $800 billion over the next decade. The fund will come from various sources, including Indian corporations, foreign investors, and sponsors. According to institutional investors, India is a befitting destination for strategic investors. The anticipated $800 billion shows how an investor can naturalize climatically with integrated operations with net zero by 2050. The money is split into three main categories. The bank forecasts that $250 billion will be invested in renewable energy sources. Other $250 billion will be invested in batteries, while the last $300 billion will be invested in grid networks, green hydrogens, and overall equipment and facilities to cushion the green environment.

Such a strong projection indicates the increased pace of India as a potential center for green energy investments. The diverse allocation of this investment across renewable energy, energy storage, and supplementary infrastructure displays the complex approach toward more sustainable practices and the need to adapt to the changing energy markets. With companies and investors becoming more aware of the benefits of green energy and the necessity of such initiatives, India can potentially become a significant figure in shaping this type of investment.

Cornell 2021 reported that Environmental, Social, and Governance investors were more attractive to the investors, including their friendliness to the world. The washout machine implies that during the transition period, when all investors are washing out their preference for ESG and green stocks, all investors period independently refer to a stationary state and prescribe to the remaining "stock decay" in those stocks that wash out from "bad and evil" companies to those representing environmentally friendly green properties "good and friendly to the world." After all, the discount rate for green stock valuation decreases, and the cost decrease becomes significant during the transition period. These factors also show that the sophisticated structure of environmentally friendly investments began investing in the new nature of today's changing world. Given the transition period, it realized that the higher risks associated with investments in green stocks could make them more demanding to the financial market and curtail their attractiveness, thus slowing down risk-adjusted return. In such conditions, it is necessary to consider the optimal investments among other assets and determine the acceptable level for each type. For additional information on green stock indices of changing volatility, it is essential to investigate the additional available data about their risk class. Although political M.P.s and some investors have already been interested in the extent of the new asset classes in the various market cycles in India, more comprehensive information about the area is still required.

Green assets are an emerging investment class, but expansive evidence needs to be provided about how they behave under different market conditions in India. However, green assets are exposed to significant events that come under market risks. These include equity, commodity, exchange, and interest rate risks, which have significant repercussions on green assets. They manifest unique patterns of risk transmission during periods of high uncertainty.

Moreover, during different market conditions, there are diverse shocks of various macroeconomic actors on green assets, such as oil, gas, gold, and silver prices, among others. The cross-impact relationship in volatility transmission may differ, and thus, the spillover effects are different. For example, according to the research conducted by Tiwari et al. (2018), during a down market, Indian green indexes are affected by asymmetric oil price shocks, and such a relationship is not characteristic of the bull market. Therefore, it is essential to consider the impact of commodities prices on environmentally friendly equities in India during the low and high uncertainty periods. Due to the fact that with the help of two separate phases of the high and low trends of oil and gold market volatilities, it is possible to notice the strong impact of these commodity prices on the demand for green assets, the high responsiveness represents a higher susceptibility of these stocks indexes to the negative news or events. Therefore, the higher vulnerability serves as a more decisive factor contributing to the riskier and more uncertain economic situation. In this way, by conducting a holistic analysis of the impact of market risk volatility on this asset class, it is possible to develop a better understanding of the potential investment risks. This information can be helpful for the market participants in the scope of prediction and, thus, managing their risks associated with green stocks more accurately.

1.7 Trends for the Next Decade of Sustainable Investing

Environmental, social, and governance practices are a top priority for investors, who increasingly view them as a way to unite financial gain and all-encompassing business ideals. 2021 became a pivotal period for Sustainability Funds, as it was anticipated by many analysts to reach a new level of growth. In line with these expectations, Morningstar's data indicated the substantial extent to which this trend was established, presenting $185.3 billion as the organic growth into sustainability funds starter within the first quarter of 2021, which reflected a 17 percent increase in comparison with Q4 2020. Moreover, these funds proved to display exceptional performance, reaching an 8.76 percent return in Q2, which became a paramount value higher than both the US Market Index and the US Large-Mid Cap Index. 2 23 remained to be an epoch of a stunning upsurge in the count of world governments and the most influential companies of today, which provided a commitment to reach 0% net carbon emissions along the vector of 2050. An aspect of this goal that could be deemed to be particularly inspiring refers to the future where the percentage of corporate-based fossil fuel utilization and GHG production would be cut dramatically, potentially down to 0%. In contrast, the inflow toward renewable energy sources would constitute a substantial portion of total energy consumption. In spite of this advancement, there is still an abundance of enterprise-angled commitments that still need to contain midrange emission reduction targets or materials that are aimed at assessing indirect supply chain emissions.

In the next decade, investors and businesses will have to deal with the intricate world of sustainable finance to make informed decisions, mitigate risks, and benefit from new investment opportunities—the most vital findings from the Institute's "Guiding through the Next Decade. Over the years to come, there will be a considerable increase in a wide array of sustainable investment products and approaches that will conform to the growing ESG consideration. In addition, the rising demand for land, minerals, and advanced technologies required for the shift to net zero will become apparent. Finally, there will be an influx of government rules worldwide, forcing companies to adapt their strategy, disclosure, and data practices.

Stakeholders and investors are becoming more aware of this gap and are pressing organizations to develop practical, short-term tactics for evaluating the progress of corporate ESG commitments and goals. Instead of relying solely on distant pledges, long-term stakeholders will demand realistic and measurable short-term benchmarks from governments and companies. This approach aims to prevent companies from making hollow ESG promises without genuine plans for implementation, fostering accountability and fostering significant strides towards decarbonization. The need for stakeholders to take immediate action is driven by climate change's imminent and rapidly escalating consequences. A report issued by the U.N.'s Intergovernmental Panel on Climate Change emphasized the vital importance of achieving global net zero emissions by 2050 to mitigate the severe impacts of climate change. These consequences were starkly characterized by the U.N. Secretary-General as "a code red for humanity," emphasizing the urgency of the matter. Creased occurrences of climate-related natural disasters in the future have shifted shareholder focus toward risk management and corporations' preparedness to deal with the aftermath of such events. While companies need to mitigate greenhouse gas emissions, they must also prioritize measures to shield themselves from the climatic repercussions of these emissions. Companies across various sectors are reacting to these pressures, with the total issuance of sustainable debt reaching an all-time high of approximately $960 billion last year, marking a 61% surge from 2020, according to data from the Environmental Finance Bond Database. This is a significant sum that encompasses green bonds, social bonds, and sustainability-linked bonds, reflecting the expanding, if not accelerating, efforts of companies and governments to fund the transition towards net zero business models and economies in alignment with their ESG objectives.

The burgeoning demand from Millennial investors, coupled with emerging government incentives and regulations, is poised to drive the expansion of sustainable investing into new asset classes and themes over the next decade. Notably, a 2021 report from the Institute revealed that virtually all surveyed U.S. Millennials (99%) expressed interest in sustainable investing. Should this demographic translate their intentions into action, it will likely result in more solutions available across the market. Concurrently, sustainable investment opportunities are expected to extend beyond public markets to encompass other sectors like private equity. Private equity investors may pursue growth prospects within sustainable brands, particularly given that 62% of younger generations in the U.S. prefer such brands. Companies may seek to enhance efficiencies in energy, inputs, and materials and explore potential acquisitions of sustainability-focused businesses. This shift signals a significant evolution in the investment landscape towards sustainability-driven strategies. Investors should anticipate a rising interest in topics beyond climate action. These encompass themes such as nature preservation and biodiversity, transition finance, supporting companies in their journey towards achieving net-zero emissions, and inclusive finance, providing financial support to marginalized individuals and communities.

1.8 Market risk and its types

Market risk refers to the possible fluctuation in the worth of a financial position due to alterations in the underlying factors that impact the market dynamics. These factors comprise a diverse array of components, including fluctuations in commodity and foreign exchange prices, shifts in inflation rates, and variations in the valuation of equities and bonds. As a result, market risk can be classified into distinct categories: interest rate, foreign exchange, equity, and commodity. Additional differentiations are established within the domain of interest rate risk between gap risk and trading risk, the latter of which pertains to the contrasting risk profiles of bonds that result from their distinct maturities. Moreover, volatility encompasses the fundamental nature of market risk by quantifying the extent to which prices fluctuate during a specified time frame (McNeil et al., 2015). Historical volatility refers to volatility, mainly when converted from past market price data. This a particular element that emphasizes the intrinsic unpredictability and the possibility of financial detriment arising from the variations in market prices, thereby highlighting the crucial significance of comprehending and controlling market risk within finance. Fig. 1.3, shows the types of Market Risks.

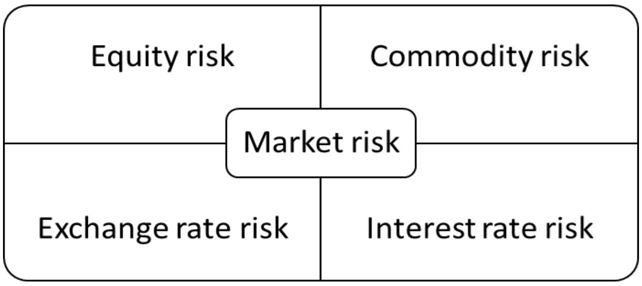


Fig. 1.3 Types of Market Risks and Proxies

1.8.1 Equity risk

The threat of a loss due to changes in the worth of a stock is identified as equity risk. Likely, since stocks are almost consistently traded and are thus identified by the number of supplies and demands accrued, it is nearly impossible to determine equity risk through predictions. As an investment, the payment you receive from the company's risk performance is entirely proportional to the stock's performance. In other words, when you buy stocks from a particular firm, you might think of yourself as a small owner of that business. Equity risk is composed of a substantial number of components that pertain to stock changes for one reason or the other. These components include the following factors:

Company Performance: According to managers of the business’s revenue, profit, possibility, growth, and other financial measures.

Market Sentiments: Emotions, feelings, and insights about the market at large can impact stock prices.

Economic Analysis represents a larger whole of economic forces, including inflation, interest rates, international market differences, and unemployment.

S&P 500

The Standard and Poor's 500, commonly known as the S&P 500, is an index that monitors the performance of the 500 stocks of the most significant companies that are traded on their respective stock exchanges in the United States. A proximately eighty percent of the total market value of publicly traded companies in the United States is represented by it, and it is a tremendously popular indicator of the stock market. As of January 2024, the overall market capitalization of these companies is over 43 trillion dollars.

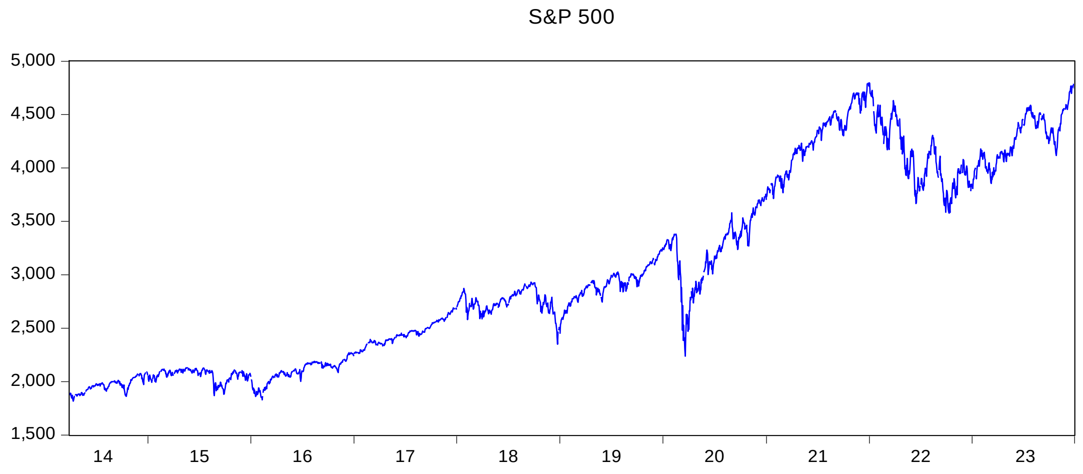


Fig 1.4 Trend in S&P 500 index

Russell 2000 Index

In the United States stock market, the Russell 2000 Index is a small-cap index comprised of the 2,000 smallest stocks. The Frank Russell Company initiated it in 1984. FTSE Russell, a subsidiary of the London Stock Exchange Group (LSEG), is the organization responsible for maintaining the index.

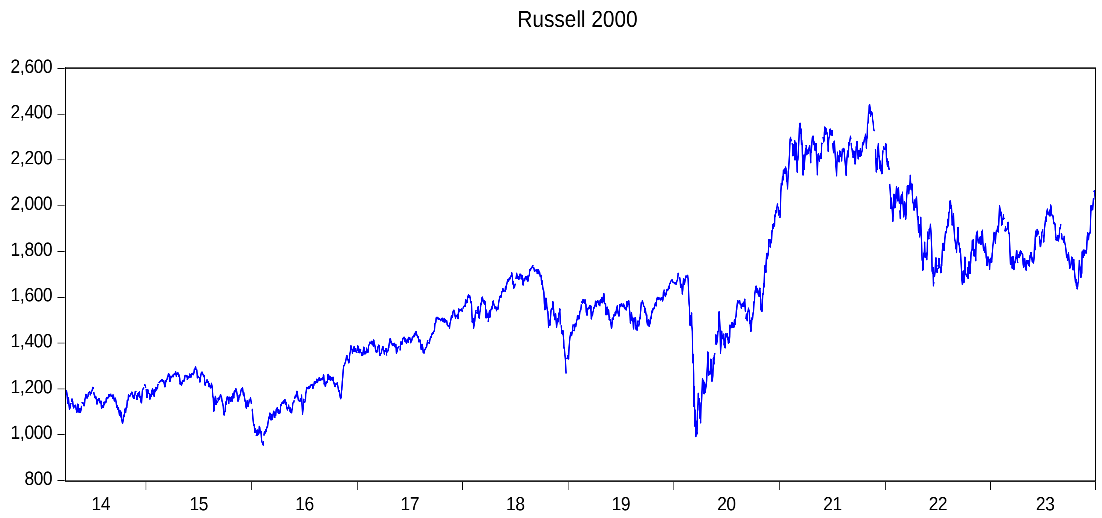


Fig 1.5 Trends in Russell 2000 index

NASDAQ 100

A stock market index known as the Nasdaq-100 is comprised of equity shares issued by one hundred of the most significant non-financial corporations listed on the Nasdaq stock exchange. The capitalization-weighted index has been updated to include this.

The weights of the stocks in the index are determined by their respective market capitalizations, and specific rules limit the influence of the components with the most significant market capitalizations. The only companies that can participate are those listed on a single exchange, which does not include any financial companies. One of the distinct indexes that consists of financial companies is the Nasdaq Financial-100.

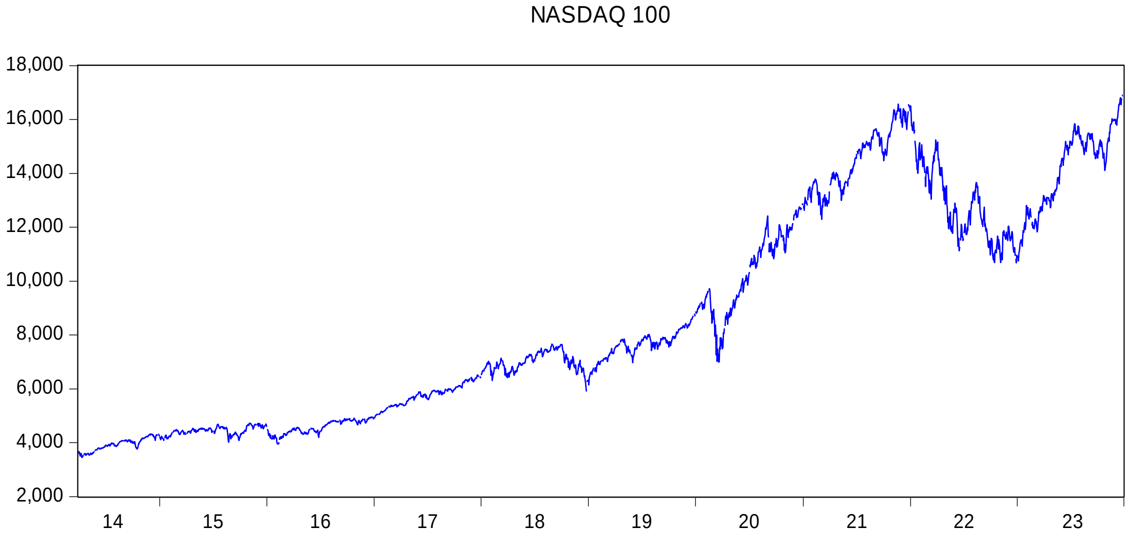


Fig 1.6 Trend in NASDAQ 100 index

1.8.2 Commodity risk.

Commodity risk is the uncertainty of future market values and the size of future income caused by the fluctuation in the prices of commodities. Fluctuations in the prices of commodities cause this uncertainty. Gains, metals, gas, energy, and other commodities could fall into this category. An enterprise that deals in commodities must address the following categories of risks: Price risk is a possibility that arises due to unfavorable fluctuations in global prices, currency rates, and the basis between local and international prices. In most cases, the associated price area risk has a relatively insignificant influence. Risk is based on quantity or volume. This known as the input price risk and the risk of politics.

Commodity risk pertains to the potential consequences that the prices of commodities may have on a company's financial performance. Commodity producers face the risk of price erosion, which reduces profits derived from the sale of their fundamental materials. Commodity-consuming enterprises, such as transportation providers and airlines, are vulnerable to price increases, resulting in augmented spending on the commodities they procure. Commodity risk is renowned for its extreme volatility. Commodity prices are impacted by various factors, including precipitation, expected inflation, interest rates, and exchange rates. The trading of commodity contracts frequently involves the utilization of futures contracts. Consequently, commodity contracts are traded on an exchange (Barned, 2012).

S&P GSCI CRUDE OIL

The S&P GSCI index is created to provide an accurate and comprehensive measure of the commodity sector's performance. The purpose of defining this index is to provide the market players with an objective and representative performance of the crude oil sector. The S&P GSCI Crude Oil is a measure of the price dynamics and performance of a range of crude oil future contracts of both WTI and Brent crude. The calculation is provided by allocating the weights to the producers, which are supposed to be large enough relative to others. In terms of investments, the S&P index operates as a benchmark for market and crude oil assessment. Therefore, the knowledge that this index is rising or decreasing is a reliable and market-accepted indicator. Traders and investors commonly use the index to navigate in what direction the oil markets are moving and, accordingly, to make investment actions.

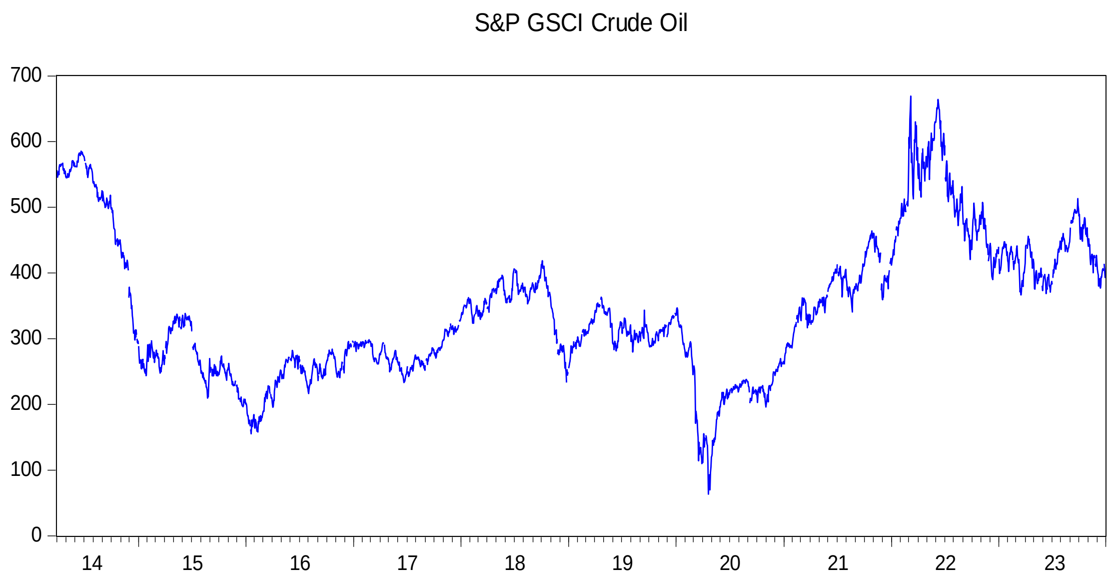


Fig 1.7 Trends in S&P GSCI Crude Oil

S&P GSCI GOLD and Silver

Firstly, the S&P GSCI Gold GSCE Index, similar to other S&P GSCI indices, offers a benchmark to track and monitor the performance of the gold market. In other words, the basket consists of gold futures contracts, and the value of the index changes in response to the changes in their prices. Investors, traders, and analysts use these indicators frequently to track the performance of the gold market. Gold is typically considered a haven asset that may be utilized to hedge inflation or economic fears. In this way, the S&P GSCI Gold index aids in tracking price trends in the gold market. The S&P GSCI Silver index monitors the performance of silver future contracts. This metal is viewed as a precious one, and, there is a wide array of industrial and investment applications. The two indices presented in the modules offer a clear and recognized way to measure the performance of the gold and silver markets. Therefore, investors use them to identify events, make investment decisions, and track the status of the markets. However, one should take into account that individual investment performance may depend on fees, trading costs, and the time at which the investment was made.

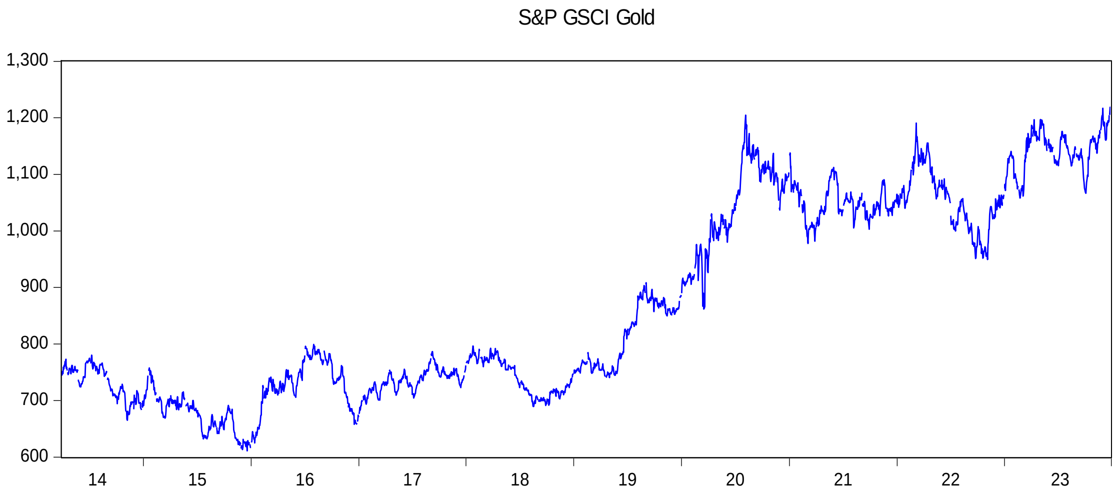


Fig 1.8 Trends in S&P GSCI Gold and Silver

S&P GSCI Aluminum and copper

The S&P GSCI Aluminum Index is used to measure the performance of future aluminum contracts. This is an industrial metal is frequently used in construction, transportation, packaging, and a variety of other applications. There is a significant quantity of information about the movement and reaction of the market available to investors, traders, and analysts concerning the product. As of 2020, there are a total of 22.5 billion pounds of metal available to the market at CME. It can also be traded on a different platform with the JPMorgan Chase Bank as a clearing member. The S&P GSCI Copper index, in turn, is used to track the movement of copper futures contracts. This an industrial metal that is essential to people while in use in electrical wiring, construction, electronics, and several other applications.

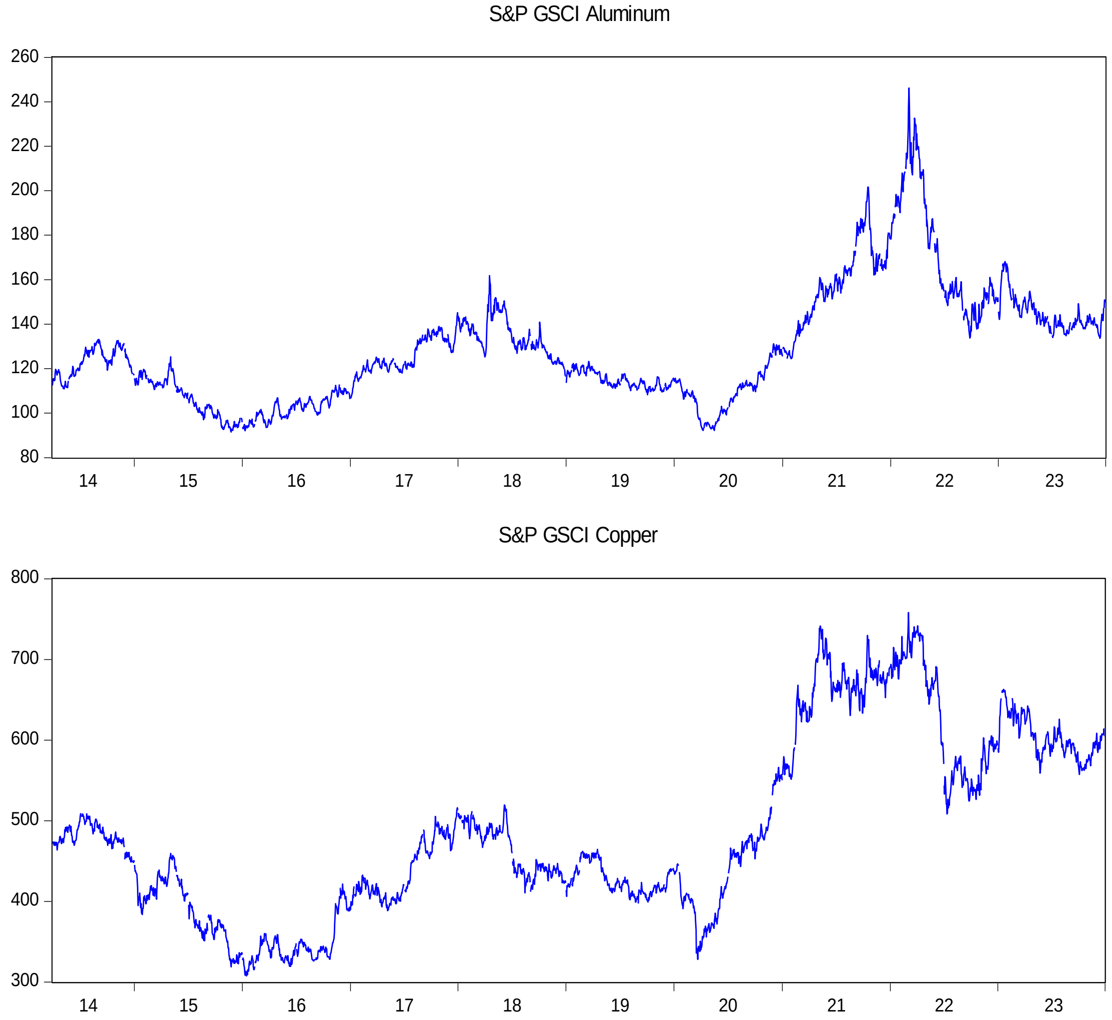


Fig 1.9 Trends in S&P GSCI Aluminum and Copper

The S&P GSCI Natural Gas index

The S&P GSCI Goldman Sachs Commodity Index Natural Gas Index is a critical benchmark for assessing the performance of the natural gas market. The given index is composed of a range of natural gas futures elements, displaying price changes of each specific component. Natural gas is one of the primary energy commodities and is widely used for heating, electricity, and industrial purposes. The S&P GSCI Natural Gas Index offers a view of the price trends and dynamics for investors, traders, and analysts. It is one of the most widely used indices for assessing performance in natural gas futures because it is relatively transparent and reliable. Most investors rely on this index to observe the natural gas market's performance. Still, traders and analysts use this information to measure the performance of their natural gas investments and identify market trends. However, the performance of each specific investment may differ because of the presence of various fees, trading costs, and the timing of investments. Concerning the natural gas market, market trends, weather, natural disasters, international relations, and supply and demand shifts have the most profound impacts on pricing. Therefore, natural gas remains highly sensitive to changes in the factors above. To conclude, the S&P GSCI Natural Gas Index is essential in the natural gas market, as it offers a transparent and reliable measure of natural gas futures performance.

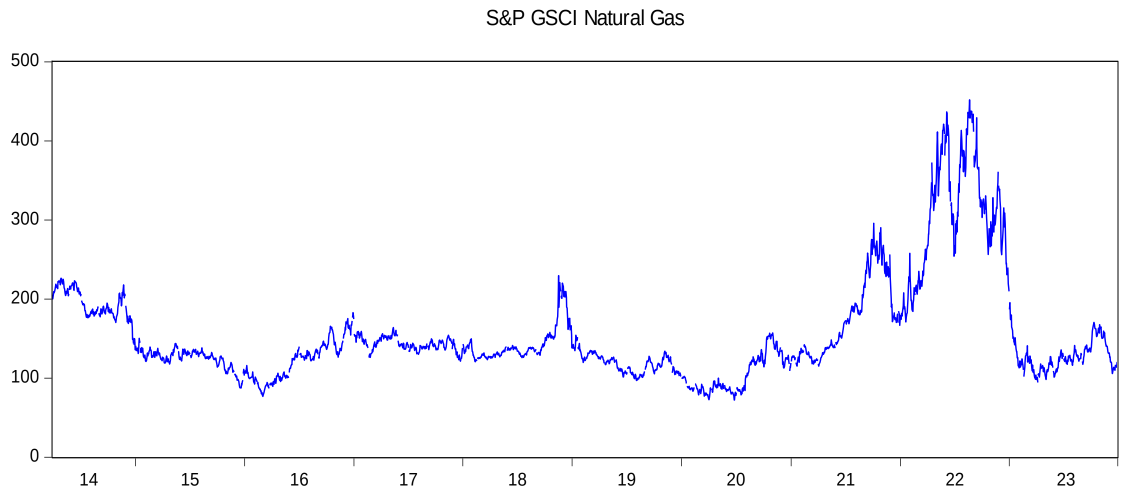


Fig 1.10 Trends in S&P GSCI Natural Gas

1.8.3 Exchange rate risk

Foreign exchange risk is the risk of firms suffering losses as a result of changes in exchange rates affecting their financial performance. This particular risk element is quite significant for companies that trade currencies. The exchange rate is a common risk factor that regularly co-occurs with other factors. One example is the widespread use of options and future contracts to reduce currency rate risk.

A wide variety of currency pairs are accessible, and you can pick and choose from among them. Three types of foreign exchange partnerships may be differentiated from one another to acquire a more in-depth comprehension of the characteristics each of these partnerships possesses. These are the major currencies, the currencies that are used for various commodities, and the currencies that cross over into one another. The following is a list of the major currencies:

EUR/USD is the currency pair traded the most on the market, with 24.0% of daily forex trading in 2019 comprised of EUR/USD transactions. The popularity of the EUR/USD pair can be attributed to its indicativeness of the two largest economies in the world, namely the European single market and the United States.

JPY/USD

Two components comprise the JPY/USD currency pair, also known as "the gopher." These components are the United States dollar and the Japanese yen currencies. In the foreign exchange market, it is the second most traded pair, and in 2019, it accounted for 13.2% of all daily transactions that took place on the trading platform. A significant amount of liquidity is regarded as present in the USD/JPY pair, just as in the EUR/USD pair. Because the United States dollar is the currency traded the most frequently globally, and the yen is the currency traded the most frequently in Asia. This liquidity is a result of the fact that the yen is the currency that is exchanged there the most often.

GBP/USD

The pound sterling and the United States dollar are the two currencies that make up this pair. Because of the deep-sea cables used to carry bid and ask quotes between London and New York, the phrase "cable" is commonly used to refer to the British pound to the United States dollar. In 2019, the GBP/USD pair accounted for 9.6% of all daily transactions in the foreign exchange market. A with most other currency pairs, the strength of the British pound to the United States dollar is derived from the various strengths of the economies of the United States and the United Kingdom. There is a good chance that the pound will increase versus the dollar if the economy of the United Kingdom expands quicker than the economy of the United States. However, if the economy of the United States is performing better than the economy of the United Kingdom, then the opposite is true.

AUD/USD

The exchange rate of AUD/USD sometimes referred to as the "Aussie," is a representation of the Australian dollar about the dollar of the United States of America. B 2019, it was responsible for 5.4% of all daily trades in foreign exchange. There is a statistically significant correlation between the Australian dollar's value and the country's exports. The amount of the country's gross domestic product (GDP) attributed to the value of the country's exports of metals and minerals, such as coal and iron ore, is considerable. The value of these commodities experiences a fall on the world market, it is expected that the value of the Australian dollar will also experience a decline. This is because the Aussie dollar is a currency used in Australia. Using the AUD/USD currency pair as an example, the U.S. dollar would strengthen, leading to a drop in U.S. dollars required to acquire one Australian dollar.

USD/CAD

It is common practice to refer to the exchange rate between the United States and Canadian dollars as the "loonie." This is because the lovebird is a symbol that appears on coins issued in Canada. This demonstrates how the United States and Canada's dollars are associated with one another. Transactions between the United States and Canadian dollars accounted for 4.4% of daily foreign exchange transactions in 2019. Because oil is the primary export that Canada is responsible for, the value of the Canadian dollar is directly tied to the oil price. This is because oil is the primary commodity that Canada exports. Because oil is valued in U.S. dollars in worldwide markets, Canada has the potential to create a significant amount of U.S. dollars by exporting its oil. This is because the United States Dollar determines the price of oil. If there is an increase in the price of oil, the value of the Canadian dollar will likely increase compared to the value of the United States dollar. This is because the value of the Canadian dollar is already relatively high.

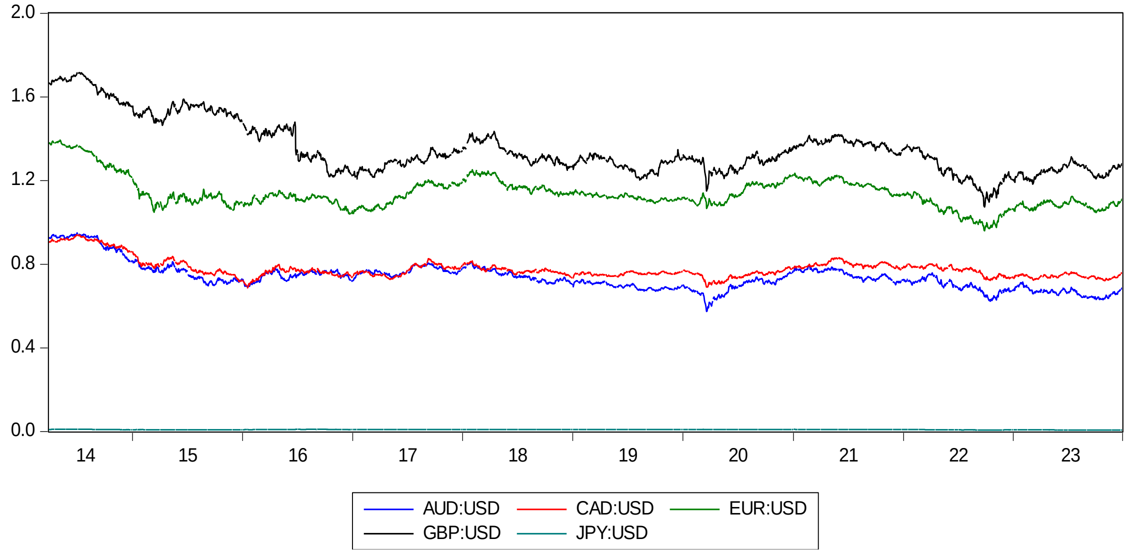


Fig 1.11 Trends in Pair of Forex Currencies

1.8.4 Interest rate risk

Interest rate risk is the possibility of suffering a loss due to shifting interest rates. It is one of the significant risks for banks when considering market risk. The yield curve provides the interest rates for various bond maturities or term structures.

United States 10-Year,5-Year, and 3 Year Bond Yield

The United States 10-year Bond Yield is a crucial indicator of the health of the U.S. economy and the direction of interest rates. This represents the return an investor can expect to receive by holding a U.S. government bond with a maturity of 10 years. Investors, economists, and policymakers closely watch this yield because it often reflects broader economic conditions and sentiment.in early 2022, the U.S. 10-year Bond Yield fluctuated significantly over the years, influenced by inflation expectations, Federal Reserve policy decisions, economic data releases, geopolitical events, and market sentiment. You should check a financial news website, the U.S. Department of the Treasury website, or a financial data provider for the most current and accurate information.

The yield on the U.S. 10-year Treasury note approached highs seen in November, reaching 4.66% before easing back to 4.63%. This movement came as traders prepared for crucial economic data that would provide insight into the strength of the U.S. economy, prompting adjustments to their expectations for interest rate cuts.

Moreover, decreased tensions between Iran and Israel reduced demand for safe-haven assets. In the upcoming days, attention will be paid to key economic indicators such as GDP growth, PCE inflation figures, and S&P Global PMIs, especially with the impending FOMC monetary policy decision. The likelihood of a rate cut in September is around 65%.

Additionally, the Treasury is scheduled to hold auctions totaling $183 billion for two, five, and seven year notes throughout the week. Generally, government bonds are issued by a nation's government and are denominated in its currency. Bonds issued by national governments in foreign currencies are typically called sovereign bonds. The yield investor's demand when lending funds to governments reflects inflation expectations and the perceived likelihood of debt repayment.

The interest rate on the Treasury note with a maturity of five years is currently at 4.66%, which is lower than the rate that was used on the previous market day, which was 4.68%, as well as the rate that was used the year before, which was 3.63%. Over an extended period, it is higher than the 3.75 percent average. The yield that an investor receives on a purchase of a treasury instrument issued by the United States government that has a term of five years is referred to as the 5 Year Treasury Rate. This rate reflects the yield that the investor receives on their investment.

The United States 3-year Bond Yield, currently at approximately 4.8%, is crucial in assessing short to medium-term economic sentiment and interest rate expectations. This yield represents the return an investor can expect from holding a U.S. government bond with a 3-year maturity. Market participants closely monitor the 3-year yield as it provides valuable insights into expectations for interest rates and economic conditions over the next few years. Changes in the 3-year yield often reflect shifts in market sentiment regarding the Federal Reserve's monetary policy stance and the broader economic outlook.

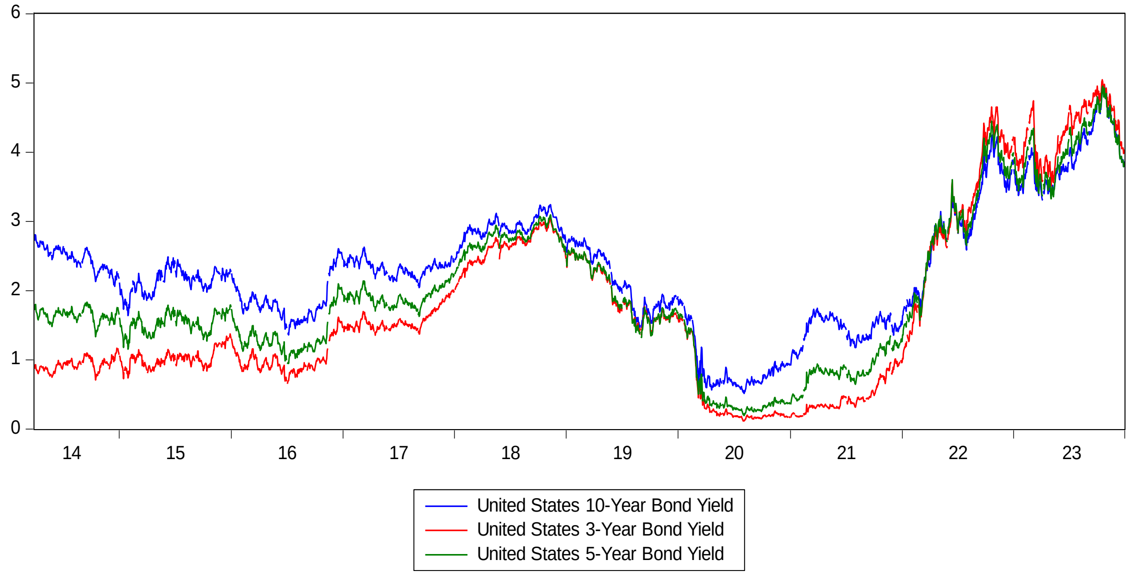


Fig 1.12 Trends in US 10-Year,5-Year, and 3-Year bond yield

According to Korinth and Lueg (2022), business risk has three primary categories. Firstly, they define total risk as the whole risk attached to a business, which may be quantified using return standard deviation or default risk. This includes most risk factors. Secondly, they identify firm-specific risks unique to a particular organization. This risk is measured utilizing the distinct volatility of a company after market adjustments. Investors may decrease the effect of certain risks by diversifying their investment portfolios. When assets are dispersed over several firms, the portfolio is far less exposed to the impacts of firm-specific risks. Systematic risk is associated with the market as a whole and is often assessed using Beta. Unlike particular risks, which may be mitigated by spreading assets out; this risk is inherent to the market. Investors anticipate a profit from their capital that considers this risk. It is essential to distinguish between systematic and market risks, even if the terms are interchangeable. Although all systematic risk is market risk, not all market-related variables contribute to systematic risk. This is because market risk is a subset of systematic risk. Zwak-Cantoriu et al. (2021) provide a more detailed definition of market risk, which is the possibility that companies might experience a decline in the value of their assets due to unfavorable changes in market prices. They classified equities, interest rates, commodities, and exchange rate risks as the four main components of market risk. Market risk is complex and affects several parts of the financial system differently; each part indicates one method in which market fluctuations might reduce the value of financial assets.

To show how The Market Risk is complex, Zwak-Cantoriu et al. (2021) introduce the concept of interdependent financial instrument prices. The authors bring before us one case in point amid such complexity: shifts in interest rates can influence not only the price of bonds themselves but also valuations for stocks and financeable instruments. Such interrelations may, in fact, lead to substantial portfolio losses unless adequately controlled. A perfect illustration of the critical role that effective market risk management plays in preventing financial instability came in the economic crisis of 2007-2008. Zang et al. (2021) are studying the complex relationships that breed volatility in markets and how that impacts beyond asset classes to engulf because of globalization interdependence across Globe markets. A detailed analysis of the complex web of stock market interaction between China and the U.S. reveals a strong pattern: increased volatility in U.S. markets increases the possibility that a financial downturn will spread to China. With such an arrangement for risk avoidance in place, Chinese investors find it rational to shift to higher-quality investments in the United States. This change is called a "flight to quality." Still, it also benefits the U.S. stock market by reducing fluctuations and indicates how intricately these two most potent economies ‘finances are. Intermingled.

Moreover, this method became popular after 1987's financial turmoil and has continued as one of the principal tools used today in risk assessment. In the late 1990s, VAR began to be included in regulations on market risks. Now, it is compulsory in regulatory reports covering such positions in financial markets if net worth exceeds £250 million or annual trading volume tops $50 billion worth. Zwak-Cantoriu et al. (2021) re-cast the above meaning in more precise language: Value-at-Risk measures the exposure level—this is the worst that can happen if we lose everything—for individual investment or a collective portfolio, all at a certain confidence level and with a given time frame attached to it. This is a barometer for risk management strategies adopted by financial institutions in order to survive the complexities of today's markets Miskolczi (2018).

People often think that it is risky to invest in the stock market. The volatility associated with the stock market itself comes from the significant macroeconomic variables that both impact stock prices and, in turn, are acted on by them. Such variables may have a double effect, affecting the stock of an individual firm, or they may be of a general nature; that is to say, they apply equally to all firms within the market. For example, the world financial crisis of September 2008 caused a crash in the market, wiping out the stock prices for almost every company listed on an exchange anywhere in the world. Voilatility represents the amount of fluctuation in asset prices during a specific period. Precisely capturing this volatility is problematic because it depends on the dynamic interplay of a number of economic factors. Thus, while volatility is a critical factor in making the stock market feel risky, it also provides openings for those who understand its intricacies. This is very important to how investments are structured in terms of risk and return.

This volatility is due to both market and firm-specific. From a company-specific viewpoint, forces, such as self-running metrics and industrial trends, will determine the price of just one company's stock. On the other hand, market-wide factors, such as economic indicators, geopolitical events, and market sentiment, collectively impact the prices of all firms; nevertheless, challenges exist for accurate measures of volatility. And it is these challenges that create opportunities for savvy investors. Markets are subject to sudden price changes in this dynamic change. The price changes thus provide new opportunities, allowing those with insight to make a little extra something by selling on rises for instead of holding out for still higher prices later. As for price drops, that is when you buy. Understanding and navigating market volatility is crucial for investors seeking to capitalize on opportunities within the stock market. While it introduces an element of risk, volatility also provides the driving force behind the potential for profit in today's ever-changing financial markets. Therefore, a comprehensive understanding of volatility is essential to successful investing, and it is not easy to earn a reasonable profit on the stock market without first learning about this principle.

1.9. Motivation for the Study

The intersection of market risk and green investment is increasingly becoming a focal point for researchers, policymakers, and investors alike, particularly in the context of emerging economies like India. Understanding how financial markets can integrate and respond to green investments is crucial as the world grapples with the dual challenges of economic development and environmental sustainability. India, with its rapidly growing economy and significant environmental challenges, offers a unique context to explore these dynamics. The motivation for this study stems from the need to understand the interplay between traditional market risks—represented by commodities, equities, interest rates, and exchange rates—and green investment indices like Carbonex and Greenex. This research aims to contribute to the evolving discourse on sustainable finance by examining the price discovery process and volatility spillover between these two crucial aspects of the financial market.

India's commitment to sustainable development has been reflected in its various policy initiatives and the increasing attention given to green investments. The introduction of indices such as Carbonex and Greenex marks a significant step towards integrating environmental considerations into financial markets. Carbonex tracks the performance of companies that adhere to low carbon emission practices, while Greenex focuses on the top companies that have made significant strides in environmental performance. These indices are part of a broader global trend towards sustainable investing, where investors seek to allocate capital to companies that not only promise financial returns but also contribute positively to the environment.

However, the integration of these green indices into the mainstream financial market is still in its early stages in India. While there is a growing body of literature on green investments in developed markets, much less is known about how these investments interact with traditional financial assets in emerging markets like India. This study seeks to fill this gap by exploring how green investments, as represented by Carbonex and Greenex, behave in relation to more traditional market risk proxies such as commodities, equities, interest rates, and exchange rates. Understanding this interaction is crucial for investors who are looking to balance their portfolios in a way that aligns with both financial performance and environmental sustainability.

India's financial markets are characterized by a high degree of complexity and volatility. Factors such as fluctuations in commodity prices, equity market dynamics, interest rate changes, and exchange rate movements all contribute to the overall market risk that investors must manage. These factors are interconnected and can influence each other in ways that are not always predictable. For instance, a sudden change in commodity prices can lead to fluctuations in the equity markets, which in turn can affect exchange rates and interest rates. In such a volatile environment, the inclusion of green investments adds another layer of complexity to the risk management process.Given the relatively recent emergence of green investment indices in India, it is crucial to understand how these indices interact with traditional market risk factors. Specifically, this study will examine the price discovery process—how prices of green investments are determined in relation to traditional assets—and the volatility spillover—how fluctuations in one market can impact another. These analyses will provide valuable insights into the stability and integration of green investments within the broader financial system in India.

1.10 Chapter Plan

The Chapter plan describes all the essential constituents of research arranged in an order. The chapter scheme aims to provide a complete structure of the Thesis. The study has Five chapters, and their details are discussed below.

1 Introduction: The chapter introduces Green stock market volatility and its importance in determining the asset prices followed by its types. After that, the concepts of volatility spillovers and correlation of markets are discussed. Further, the financial crisis phenomenon is discussed, and its related theories are advanced from the academic literature. The financial contagion, a product of an economic crisis spreading over major geographical regions, is also detailed. This chapter ends with a description of the motivation for the study.

Chapter 2 Literature Review: This chapter explores the available academic literature related to the investigation. It covers seminal papers as well as recent research issues. The chapter starts with a brief mention of the evolution of research on financial contagion. Later, after a systematic review of the literature, two categories are made, and papers are divided accordingly. The first category discusses theoretical and empirical papers that comprise several alternate definitions and modeling techniques. The second bifurcation deals with the research work relating to volatility spillovers and co-movement of markets with price discovery function. In the end, a well-crafted research gap is discussed.

Chapter 3 Research Methodology: The research Methodology chapter deals with the rationale for selecting the data set used in the study. The time frame of the study is also explained in this chapter. The sources of data extraction are also mentioned. Moreover, the econometric tools required to answer the research questions and meet the study's objectives are discussed at length. The selection of the optimum technique for identifying contagious effects is also mentioned in this chapter.

Chapter 4 Empirical Analysis: The data is empirically tested, and the model results are discussed in detail. This chapter is crucial to the research, as the study's objectives are attained based on the findings. The fourth chapter mentions the results of price discovery and volatility spillovers.

Chapter 5 Findings and Implications: Chapter Fifth concerns the research conclusions. It discusses the managerial and policy implications, aiding in understanding the study's results for the actual implementation of portfolio diversification strategies. The chapter also discusses the scope for future research.

CHAPTER 2
REVIEW OF LITERATURE

This chapter presents the research's conceptual framework, starting with definitions of basic concepts used in the study's objectives. It also covers earlier studies on the topic. It aims to add to the current body of knowledge by critically evaluating the literature on price discovery and the transfer of volatility from market risk to green investment.

Price Discovery

The stock market is seen as a crucial component of the economy and is frequently referred to as its barometer. The nation's industry and commerce growth, primarily reliant on the stock market status, significantly influences the country's economy. Changes in the stock market are constantly monitored by the government, the corporate sector, and the nation's central banks because of this rationale. The stock market is significant from the perspective of the industry and the investor. The constant discovery of the prices of financial assets traded on the exchange is an essential function of the stock market. Price discovery is defined as the process that takes into account the speed at which price of an asset reacts to new information (Booth et al., 1999).More specifically, price discovery indicates the lead-lag relationship between futures and spot prices (Theissen, 2011).

Price is the amount negotiated between two parties to complete a transaction. Price may be stated as the amount that is bargained. It indicates the company's value and the amount of money the general public is willing to pay for a share of that particular company. The market's conditions continue to impact this price, which means it does not remain stable but continues to fluctuate to a certain level. In finance, it is typical practice for analysts to model the price using a random walk, which has been demonstrated unsuitable by several empirical research studies. However, this kind of modelling needs to be revised.

The word "price discovery" refers to identifying the price or worth of a financial asset, mainly a stock, by looking at how the market forces operate at a particular moment. Without a doubt, the engagement of other markets in the price discovery process is not something that should be considered insignificant. While it is possible that these positions are informational, it is also possible that they are actual. The roles may take the form of direct participation of institutional investors from other nations in the stock market. This would include a direct flow of capital, which is likely the case. Even though the informational roles could take the shape of the replies of participants who are already present with the information delivered in the other, they do not impact the movement of capital between different markets. As part of this research, these functions are considered part of the Price Discovery process.

Nevertheless, the transmission of innovations for price discovery over a wide range of markets may occur through rewards to investors and volatility, frequently referred to as spillover. This is because volatility plays a role in the spreading of innovations.

Volatility Spillover

The risk connected with the security of financial assets due to changes and fluctuations in the return of such assets from their anticipated value is usually referred to as "volatility." The word "volatility" is widely used to refer to this risk. Calculating the standard deviation of the return over the specified period is the typical method used in the evaluation process. In the context of the financial market, the word "volatility" refers to the period during which the price of a security will either decrease or increase. When the cost of a security moves within a broader range than the value predicted for it during a specific period, the security is very volatile. This is the case when the period in question is defined. A security is considered low volatility; conversely, it is if the security price moves considerably closer to its expected value over a particular time. This term is used to describe the behavior of the asset.

A phenomenon that happens when the occurrence of an event in one market has an impact on another market is referred to as the "spillover effect." To check the spillover effect, we must first verify the conduction process of volatility from one marker to another. This is necessary to validate the spillover impact. The spillover effect may be produced in two distinct ways: first, it can be made by interlinkages between stock markets, and second, it can be induced by connections between macroeconomic systems. Both of these methods are possible.

Within the scope of this research, the term "volatility spillover" refers to the phenomena in which the volatility of stock market returns in one country is influenced by the volatility of returns in other nations. In this study, we have selected volatility spillover from (the equity market, commodity market, forex market, and interest rate) to sustainable stock market, namely Carbonex and Greenex. A complete understanding of volatility spillover across stock markets is essential for appropriately estimating the risk of a globally diversified portfolio when adopting a hedging strategy and determining asset allocations. This is because volatility spillover may occur across many stock markets. An international portfolio manager must consider the potential for fluctuating returns to choose the optimal portfolio. This is because the manager invests in emerging countries and established economies, contributing to risk reduction via portfolio diversification.

Furthermore, understanding the volatility spillover is beneficial when formulating rules linked with the movement of capital in the markets. During times of crisis, the regulatory body may consider the risk of volatility to impose limitations on foreign investment in completely integrated markets; global factors are responsible for a more significant share of the repercussions associated with volatility. On the other hand, local variables are the dominant cause of volatility in fragmented markets (Bekaert & Harvey, 1997).

Segments of Review of Literature

Segment 2.1: Equity Market Risk Spillovers

Due to the improvements in globalization, liberalization, and technology, economies worldwide have become more interconnected. The interconnectivity has enabled the expansion of countries and created diverse prospects for worldwide investment, resulting in wealth accumulation. The financial market is an excellent choice for such investments due to its potential for significant returns within a very short period and its ability to provide liquidity to investors, which is sometimes lacking in other investment options such as real estate. Hence, investors, financial institutions, and governments must comprehend the interdependent nature of diverse financial markets. A clear comprehension of this concept is especially crucial in emerging markets, as they attract interest from local and global investors looking for more significant monetary gains. These markets are emerging as attractive investment destinations, driven by the worldwide economic interconnectedness (Henry, 2000; Zhou et al., 2012).

Year	Authors	Title	Purpose	Methodology & Findings and conclusion
2023	Zeng H.; Lu R.; Ahmed A.D.	“Dynamic dependencies and return connectedness among stock, gold and Bitcoin markets: Evidence from South Asia and China."	This research examines the dynamic relationships between major stock markets in South Asia (Pakistan and India), China, the MSCI-developed markets, Bitcoin, and gold markets. The study will specifically	This study uses connectivity approach is designed on the foundations of the GARCH-Vine-Copula & TVP-VAR models has been used and The findings reveal that risk shocks from developed equity markets play a significant role in these dynamic connections. Gold

			focus on the interactions between these markets.	is a good way to protect and diversify investments in China and other big South Asian markets, especially after the COVID-19 pandemic.
2023	Wang G.; Meng J.; Mo B.	"Dynamic Volatility Spillover Effects and Portfolio Strategies among Crude Oil, Gold, and Chinese Electricity Companies"	This study looks at the dynamic relationships and volatility spillover effects between the stock prices of Chinese electricity companies, crude oil, and gold	The Dynamic conditional correlation (DCC) model, VAR model (TVP-VAR) has been used and The findings show notable spillover effects between Chinese electricity companies, gold, and crude oil stock volatility. These effects collectively exhibit a sharp increase in response to the crisis. It is important to keep in mind, though, that how a crisis affects different assets will depend on the specifics of the crisis and the assets in question.

2024	Mensi W.; Lee Y.; Al-Kharusi S.; Yoon S.-M.	“Switching spillovers and connectedness between Sukuk and international Islamic stock markets."	This study investigates the connections and switching volatility spillovers between global markets, two local Islamic stock markets (in Asia and Europe), and the Dow Jones Sukuk.	The Markov switching-vector autoregression and spillover index models were used in this study. The results show that shocks have a big effect on Islamic stock markets in the low-volatility regime (Regime 1). But they have almost no effect in the high-volatility regime (Regime 2), unless you look at the global Islamic markets. Additionally, regime changes tend to be more enduring compared to changes in the opposite direction.
(2023).	Yousaf I.; Mensi W.; Vo X.V.; Kang S.	“Spillovers and connectedness between Chinese and ASEAN stock markets during bearish and bullish market statuses."	This research investigates the tail connectedness between the stock markets of the Association of Southeast Asian Nations (ASEAN) and China.	This study uses Quantile connectedness approach as, Instead of using an average measure to look at connectedness, a quantile-based approach is recommended. This is because the results show that the Chinese and

				ASEAN stock markets are more connected at the extreme upper and lower quantiles than at the median quantiles. Additionally, the time-varying connectedness examination reveals that the COVID-19 pandemic, the Chinese stock market crash, and the global financial crisis are when the total spillovers peak at the upper, lower, and median quantiles.
2023	Doblas M.P.; Lagaras M.C.	"The Granger Causality of Bahrain Stocks, Bitcoin, and Other Commodity Asset Returns: Evidence of Short-Term Return Spillover before and during the COVID-19 Pandemic".	This research looks at the short-term return spillover tendency across commodities assets, bitcoin, and Bahraini stocks while accounting for the COVID-19 pandemic's dynamic impact.	The VAR model was used in this study, and the data showed that there was a steady, one-way, short-term flow of return from the Bahrain stock market to the futures gold market before and during the epidemic. There was spillover in both ways. The results also showed that the big boost to bitcoin profits as a hedge fund that

				came from the rise in the Bahrain stock market only happened before the pandemic. The findings presented the evidence. .
2023	Wang J.; Liu T.; Pan N.	“Analyzing quantile spillover effects among international financial markets."	This article investigates the spillover effects based on quantiles across 17 stock markets. A positive shock to bitcoin returns as a granger induced by Bahrain stock market gains only happened before the epidemic between 1993 and 2022	Applying a quantile methodology derived from the quantile vector autoregression (QVAR) model's variance decomposition. The results indicate the following: (1) the overall spillover is substantial and exhibits notable temporal variations; (2) the spillover demonstrates a rising trend at every quantile level, with a particular emphasis on the periods of the COVID-19 pandemic and the 2008 financial crisis; and (3) the seventeen stock markets constitute

				unique local financial networks.
2023	Cevik E.; Cevik E.I.; Dibooglu S.; Cergibozan R.; Bugan M.F.; Destek M.A.	“Connectedness and risk spillovers between crude oil and clean energy stock markets."	This study looks into the correlation between returns on the oil market and clean energy stocks.	Applying Granger predictability to the analysis of quantile impulse responses and distributions. According to the center of the distribution, returns on renewable energy securities, Granger forecasts oil price returns during "normal times" but not vice versa. During optimistic market conditions, the returns of renewable energy shares and the oil market exhibit bidirectional Granger predictability.

2023	Jiang W.E.I.; Liu X.	"RETURN CONNECTEDNESS among ENERGY and FINANCIAL MARKETS PRE and during the COVID-19 PANDEMIC: EVIDENCE from CHINA and the U.S.".	This study investigates the return connectivity between the U.S. and Chinese energy and financial markets before, during, and after the COVID-19 pandemic.	The spillovers were significantly more significant during the COVID-19 pandemic than the standard period. Furthermore, the total spillover effects from Chinese markets were more important than those from the United States before the outbreak, but this situation was entirely reversed during the COVID-19 pandemic.
2023	Fasanya I.; Oyewole O.	"Dynamic spillovers between precious metals and travel & tourism stocks in Southeast Asia: do infectious disease outbreaks matter?"	We examine how infectious disease-based uncertainty affects the dynamic relationship between the travel and tourism stock indices for Southeast Asia and the four primary precious metals.	TVP-VAR and the nonparametric causality-in-quantiles approach has been used in this study and the results indicates Silver and platinum are the most useful precious metals for portfolio diversification. The relationship between market volatility and infectious disease

				risk is most substantial in the lowest and normal quantiles.
2023	El Khoury R.; Mensi W.; Alshater M.M.; Kang S.	“Extreme risk spillovers and hedging strategies between Indonesia sectorial stocks and commodity markets."	This study investigates the risk contagion effects on the Indonesian sectorial equities Energy, Essential Materials, Industries, Consumer Cyclicals, Consumer Noncyclical, and Financials, in addition to the aggregate index (IDX) and two commodities (gold and West Texas Intermediate Crude Oil [WTI] futures).	Comparing the TVP-VAR model and the quantile connectedness method Each sector plays a different and asymmetric role and the return spillover increases with decreasing and increasing quantiles. Oil provides more excellent diversification benefits than gold, and oil hedging is more successful during a pandemic.

2023	Kartsonakis-Mademlis D.; Dritsakis N.	"The stock market – oil prices variability relationship in the USA: the financial crisis effect."	This essay examines the connection between the Brent crude oil price and the Dow Jones industrial average index.	GARCH models has been used and The findings prove that Brent's and Dow Jones's volatility do not correlate over the sample period. There is proof of a one-way link between the transmission of shocks from the stock market to the oil market and a two-way link between the spillover of instability between the markets in the years before the financial crisis.
2023	Xue X.; Fu Y.; Xia S.; Li X.	"A study on systematic risk among financial sub-markets based on the SETAR-Copula model"	Crude oil price fluctuations impact the flow of input funds among stock markets due to the increasing number of investors trading and investing in oil as a financial asset and the gradual financialization of the global oil market. Consequently,	The SETAR-Copula model was used for this work. The study says that when the global crude oil market is growing quickly, the influence of unstable markets can be lessened by the security of China's stock and exchange markets.

			fluctuations in a nation's exchange rate will be brought about by the movement of money in stock markets. Crude oil is, therefore, a vital strategic resource, and changes in its price will inevitably affect the nation's stock or currency markets, posing a systemic risk.	
2023	“Bhardwaj N.; Sharma N.; Mavi A.K.”	“Financial Integration and Variance Decomposition of Asian Stock Market: Evidence from India”	Portfolio diversification is a benefit of foreign investments done in non-integrated economies, but volatility spillover from these investments may cause oscillations in integrated economies. For this reason, regulators and investors alike must understand how an economy's	The vector error correction model, the impulse response function, the causality test, the variance decomposition, and the Johansen cointegration method are all used in this study. The results show that the chosen markets are cointegrated. It was found that there were two-way causal links between the U.S. and Indian stock markets. The results show how responsive the

			markets are linked. This study looks at how the Indian stock market works with the stock markets of China, Hong Kong, Japan, the UK, and the US.	Indian stock market is to new ideas from the US and UK. Since India's economy has become more interconnected in recent years, it will be beneficial to examine these connections.
2023	"Mensi W.; Hanif W.; Bouri E.; Vo X.V."	"Spillovers and tail dependence between oil and U.S. sectoral stock markets before and during COVID-19 pandemic"	This research looks at how ten U.S. stock sector indices and crude oil futures are very dependent on each other and how their risks spread unevenly.	Conditional Value at Risk (CoVaR) and static and dynamic symmetric and asymmetric copula models are the methods used in this study. In the end, reliability tests prove that their results are correct. Before the COVID-19 pandemic, all stock sector returns for crude oil showed an asymmetric tail dependence. For health care and industries (materials), on the other hand, an average (symmetric tail dependence) dependence was seen, and risk spillovers from stock sectors to

				crude oil were stronger than those from crude oil to stock sectors.
2023	"Afzal F.; Choudhury T.T.; Kamran M."	"Volatility spillover effect between Pakistan and Shanghai Stock Exchanges using copula and dynamic conditional correlation model"	The goal of this study is to find a random model that can predict how volatility will affect other markets in real-time stock markets.	The dynamic conditional correlation model, copula, and extreme-value theory were all used together in this study to look at how volatility and time-varying dynamics affected each other. The model shows that all big PSX and SSE portfolios are more dependent on each other, with a parametric value of 0.98. Subsequently, the dependence structure results yield an optimistic estimate of the SSE spillover effect over PSX.

2023	“Hussain M.; Rehman R.U.”	“Volatility connectedness of GCC stock markets: how global oil price volatility drives volatility spillover in GCC stock markets?”	This research investigated the link between volatility and the returns of the S&P global oil index and the stock market in the Gulf Cooperation Council (GCC).	Diebold and Yilmaz (2012) method. The stock markets in the GCC experience higher levels of volatility than those in other GCC nations. More study shows that the net spillover in the GCC stock markets and the changes in oil prices around the world are not directly linked.
2023	“Zhou X.; Li Y.; Chen B.; Jiang H.”	“Research on the spillover effect of foreign market risk on Chinese capital market from the perspective of full financial opening-up”	This essay examines the mechanism underlying the risk spread between developed and Chinese capital markets. Next, this paper will look at how established capital markets affect the Chinese capital market in terms of risk spread.	The DCC-GARCH model is used in this study. As soon as it is known and assessed how much big changes in the world stock market affect the Chinese stock market. Scientists have studied and found that there is a big risk that moves from developed capital markets to the Chinese capital market. It started to lose some of its power after the financial crisis,

				though. The strength of the spread effect can also be changed by big factors like location, international trade, and foreign investment.
2023	“Wu H.; Xie Q.”	“Volatility spillovers and Asymmetric effects of Chinese A-share markets—Enterprise-Level data Based on high-dimensional social network models”	From the point of view of a company, the goal of this study is to look into the uneven effects of volatility spillovers in the Chinese A-share market.	Using a high-dimensional social network technique, they determined the relationships between the high-frequency realized semi-variance volatilities of 81 stocks that occur every five minutes. The findings suggest that stock volatility significantly influences corporate-level dynamics. Robust and vigorous connections distinguish this phenomenon among various equities and the tendency for stocks within specific sectors to group. Economic stimulation and severe situations may worsen the

				asymmetry of volatility spillovers. A direct and positive correlation exists between the imbalances in the transmission of volatility spillovers from specific stocks, both in emission and reception. The financial sector influences the positive volatility spillover system and is more susceptible to its effects.
2023	“Mensi W.; Ziadat S.A.; Vo X.V.; Kang S.H.”	“Spillovers and Portfolio Management Between the Uncertainty Indices of Oil and Gold and G7 Stock Markets”	The purpose of this study is to look into how and why uncertainty indices of key commodities (like oil and gold) and stock markets of G7 countries are linked, and what this means for diversified investment portfolios.	The study uses Baruník and Křehlík (J Financ Econom 16:271-296, 2018) method. The results show that there are large time-varying spillovers among the series that were being studied. Also, the effects on other areas are stronger during an oil collapse than during other crises like the Great Financial Crisis, trade issues in the

				G2, and the COVID-19 pandemic. Most volatility spillovers are short-term in nature. It looks like oil is less likely to be affected by shocks from the G7 stock markets since it has more spillovers than gold.
2024	"Xiao X.; Li A.; Kchouri B.; Shan S."	"Tracing the dynamic impact of energy transitions on equity market volatility in an era of financial turbulence."	This research analyzes the dynamic correlation between the adoption of clean energy and shifts in the stock market, using data from January 2004 to August 2021.	Using data from January 2004 to August 2021, this study looks at the changing relationship between the use of clean energy and changes in the stock market. TVP-VAR stands for time-varying parameters vector autoregressions. Because of unstable financial and economic conditions, the spillovers were not evenly distributed. This showed that most of the spillovers were bad and harmful. The

				global financial crisis, the European debt crisis, the Shale Oil Crisis, Brexit, the U.S. interest rate plan, and the COVID-19 pandemic are the most important negative events that happened over time. At the same time, time-varying analysis showed that negative asymmetries were more common, which is similar to how negative crisis times were more common.
2024	Lamine A.; Jeribi A.; Fakhfakh T.	“Spillovers between cryptocurrencies, gold, and stock markets: implication for hedging strategies and portfolio diversification under the COVID-19 pandemic."	This research investigates risk transmission among gold, cryptocurrencies, and the United States and China stock markets regarding static and dynamic effects.	Diebold and Yilmaz (2012) developed a method for calculating spillover indices. This method uses the forecasting error variance decomposition derived from the vector autoregression methodology. The results indicate that the combination of gold, equities, and Bitcoin (or Ethereum) may

				present opportunities for diversification for investors in the U.S. and China. Gold, bitcoin, and Ethereum can be thought of as safe havens or hedges during the COVID-19 disaster. Stablecoins, like Tether and TrueUSD, don't offer U.S. and Chinese buyers any ways to hedge their bets, though.
2024	Behera C.; Rath B.N.	“The interconnectedness between crude oil prices and stock returns in G20 countries”	A study looks into the link between the stock values of G20 countries and the price of crude oil.	Dynamic method to connectivity is used in this study. It is found that the average shock to one asset has an effect on all other assets by 51.22%. We found that shock transfer is almost non-existent in oil-exporting countries but very important in oil-importing countries.

2024	Alomari M.; Selmi R.; Mensi W.; Ko H.-U.; Kang S.H.	“Dynamic spillovers in higher moments and jumps across ETFs and economic and financial uncertainty factors in the context of successive shocks."	High-frequency data are used in this study to look at the effects that ten US stock exchange-traded funds (ETFs) have on different amounts of economic and financial uncertainty.	The time-varying parameter vector autoregression (TVP-VAR) model is used in this work. Notably, skewness and kurtosis have big effects on higher-order moments and can spread across markets, especially when the market is unstable. It's interesting to see that the expected 30-day volatility of gold and oil returns has less of an effect on U.S. sector equity ETFs than the expected 30-day volatility of the U.S. stock market (VIX).

Segment 2.2: Commodity Market Risk Spillovers

Year	Authors	Title	Purpose	Methodology & Findings and conclusion
2024	Zeng H.; Xu W.; Lu R.	"Quantile frequency connectedness between crude oil volatility, geopolitical risk, and major agriculture and livestock markets"	This paper looks at the quantile frequency risk correlation between the GPR, OVX, and major agricultural and livestock indexes.	Using a quantile vector autoregression (QVAR)-based frequency connectedness approach. The empirical findings indicate spillover effects are more pronounced in excessive market circumstances than in regular market conditions. Furthermore, grain markets are the leading cause of spillovers, whereas OVX is typically a net recipient of risk spillover effects.
2024	Huszár Z.R.; Kotró B.B.; Tan R.S.K.	"European equity markets volatility spillover: Destabilizing energy risk is the new normal."	The aim of this study is to find out how changes and shocks in the prices of oil and natural gas affect the stock market in 24 European Economic Area (EEA) countries and how volatile	Standard panel regressions and the Diebold-Yilmaz (2014) spillover measure were used in the study to look at a closed network. At least until 2019, we found that the main reason for volatility spillover in the EEA economic network was political or economic instability. Large price changes for

			and profitable it is.	natural gas and crude oil show that energy risks also played a big part in how volatile the stock market was. Especially natural gas raised the risk of instability.
2024	Cunado J.; Gabauer D.; Gupta R.	"Realized volatility spillovers between energy and metal markets: a time-varying connectedness approach."	The amount of dynamic link between energy and metal commodity costs before and after the COVID-19 pandemic is being looked into in this study.	The results show that there was a small increase in how linked markets were after COVID-19. Aside from that, the study shows that before the COVID-19 outbreak, heating oil, gold, and silver were the best at sending shocks. During the pandemic, however, crude oil was the main thing that sent waves. We learned this about something. On the other hand, palladium and natural gas were the main things that got net positive shocks during the study time.
2024	Kočenda E.; Moravcová M.	"Frequency volatility connectedness and portfolio hedging of U.S. energy commodities"	From 1997 to 2023, we look at portfolio hedging and (frequency) connectivity between energy	The results show that investors think there is the most risk when they are planning to spend for a longer time, especially during the

			assets in the United States.	three main times of economic trouble.
2024	Chen Y.; Msofe Z.A.; Wang C.	"Asymmetric dynamic spillover and time-frequency connectedness in the oil-stock nexus under COVID-19 shock: Evidence from African oil importers and exporters"	This study looks at how the average and volatility of the link between crude oil and stock markets changes over time in the setting of African countries that import and export oil.	The Wavelet Coherence method and the asymmetric BEKK-Copula-GARCH method is used in this study. The results show that there wasn't a strong link between the returns of African stocks and crude oil before COVID-19, but it got stronger during the pandemic. The two have a connection that changes based on frequency and time, with a strong correlation seen in the middle and long term at certain points in time.
2024	Abid I.; Benkraiem R.; Mzoughi H.; Urom C.	"From black gold to financial fallout: Analyzing extreme risk spillovers in oil-exporting nations."	The point of this study is to look into how the market for crude oil affects the financial markets of important oil-exporting countries in a big way.	Wavelet method, frequency-based connectivity method is used in this study. These markets were linked in a way that changed over time during the crisis between Russia and Ukraine, but not in the way that was seen during the COVID-19

				pandemic, which was driven by short-term factors. The main reason for this was that long-term trends were common. The United States and Canada, on the other hand, were the main places where shocks to the network of things were sent during the war. The United States and Canada did better than Iraq in terms of unique shocks, but Iraq had the most of them.
2024	Lu X.; Huang N.; Mo J.	"Time-varying causalities from the COVID-19 media coverage to the dynamic spillovers among the cryptocurrency, the clean energy, and the crude oil."	This study looks into how the COVID-19 news coverage (MCI) affects the volatile spillovers between crude oil, clean energy, and cryptocurrencies over time.	The second step uses a new time-varying causality method to look at the temporal heterogeneity and persistence of causalities from MCI to the dynamic spillovers among the three elements. The first step is to use the TVP-VAR extended joint connectedness method to figure out the dynamic spillovers between the three elements. It has been said that the dynamic spillovers between the three parts are bigger when there is a lot of

				chaos, like during the COVID-19 pandemic. This has been seen. Not only that, but researchers have found links between MCI and the dynamic net total pairwise directional spillovers for cryptocurrency, clean energy, and crude oil. These effects last less time than the ones for cryptocurrencies and clean energy.
2024	Yousaf I.; Ijaz M.S.; Umar M.; Li Y.	"Exploring volatility interconnections between A.I. tokens, A.I. stocks, and fossil fuel markets: evidence from time and frequency-based connectedness analysis."	This research looks at how volatile the markets for fossil fuels and stocks in companies that make AI are.	The goal of this study is to use a special three-dimensional framework to find the volatility spillovers in time and frequency domains at the middle, lower, and higher quantiles, both when the settings are static and when they are changing. The data shows that the spillovers benefit AGIX, BRENT, FET, MSFT, and WTI at the median quantile. On the other hand, AMZN, GAS, GOOG, and OCEAN are the companies that send the spillovers. Furthermore, the results of our study

				show that the short-term changes have the biggest effect on the network's general ability to transmit shocks. Long-term characteristics, on the other hand, can change who sends or receives a net shock.
2024	Li B.; Haneklaus N.; Rahman M.M.	"Dynamic connectedness and hedging opportunities of the commodity and stock markets in China: evidence from the TVP-VAR and cDCC-FIAPARCH."	This research looks into the ways that China's PTA, soybeans, gold, copper, and CSI300 can be used to hedge risks and make dynamic links.	There are two modeling frameworks: TVP-VAR and cDCC-FIAPARCH. The results show that the total connection index is a good way to measure how information moves between assets in China's financial markets. Copper returns are the main ones that send volatility, while gold, soybean, and CSI300 returns are net receivers of volatility.

2024	Gao Y.; Liu X.	"Time and frequency spillovers and drivers between rare earth and energy, metals, green, and agricultural markets"	The markets for gold, base metals, renewable energy, oil, rare earth elements, green bonds, ESG, and agriculture are looked at in this study. It focuses on the exact times and numbers of times that return and volatility spread happen in these markets.	These are the spillover indices, which were first used by Diebold and Yilmaz (2014) and Baruník and Křehlík (2018), as well as regression analysis. The base metal, clean energy, and ESG industries are the top three sources of net risk pollution. The rare earth metals (REM) market is affected by these industries. The regression analysis shows that the main things that affect connection are investor mood and financial status. These two things have different effects at different frequencies.
2024	Ben Salem L.; Zayati M.; Nouira R.; Rault C.	"Volatility spillover between oil prices and main exchange rates: Evidence from a DCC-GARCH-connectedness approach."	This paper looks at how the foreign exchange rates of the top 10 countries that buy and sell oil are related to each other.	VAR, DCC-GARCH, and CONNECTEDNESS methods are used in this study. The data show that when there is a crisis, the exchange rates of countries that import and export oil are more likely to change because of changes in the price of oil than when things are stable. This means that there is still volatility

				contagion between these two markets, which shows how important oil price shocks are as extreme situation net carriers throughout the network.
2024	Chen Z.-H.; Zhao S.-Y.; Song H.-B.; Yang M.-Y.; Li S.-P.	"Dynamic volatility spillover relationships between the Chinese carbon and international energy markets from extreme climate shocks"	This research looks at how extreme weather events affect the links between the Chinese carbon market and the world's energy markets, as well as how dynamic volatility is sent between them.	There is proof that the Chinese carbon market (GDC) takes on the risk of moving from the global gas (GAS) and oil (OIL) markets. Extreme weather and high temperatures can cause problems that increase GDC's trade activity and make it more volatile, turning it from a place where risks are received to a place where risks are sent.
2024	Yousaf I.; Mensi W.; Vo X.V.; Kang S.H.	"Dynamic spillovers and connectedness between crude oil and green bond markets"	This research looks at how volatility, co-movements, and dynamic frequency spillovers are sent between the rates on crude oil and green bonds.	BK-18, DCC-GARCH, BEKK-GJR-GARCH, and Wavelet coherence are the methods that are used. The data show that green bonds can be used as a hedge against oil. This means that oil can cause negative unidirectional volatility in the global green bond markets. It gets worse: most of the

				short- and long-term connections between green bonds and crude oil could be better.
2024	Mensi W.; Selmi R.; Al-Kharusi S.; Belghouthi H.E.; Kang S.H.	"Connectedness between green bonds, conventional bonds, oil, heating oil, natural gas, and petrol: new evidence during bear and bull market scenarios."	This study looks at how the four main energy markets (U.S. green and non-green bonds, 10-year U.S. Treasuries), affect each other.	The spillover measure and the quantile connectedness method from Diebold and Yilmaz (2012) and Ando et al. (2022) were used in this study. The main results show a strong temporal connection between the focal asset classes during critical times of crisis, like when oil prices dropped, trade disputes erupted between China and the U.S., the coronavirus spread, and Russia and Ukraine went to war. Based on the network study, WTI, heating oil, and green bonds are the only asset classes that send risk into the market. All other asset classes, on the other hand, receive spillovers.

2024	Kyriazis N.; Papadamou S.; Tzeremes P.; Corbet S.	"Quantifying spillovers and connectedness among commodities and cryptocurrencies: Evidence from a Quantile-VAR analysis."	This research looks into how valuable metals, industrial metals, natural gas, oil, and Bitcoin are all connected in a dynamic way.	The Quantile-VAR method is used. At the very edges of the quantiles, where the connections between gold and silver and copper and oil are the strongest, the results show that pairs are much more strongly linked. Copper is the most stable flow generator. Silver, nickel, and zinc are the next strongest. When you look at gold and aluminum, you get mixed results, but Bitcoin, natural gas, and oil are net winners.
2023	Nguyen M.T.N.	"Examining contagion effects between global crude oil prices and the Southeast Asian stock markets during the COVID-19 pandemic."	Within this study, the impact of changing West Texas Intermediate crude oil prices on stock markets in six developing Asian economies is looked at.	A Bayesian test and a DCC-GARCH model is used. The results show that rising crude oil prices cause these developing stock markets to become more volatile. When there is a health problem, co-movements get stronger, which suggests that there may be contagion effects.

2023	Ha L.T.	"Dynamic interlinkages between the crude oil and gold and stock during Russia-Ukraine War: evidence from an extended TVP-VAR analysis."	The reasons for the unstable oil market must be found by looking at the links between the crude oil, gold, and stock markets. It is important to see how these four markets are linked.	Time-varying parameter vector autoregression regression, or (TVP-VAR) method is used. If you look at the net total directional connection, the oil and gold markets are the ones that send shocks through the system. Even so, the shock of the war between Russia and Ukraine changed the roles of these two economies. When bad shock waves hit other markets, the oil market is very important, especially when there is tension between Russia and Ukraine. This market is very important, as shown by the pairwise link.
2023	Lei H.; Xue M.; Liu H.; Ye J.	"Precious metal as a haven for global ESG stocks: Portfolio implications for socially responsible investing"	This research looks at how valuable metals can act as safe havens for Environmental, Social, and Governance (ESG) stocks around the world.	A model for connecting quantiles in terms of time and frequency, as well as cross-quantilogram analysis is used. A study looked at how risk moves between the precious metals market and the environmental, social, and governance (ESG) market. It found that palladium and gold

				are still the net risk consumers. This is still true even when the market is very bad.
2023	Fang Y.; Shao Z.; Zhao Y.	"Risk spillovers in global financial markets: Evidence from the COVID-19 crisis"	In the setting of COVID-19, a full look is taken at the short-, medium-, and long-term risk spillovers that happen across the main financial markets.	Gold and foreign exchange markets took on more risk, while the bond market moved risk from one place to another. The stock and crude oil markets sent more risk.
2023	Yang L.; Hamori S.; Cai X.	"A Multiple Timescales Conditional Causal Analysis on the Carbon-Energy Relationship: Evidence from European and Emerging Markets"	This paper uses a multiple-timescale conditional analysis of the carbon-energy link to look into how emerging and European markets affect each other.	The study uses conditional analysis on more than one time scale (Granger). A drop in the market for coal and a rise in the market for gas and crude oil may have long-term effects on the carbon market. The results show that information flows unevenly between emerging and European markets, especially over a long length of time.

2023	Bouri E.; Lei X.; Xu Y.; Zhang H.	"Connectedness in implied higher-order moments of precious metals and energy markets"	This paper looks into how option implied moments are linked in the time and frequency domains for the energy (crude oil, natural gas) and valuable metals (gold, silver) markets.	This study uses tools for time-frequency spillover and network analysis. The results show that while the moment order goes up, system-wide connectivity goes down. This is because the level of spillovers is much higher at lower frequencies. During times of upheaval, the spillovers change in strength and last for a long time at different times.
2023	Kallandranis C.; Dimitriou D.; Tsioutsios A.; Vlassas I.; Diakodimitriou D.	"On the contagion effect between crude oil and agricultural commodity markets: a dynamic conditional correlation and spectral analysis."	This paper looks at the real-world effects of the unstable prices of crude oil and important farm goods, which have had many negative effects on the world economy.	Wavelet coherence, the multivariate Baba–Engle–Kraft–Kroner generalized autoregressive conditional heteroscedasticity (BEKK-GARCH) model are used in this study. There is a trend of contagion for all assets, which may be because they all have similar financial and trading traits. Investors, fund managers, and government agencies will all be affected by this in big ways.

2023	Teng Z.; Wu R.; He Y.	"Swings in Crude Oil Valuations: Analyzing Their Bearing on China's Stock Market Returns amid the COVID-19 Pandemic Upheaval"	This paper looks at the difficult link between returns on the stock market and prices of crude oil. For the second time, it deals with volatility spillover. It mainly talks about China.	The study found that the QDII-LOF, which is a measure of oil prices, has a big effect on stock market results. Still, the whole group shows that changes in oil prices don't have any clear spillover effects. Because of these discoveries, the Chinese government should really think about how their decisions will affect other countries.

2023	Papathanasiou S.; Vasiliou D.; Magoutas A.; Koutsokostas D.	"The dynamic connectedness between private equities and other high-demand financial assets: A portfolio hedging strategy during COVID-19"	A spillover approach to look at how a private equity ETF is connected to a number of popular asset classes, including stocks, currencies, commodities, gold, shipping, and crude oil.	The study uses the improved version of the Diebold and Yilmaz method. The results show that investors who are long in bonds, crude oil, shipping, Bitcoin, and private equity ETFs can protect their positions by shorting the private equity ETF's volatility.
2023	Shirazi M.	"Dynamic behavioral characteristics of maritime liquefied petroleum gas freight rate"	This study looks at how the LPG freight rate changes over time to see how secure the energy supply is in the face of shocks from three different propane prices, the actual price of Brent crude oil, and the arbitrage between propane prices in the Middle East and the U.S.	Based on real-world data, the level of integration through Baltic LPG return and realized volatility networks changes over time and in different ways for different people. To make sure there is a steady supply of energy, boost economies of scale, and make transportation more efficient, it would be very helpful to do a different network study that looks at how the factors that define LPG transportation behavior have changed.

2023	Sheng J.; Li J.; Yang J.; Wang Y.; Li J.	"High-dimensional CoVaR risk spillover network from oil market to global stock markets—Lessons from the Kyoto Protocol"	This research looks at the connection and risk spillover between the crude oil market and the stock markets of 28 countries during the two pledge periods of the Kyoto Protocol in order to figure out how the agreement worked.	Lasso-VAR model is used in this study. The results show that the stock markets and crude oil are linked in a good way. In general, countries that have signed the Kyoto Protocol send risk spillovers to countries that have not signed it when the crude oil market is in a crisis, while countries that have signed the Protocol receive risk spillovers.
2023	Saleem K.; AlHares O.; Khan H.; Farooq O.	"FAANG Stocks, Gold, and Islamic Equity: Implications for Portfolio Management during COVID-19"	The study is conducted on how the daily returns of gold, sharia-compliant stocks, and the stocks of the FAANG companies are linked and affected by changes in volatility.	During the COVID-19 pandemic, gold and Sharia-compliant stocks had lower connections with each other. This suggests that portfolio diversification might be possible. The results also show that Shariah-compliant stocks and gold are good ways to protect against FAANG stocks.

2023	Kirkpinar A.; Mandaci P.E.	"A Volatility Spillover Analysis between Bond and Commodity Markets as an Indicator for Global Liquidity Risk"	This study looks at how volatility spread affects the risk of running out of cash in the bond and commodity markets around the world.	Hong's Causality in Variance Test and the DCC-GARCH model is used in this study. There is a lot of instability that spreads between most of these bond markets (Brazil, China, Russia, and Turkey), some of these bond markets (Russia, India, and Turkey), and gold.
2024	Shang J.; Hamori S.	"Quantile time-frequency connectedness analysis between crude oil, gold, financial markets, and macroeconomic indicators: Evidence from the U.S. and E.U."	This study looks at how different parts of the economy and finance are connected.	Quantile method to time-frequency connectivity method is used in this study. It was found that system risk changes over time and across quantiles, with short-term effects on both the U.S. and the E.U. long-term spillovers being less important than dynamic total connectedness being more important in extreme market situations (5% and 95% quantiles).

Segment 2.3: Currency Market Risks Spillovers

Year	Authors	Title	Purpose	Methodology & finding
2024	Moro A.; Nispi Landi V.	"The external financial spillovers of CBDCs"	The point of this study is to look into what happens to the economy as a whole when people in a small open market can use a foreign central bank's digital currency (CBDC).	Model of DSGE is used in this study. This research found that a steady rise in the desire for foreign CBDC by households in the United States leads to a fall in economic activity, especially if the CBDC is made to look like deposits from the United States. It might be easier to make the change if macroprudential policy is made easier, foreign funds are sold, or outflows of capital are controlled.
2024	Chen S.; Schienle M.	"Large Spillover Networks of Nonstationary Systems"	In this study, we present a vector error correction framework based on Diebold and Yimaz's network theory for creating large, stable spillover networks of nonstationary systems.	Lasso-type method for selecting VECM models are used in this study. We come up with a way to improve practical estimates and show what it means and how to make changes for general-dependent innovations. We show that our method works well with finite samples in

				all cases of intermediate and low dimensions by running a large simulation study.
2024	Liu J.; Wang S.; Xiang L.; Ma S.; Xiao Z.	“Unveiling hidden connections: Spillover among BRICS' cryptocurrency-implied exchange rate discounts and U.S. financial markets”	This research looks at how the U.S. financial markets are connected to the assumed exchange rate discount that comes with cryptocurrencies in the BRICS countries.	The TVP-VAR and DCC-GARCH models are used in this study. The most important link with cryptocurrency is the U.S. Financial Stress Index, which shows that the exchange rate discount between BRICS countries is related to cryptocurrency. At the same time, Russia has the biggest general spillover effect and makes markets more connected. In both groups, Brazil's directional spillover score is also high.

2024	Çiçek S.; Yıldırım A.	“The impact of domestic and global factors on individual public, domestic and foreign bank performances in Türkiye”	This study looks into how interest rates, exchange rates, and the VIX index affect the profits on stocks in the banking sector.	The BEKK-GARCH method is used in this study. The data show that interest rate policy has become the most important factor affecting stock returns in Turkey over the past ten years. As a result, foreign exchange has become a safe haven, and the previously established link between the exchange rate and stocks has been thrown off.
2024	Wang X.; Fang F.; Ma S.; Xiang L.; Xiao Z.	“Dynamic volatility spillover among cryptocurrencies and energy markets: An empirical analysis based on a multilevel complex network”	The dynamic volatility spillover between three energy markets and ten bitcoin markets is looked at in this study.	The DCC-GARCH-CONNECTEDNESS method is used in this study. The results show more complex parts of how the volatility of different cryptocurrencies affects each other in the cryptocurrency market. Traditional cryptocurrency markets

				have higher risk frequency levels than stablecoin markets. When it comes to risk spillover structure, different markets usually use market traits to show how their agglomeration and spillover characteristics work.
2024	Fukuda S.-I.	“Spillover effects of Ruble’s turmoil on foreign exchange markets after the invasion of Ukraine”	This research looks at how the sharp changes in the ruble affected other currencies in different ways when Western countries put economic sanctions on Russia.	A study said that European currencies went down because they lost a lot of value. This could be a sign of how the sanctions against Russia hurt the budgets of European nations that relied on Russian energy the most. But we also learned that the Chinese yuan lost a lot of value when it appreciated, while the Swiss franc gained a lot of value when it appreciated.
2023	Bhargava V.; Konku D.	“Impact of exchange rate fluctuations on U.S. stock market returns."	The S&P 500 is used to measure returns on the U.S. stock market. This study looks at	The EGARCH and TGARCH methods are used in this study. The study says that changes in the Australian dollar, the Canadian dollar,

			how changes in the exchange rates of several major countries affect those returns.	and the euro affect market return. These changes also affect how volatile the S&P 500 is. They also found that the spillover was not the same for Australian funds.
2024	Bigerna S.	“Connectedness analysis of oil price shocks, inflation, and exchange rate for the MENA region countries”	To look at this relationship in the MENA area, this study will use an empirical estimate.	VARX approach is used in this study. The real-world results show that (i) the effects of different oil prices on each country are different; (ii) the effects of changes in oil prices depend on the direction and length of the shock; and (iii) only some countries have different effects on inflation and exchange rates when oil prices change.
2023	Trancoso T.; Gomes S.	“Beyond the dollar: A global perspective on exchange rate dynamics via currency factors."	By taking the idea of "currency factors" to include more things, this paper looks at how currency exchange rates change around the world.	By looking at the G10 currencies, we can see the connections and patterns that affect exchange rates. This helps us understand how important the euro and the Swiss franc are in how shocks are spread. We also want to point out that factors related to the pound

				and the yen have effectively absorbed effects from other currencies.
2024	Boakye R.O.; Mensah L.; Kang S.; Osei K.	“Connectedness across commodities, stocks, exchange rates and bonds markets in Africa: the Covid-19 pandemic case”	During the COVID-19 pandemic, the study figures out the general systemic risks and how the bond, stock, commodity, and exchange rate markets in Africa are connected.	In a generalized VAR paradigm, the Diebold-Yilmaz spillover and connectedness measures are used in the study. The study found that all assets and countries had low structural risks. We still found that systemic risks were bigger in South Africa than in other places, and in the forex market than in the stock and bond markets. The dynamic study found connectedness return shocks that changed over time and got stronger during the first and second wave peaks of the pandemic. Both oil and gold got net shocks, that's what we found.

2023	Živkov D.; Gajić-Glamočlija M.; Đurašković J.	“Volatility spillover analysis between stocks and exchange rate markets in short and long terms in East European and Eurasian countries”	This essay looks at how volatility can be transmitted both ways between the stock and exchange rate markets in six East European and Eurasian countries.	The CGARCH model is used in this study. In every country, the authors found that the long-term effect of exchange rates on stocks was bigger than the short-term effect. It's possible that this result shows that the flow-oriented model, not the portfolio-balance approach, better describes how the markets are connected.
2024	Wuri J.; Hardanti Y.R.; Harnoto L.B.; Rahayu C.W.E.; Rahmawati C.H.T.	The Impact of Interest Rate Spillover on Output Gap: A Dynamic Spatial Durbin Model	The U.S. interest rate and the output gap between ASEAN+3 countries are looked at in this study.	Durbin model for dynamic space is used in this study. As expected, the findings show that the interest rate set by the U.S. central bank hurts the output gap in the ASEAN+3 countries. There were important direct and indirect short-term effects of the result. The productivity gap is also hurt by exchange rates. There was less of an output gap after the COVID-19 outbreak.

2023	Rastogi S.; Kanoujiya J.; Singh S.P.; Doifode A.; Parashar N.; Tejasmayee P.	“Fossil Fuel-Based versus Electric Vehicles: A Volatility Spillover Perspective Regarding the Environment”	Because of worries about the environment, we use the volatility spillover effect (VSE) to figure out whether these two types of vehicles can make money.	A family of GARCH models are used in this study. In terms of technology, we find that electric vehicles (EVs) are better than cars that run on carbon fuels as a possible source of clean energy. Similar worries about how E.V.s can't be used for business purposes compared to fossil fuels have been raised in studies. On the other hand, using VSE to look at financial feasibility gives a new point of view.
2024	Kyriazis N.; Corbet S.	“The role of international currency spillovers in shaping exchange rate dynamics in Latin America”	This research looks at how important world currencies and a few Latin American currencies are constantly linked to each other.	More advanced Quantile-VAR methods are used in this study. It was found that during these kinds of crises, big international currencies don't have as much of an effect on exchange rates in Latin America. The Argentine and Uruguayan pesos take most of the shocks, and the Brazilian real and the Peruvian sol are the main ones that cause them to spread.

2024	Urak F.; Bilgic A.; Florkowski W.J.; Bozma G.	“Confluence of COVID-19 and the Russia-Ukraine conflict: Effects on agricultural commodity prices and food security”	The study looks at how the COVID-19 pandemic, the Russian-Ukrainian War, and changes in exchange rates affect the average return, the spread of disease, and the long-term risks of three important foods in Turkey: corn, sunflower oil, and wheat.	Model of VECM-Asymmetric BEKK-MGARCH are used in this study. The results also show that changes in the value of the dollar have made the impact of the pandemic and the war between Russia and Ukraine worse. To lower market risk, the agriculture exchange could help more licensed grain warehouses open.
2023	Qabhobho T.; Adam A.M.; Asafo-Adjei E.	“Do Local and International Shocks Matter in the Interconnectedness amid Exchange Rates and Energy Commodities? Insights into	The study looked at how exchange rate returns and volatility, implied volatility for crude oil, and returns on energy commodities	Wavelet approach is used in this study. The study's results show that exchange rate returns and energy commodities move together in a variety of ways that are flexible and adaptable. Furthermore, when compared to the

		BRICS Economies”	(Brent, natural gas, and petroleum) are linked across time and frequency in the setting of BRICS.	expected volatility of crude oil, local shocks, or changes in the exchange rate, have the biggest impact on the returns on exchange rates and energy commodities.
2023	Zhou W.; Guo J.; Chen N.; Lu S.	“Key market identification, mechanism transmission, and extreme shock during the risk spillover process: an empirical study of the G20 FOREX markets”	In this study, the risk spillovers in the G20 FOREX markets are measured.	The multi-scale method is used in this study. The United States is always at the center of the G20 FOREX risk spillover links, and there is a lot of risk spillover. In different highly global events, the size and instability of risk spillovers within the G20 countries are now uneven, and the most important markets in the risk spillover process have been found.
2024	Ben Salem L.; Zayati M.; Nouira R.; Rault C.	“Volatility spillover between oil prices and main exchange rates: Evidence from a DCC-GARCH-connectedness approach."	The paper looks at how the exchange rates of the top ten oil-importing and exporting countries change together.	The DCC-GARCH-CONNECTEDNESS method is used in this study. Our results strongly support the idea that volatility in oil prices can be transmitted to markets for foreign exchange. They also show that volatility stays the

				same for the series we looked at, which is good for using the dynamic connectedness method.
2024	Trichilli Y.; Kharrat H.; Boujelbène Abbes M.	"Can fiat currencies hedge Pax gold? Evidence from range-based DCC models."	This essay looks at how Pax gold and six fake currencies move together. It also looks at the best time-varying hedge rates to figure out how Pax gold works as a hedge asset and a diversifier.	Models of BEKK-GARCH and DCC-GARCH are used in this study. The wavelet coherence method shows that the exchange rates for Pax gold/EUR, Pax gold/JPY, and Pax gold/RUB all move together a lot at low frequencies. The BEKK results also show that there are unidirectional (bidirectional) transfer effects between Pax gold and fiat currencies like EUR, GBP, JPY, and CNY (INR, RUB). Also, the Range DCC shows that the returns on paper currency and Pax gold are only weakly related, with coefficients that are very close to zero. In light of this, Pax gold is a safe investment that goes against the

				inherent risk of paper currency markets.
2023	Chiranjivi G.V.S.; Sensarma R.	“The effects of economic and financial shocks on private investment: A wavelet study of return and volatility spillovers”	The subject of this essay is the connection between private investments and changes in economic and financial data.	Wavelet multiresolution analysis with the ARMA-GARCH model are used in this study. The results show that there are effects on the timescale decomposed sequence that are not visible in the original data. This gives us a new understanding of the connection between private investment and macroeconomic shock. In private investments, return spillovers through all factors happen less often.

2024	Tian S.; Wang L.	"Global spillover impact of U.S. monetary shocks on China–based on an empirical test of GVAR model."	This paper creates an open country theory model to look at how the shock of the U.S. tightening monetary policy affected China's economy.	GVAR real-world model is used in this study. The shock of the U.S. tightening of money supply caused the international risk index to rise and the RMB to lose value against the U.S. dollar. Because of how important foreign countries are and the fact that both China's current account and capital outflow are growing, China's capital outflow has a bigger negative effect than its positive effect.
2024	Reisinezhad A.	"The Dutch disease revisited: consistency of theory and evidence."	There are a lot of gaps between theory and real-world facts in the literature about diseases in the Netherlands. To fill in these gaps, this study makes a model that looks at how technological progress spreads unevenly from the resource sector to other businesses in the country.	Dynamic panel method is used in this study. Research shows that countries with fewer resources have a more noticeable rise in their real exchange rate than countries with plenty of resources. This is because of the spending that happens when resources are in high demand. The routes of resource movement also show differences between countries that have lots of resources and those that don't.

2023	Asadi M.; Balcilar M.; Sheikh U.A.; Roubaud D.; Ghasemi H.R.	"Are there inextricable connections among automobile stocks, crude oil, steel, and the U.S. dollar?"	A lot of people think that crude oil, steel, the U.S. dollar, and the stocks of the three biggest automakers (Toyota, Daimler, and Volkswagen) are all connected in a way that can't be broken.	TVP-VAR method is used in this study. Here are the data that show how the car stocks with the biggest market capitalization and sales changed in response to error changes sent through oil, steel, and USD. Overall steel works as a net emitter and USD as a net receiver in the TYP-VAR system for Toyota and Daimler. It can be used as a diversifier in this way.
2024	Uddin G.S.; Yahya M.; Ahmed A.; Park D.; Tian S.	"In search of light in the darkness: What can we learn from ethical, sustainable and green investments?"	We look at how risk spreads and depends on other risks over time to figure out the systemic risk benefits of investments that are moral, long-	Based on measures of systemic risk, our research shows that there is less systemic risk connectivity over time when ESG and ethical assets are added to commodities and currencies.

			lasting, and good for the environment.	
2024	Wang X.	“What influences the dynamic spillovers of China’s financial market uncertainties?”	The affects of China's uncertain financial markets on the capital market, currency market, foreign exchange (FX) market, and derivatives market are looked at in this study, along with any possible causes.	The TVP-VAR-DY model is used in this study. The results show that uncertainty in the capital and currency markets mostly cause effects to spread. Even though F.X. While market uncertainty is pretty steady, derivatives market uncertainty mostly just takes in information from other markets.
2023	Wang X.; Wang J.; Wang W.; Zhang S.	“International and Chinese energy markets: Dynamic spillover effects”	This study look into what happens when prices change in the Chinese and global energy markets.	Model of TVP-VAR is used in this study. The real-world data shows that the price trends for natural gas, coal, and crude oil are strongly linked to those in China. Extreme events have made the effects of changes in the energy market much worse. In addition, the global energy market is a net producer of changes and spillovers, especially in natural gas and crude oil. This

				is because China imports a lot of energy.
2024	Yang F.; Zhang L.; Zhang M.	“Option-implied volatility spillovers between onshore and offshore RMB exchange rates”	This research looks at how option-implied volatilities affect the RMB exchange rate from both onshore and offshore points of view, from both steady and dynamic symmetric and asymmetric views.	A connectedness method based on FIVAR is used in this study. We found strong links between how volatile onshore and offshore RMB exchange rates were, with overseas rates having a bigger impact on onshore rates. To make things even more complicated, the spread effect can change over time. It is easily affected by changes inside and outside of China, such as the 8.11 RMB exchange rate reform, trade disputes between China and the US, and the COVID-19 pandemic.
2024	Abakah E.J.A.; Abdullah M.; Dankwah	“Asymmetric dynamics between the Baltic Dry Index and financial markets during	This research looks at how the Baltic Dry Index relies on standard financial markets	TVP-VAR method is used in this study. The RWWC data show that these markets are connected in a big way in the next few to three years. In the long run,

	B.; Lee C.-C.	major global economic events”	differently during major world economic events.	though, the link changes constantly between good and bad. The TVP-VAR shows that the results for upward and downward movement spillover are not the same.
2024	Giorgadze S.	“Exchange rate spillovers in the CIS”	This research looks at how the exchange rate affects risk spillovers to figure out how connected the economies of the Commonwealth of Independent States (CIS) are as a whole.	The Diebold-Yilmaz method is used to break down variation. The research shows that macroeconomic shocks cause a sharp rise in macroeconomic risk in the region. This risk has been slowly rising since 2015, a difficult year with problems both locally and globally. To show that currencies with more flexible exchange rates usually carry more macroeconomic risk in the area, this is also shown.

Segment 2.4: Interest Rate Market Risk Spillovers

Year	Authors	Title	Purpose	Methodology and Findings and conclusion
2023	Kearns J.; Schrimpf A.; Xia F.D.	“Explaining Monetary Spillovers: The Matrix Reloaded”	A high-frequency identification method is used in this study to give new insights into the monetary policy spillovers that big central banks do.	A method for high-frequency identification is used in this study. Interest rate spillovers aren't affected by trade flows very much, but financial openness and exchange rate regimes have a big effect on how big they are. There are strong financial links between the US and the euro area that make these effects even stronger, especially when it comes to longer-term debts.

2023	Lau W.-Y.; Yip T.-M.	“The effect of different periods of unconventional monetary policies on Japanese financial markets”	The point of this study is to look into how the Bank of Japan's unconventional monetary policies (UMP) have affected the Japanese financial markets over the four years, from 2013 to 2020.	To look into UMP's effect on Japanese financial markets, this study uses four sub-sample times from 2013 to 2020. The daily 10-year term spread is a good way to measure how easy monetary policy is. The study shows that the Bank of Japan's unusual monetary policies have many effects on the Japanese financial markets. Even though this is true, during the growth phase of quantitative easing (QQE), monetary policy has less of an effect on the financial markets. In the same way, quantitative easing (QQE) along with a policy of negative interest rates only affects the banking business. Lastly, the policy of quantitative easing (QQE) has a big effect on the stock market because it controls the yield curve.

2024	Liu Z.	“Chinese monetary policy spillovers on its international portfolio investment flows."	This study looks into how China's monetary strategy affects the flow of investments between countries. The study can find the monthly foreign portfolio investment flows (FPI) by taking an FPI component from a certain time series.	There is a model called FAVAR, which stands for factor-augmented vector auto regression is used in this study. The results show that interest rates and bank loans have a big effect on the flow of Chinese foreign portfolio investments. After decades of China opening up its capital account and lowering interest rates, this shows how its monetary policies are having a bigger and bigger impact on the flow of cross-border portfolio investments. This makes it seem like China's economic policy is moving

				toward one that is built on markets.
2023	Rashad A.S.; Farghally M.	“The U.S. monetary conditions and Dubai's real estate market: twist or tango?”	For this study, Dubai is used as an example to look at how the US's monetary policy affects the real estate markets in countries that use the dollar.	Analysis of panel data is used in this study. The results show that there is a strong negative relationship between the desire for housing in Dubai and the interest rate in the US. The results are good when compared to different criteria. Some possible ways to ease the tighter financial situations that might happen if policies aren't matched properly are fiscal policy measures.

2023	Irani F.; Hadood A.A.; Katircioglu S.; Katircioglu S.	"Impact of sentiment and monetary policy on Mexican tourism stock returns: the domestic and U.S. role"	The main point of this study is to look at how mood and monetary policy, both in the U.S. and Mexico, affect the stock returns of Mexican tourist businesses and how these returns change over time.	Simple least squares regression is used in this study. Research shows that changes in the mood of Mexican consumers have a bigger positive effect on the stock returns of tourist companies than changes in the mood of Mexican businesses. In any case, the way U.S. customers and businesses feel doesn't affect the stock returns of tourism companies. The study also found that changes in U.S. interest rates have a positive effect on the stock returns of tour companies.

2024	Çiçek S.; Yıldırım A.	"The impact of domestic and global factors on individual public, domestic and foreign bank performances in Türkiye"	The study looks at how sensitive stock returns in the banking sector are to changes in the VIX index, interest rates, and exchange rates.	Dynamic diagonal BEKK-GARCH method for multiple variables is used in this study. The results show that interest rate policy has become the main factor affecting stock returns in Turkey over the last ten years. As a result, foreign exchange has become a safe haven, and the previously established link between stocks and the exchange rate has been broken.
2024	Chen C.; Chen W.; Shang L.; Wang H.; Tang D.; Lansana D.D.	"Price discovery and volatility spillovers in the interest rate derivatives market"	The purpose of this study is to look at the structure and function of price discovery in the interest rate derivatives market.	The spread index model and the information share model is used in this study. The data show that price discovery is stronger in the spot market compared to the interest rate swap and Treasury bond futures markets. Interest rate swaps and treasury bond futures don't have three breakpoints like the live price of a Treasury bond does. People say that this market spillover is

				because government bond futures are pretty stable.
2023	Stephen G.C.; Narita M.; Rawat U.; Sahay R.	“Addressing Spillovers from Prolonged U.S. Monetary Policy Easing”	We figure out how successful these policy interventions are by looking into whether proactive or reactive policy interventions can lower these risks.	We show that financial companies are taking on less debt than they would if officials had time to make changes before interest rates fell again in a row. It is harder to use reactive policy measures to stop the spillovers, on the other hand.

2023	Shaheen R.; Almaktoom A.T.	"Testing Monetary Policy Trilemma for Middle Eastern Economies under a Bayesian Panel VAR"	To find out if there is an economic policy trilemma, this study looks at how U.S. monetary policy affects the Middle East.	A Bayesian panel vector autoregression method that changes over time is used in this study. This research says that when the U.S. federal fund rate went up, local interest rates in the economies of the Middle East went up too. Also, changes in the price of oil have a bad effect on interest rates in the United States.
2023	Souza F.M.; De Souza Ramser C.A.; Souza A.M.; Da Veiga C.P.	"Spillover Effects in the Presence of Structural Breaks, Persistence and Conditioned Heteroscedasticity"	The goal of this piece is to present a combined STR model for examining the ripple effects of the 2008 financial crisis. It does this by creating a tool that can get around the	The EGARCH, FIEGARCH, and STR models are used in this study. The results show that the mixed models were better at predicting how changes in interest rates would affect stock market indices when there were structural breaks. Using STR

			problems that regular studies have.	and the ARCH family of instruments makes it easier to choose instruments that will help you figure out how long-term interest rates affect the profitability of global financial markets in a clear and objective way.
2023	Gao S.; Cui B.	“NONLINEAR AND TIME-VARYING HETEROGENEITY OF THE SPATIAL EFFECT OF G20 COUNTRIES' MONETARY POLICIES”	This study looks at how the nonlinear and changing effects of price-based and quantitative monetary policy tools on the economic growth of G20 countries are affected by differences in how they affect different areas over time.	Models for smooth transitions in spatial panels is used in this study. A drop in interest rates in the G7 can't help the economy when times are tough. When times are good, however, price-based monetary policy works better. Conditions in the economy have an impact on price-based monetary policy, but not on quantitative control in the BRICS countries.

2023	Bossman A.; Umar Z.; Agyei S.K.; Teplova T.	"The impact of the U.S. yield curve on sub-Saharan African equities"	The research looks into how the different parts of the U.S. yield curve impact stocks in sub-Saharan Africa (SSA).	Changing parameter vector auto-regressions connectivity model over time. We want to stress how important it is to use SSA stocks for cross-market and asset trading because they don't react the same way to returns and volatility spillovers in a system made up of the components of the yield curve.
2024	Cunado J.; Gabauer D.; Gupta R.; Lee C.-C.	"On the propagation mechanism of international real interest rate spillovers: evidence from more than 200 years of data."	This piece looks at how interest rates are actually passed on between eight countries.	Approach to Connectedness (TVP-VAR) is used in this study. During the sample time, the empirical results show that international real interest rate spillovers change by 30% to 75%. In addition, real-world examples such as the Great Depression of 1929, both World Wars, the recessions of 1980 and 1990, and the Great Financial Crisis of 2009 show that these spillover effects are stronger during times of chaos. In addition, our results

				show how the net transmission or acceptance of changes in monetary policy has changed over time in these eight countries.
2023	Thomas L.	“Ripple effect: Disentangling the global impact web of U.S. monetary policy”	To look into the direct and indirect effects of U.S. monetary policy on other economies, as well as the effects that these policies have on the U.S. through changes in the prices of goods and exchanges between countries.	Model of GVAR is used in this study. These results show that the recent rise in spillovers is mostly due to global integration, not integration in the US. No matter what kind of exchange rate system they use, countries that are financially open have the biggest indirect effects on other countries.

2024	Vo D.H.; Nguyen H.L.-P.	"Market risk spillover and the asymmetric effects of macroeconomic fundamentals on market risk across Vietnamese sectors"	When macroeconomic factors have different effects on market risk and market risk spillovers, this study looks into those effects.	The NARDL model, the VaR method, and a vector autoregression (VAR) model were all looked at. Our results show that Vietnam's market risk goes up quickly when bad things happen. Additionally, there is a high level of connection between market risks in the Vietnamese sectors. The main sectors that take on risk are education, minerals, and development investment. The main sectors that send risk are building materials, technology, and stocks.
2024	Regmi M.; Featherstone A.M.	"Differential taxation in agricultural credit market"	The purpose of this study is to find out if the U.S. tax policy for the farm credit system (FCS) and how it might affect farmers' ability to borrow money affects the ability of farm loan companies to	The results show that FCS may be more competitive in the farm lending market if it gets better tax treatment. In addition, there is a link between the rising interest rate on farm loans and the growing share of FCS in the farming credit market.

			compete in the market.	
2024	Ni J.; Ruan J.	“Contagion effects of external monetary shocks on systemic financial risk in China: Evidence from the Euro area and Japan."	The goal of this study is to look at how changes in foreign economic policy affect systemic financial risk in China by using the cross-country spread features of monetary policy risk and market interactivity.	At different points in time, there are big differences in how external monetary policy risks and financial risks move through different pathways. There are also uneven spillover effects between markets, and different markets react in different ways to changes in foreign monetary policy.
2023	Thomas L.	“The tale of two titans: US and China's distinct impact on the global economy”	The objective of this study is to look at how the world is affected by China's and the U.S.'s monetary policies.	GVEC is used in this study. The results show that trade and banking will be two ways that China and the U.S. will have an impact on the world.

2023	From C.; Guesmi K.; Abid I.; Dagher L.	"Dynamic integration and transmission channels among interest rates and oil price shocks"	In the short term, this study looks at how interest rates and changes in the price of oil affect the U.S., the Eurozone, and twelve Asian countries.	TVP-VAR stands for Time-Varying Parameter Vector Autoregression model is used in this study. The transmission channel analysis shows that higher levels of external exposure through trade and economic linkages, unequal access to information, and political stability tend to lead to higher integration for the whole group. Financial crises, on the other hand, make integration lower. Finally, in highly developed markets, the level of time-varying integration is affected by how open the markets are to outside influences and how stable the political and financial systems are.

2024	Le C.; Nguyen H.; Vo D.	“Global liquidity spillovers in the Asia–Pacific region: policy-driven versus market-driven effects."	This study looks at how global liquidity gets into Asian and Pacific countries. It focuses on how market-driven liquidity from the private banking industry and policy-driven liquidity from developed economies' monetary policies can have opposite effects.	This study looks at how global liquidity gets into Asian and Pacific countries. It focuses on how market-driven liquidity from the private banking industry and policy-driven liquidity from developed economies' monetary policies can have opposite effects.
2023	Mei D.; Zhang M.	“Non-Symmetry of China's and U.S. Monetary Policy Spillovers: Theoretical Modelling and Empirical Analysis”	The main goal of finding any possible differences in these effects is to see if there are any differences in the processes that cause the monetary policy spillover effects between the two countries.	SVAR system for structural vector autoregression model is used in this study. The real-world data show that trade is the main way that China's monetary strategy affects other countries. China's internal economy will shrink if interest rates go up, which will hurt investment and output. China will buy fewer industrial goods from the U.S. as a result, which will hurt

				the output of the U.S. economy.
2023	Beirne J.; Renzhi N.; Volz U.	"When the United States and the People's Republic of China Sneeze: Monetary Policy Spillovers to Asian Economies"	It looks at how the U.S. and the People's Republic of China (PRC) handle money and how that affects the real and financial parts of emerging and developed Asian economies.	SVAR (structural vector autoregression) method is used in this study. We find that changes in monetary policy in the PRC have a bigger effect on interest rates in rich Asia. Also, the PRC can cause more damage to emerging Asian countries when it comes to changes in the exchange rate and the stock market.

2024	Dobronravova E.P.; Trunin P.V.	International monetary policy transmission in EAEU countries	This essay looks at how Russian monetary policy might affect the economies of Eurasian Economic Union countries and the different ways it might do so.	The changes in Russia's monetary policy had an impact on the economies of the EAEU, as shown by our study. One important way that the effects are felt is through international trade. When Russia tightens its money supply, it lowers the exports of its member states, which in turn lowers the economic activity of those states.
2024	Wuri J.; Hardanti Y.R.; Harnoto L.B.; Rahayu C.W.E.; Rahmawati C.H.T.	"The Impact of Interest Rate Spillover on Output Gap: A Dynamic Spatial Durbin Model"	The U.S. interest rate and the output gap between ASEAN+3 countries are looked at in this study.	Durbin model with changing boundaries of space is used in this study. As expected, the findings show that the interest rate set by the U.S. central bank hurts the output gap in the ASEAN+3 countries. There were important direct and indirect short-term effects of the result. The productivity gap is also hurt by exchange rates. There was less of an output gap after

				the COVID-19 outbreak.
2024	Iqbal N.; Umar Z.; Ruman A.M.; Jiang S.	“The term structure of yield curve and connectedness among ESG investments”	The goal of this project is to find out how different parts of the U.S. The Treasury's term structure and ESG leader measures show how volatile and profitable the market is.	TCP-VAR model is used in this study. Different parts of the yield curve had different effects on behavior and attitudes during the Great Financial Crisis and the COVID-19 epidemic. These effects were caused by the return and volatility spillovers. In times of stress, long-term interest rates work well as shock cushions, which is an important job.

2023	Naeem M.A.; Karim S.; Tiwari A.K.	“Risk Connectedness Between Green and Conventional Assets with Portfolio Implications”	The connection between traditional and green asset risk is looked at in this study.	The DECO-GARCH model is used to look into dynamic equi-correlations in this work. The average, lower, and higher quantile volatility analysis also shows that conventional and green assets change over time. Also, network numbers of traditional and green assets show where there may be chances to diversify. According to data on hedge efficiency, green bonds seem to be a good way to protect against cryptocurrencies and precious metals.
2023	Goczek Ł.; Witkowski B.	“Spillover effects of the unconventional monetary policy of the European Central Bank”	The study looks into what happens when the European Central Bank's unusual monetary policies affect countries in Central and Eastern Europe (CEE) that are trying to curb inflation.	The unusual ECB strategy doesn't have many spillover effects and isn't much different from normal spillover effects. The main result is that the global spillovers show up as a rise and fall in volatility, and they happen through the risk-taking channel instead of the bond/interest rate channel.

The recent increase in interest in environmentally friendly stock and sustainable portfolios has been driven by investors looking for an equilibrium between their financial goals and environmental beliefs. Socially Responsible Investing (SRI) emphasizes the necessity of taking into account environmental, social, and corporate governance (ESG) aspects while making investment decisions. However, research on the outcomes and efficacy of such initiatives is still in its early phases, especially in India. This literature review will undertake a detailed analysis of existing studies on volatility for both conventional and environmentally responsible stocks. This review aims to contribute to the broader discussion on how sustainable investment practices might contribute to a more sustainable future by summarizing key results and indicating areas that require additional research. Numerous studies on sustainable investing have been conducted by Indian researchers and authors, each contributing to advancing knowledge in this field.

These studies have consistently found that green stocks and portfolios exhibit a reduced relative risk, regardless of their elevated systematic risk in comparison to general stocks. Furthermore, these portfolios have exhibited significantly greater returns throughout and in the aftermath of the Indian stock market crises. Throughout numerous sub-periods, ESG and green index funds have both generated positive net selectivity returns, especially in times of crisis. The significance of prioritizing sustainability in financial endeavors is highlighted by these results. The sustainable indices in the Indian stock market have shown greater profitability in terms of net selectivity returns as compared to the Nifty index. These findings suggest that investors who emphasize social responsibility in their investments and choose companies with good social responsibility credentials tend to get higher returns compared to those who do not focus on social responsibility. Tripathi and Bhandari (2015 & 2020) conducted a study that found that green blue-chip stocks generated greater returns than the market/benchmark returns during times of crisis. They concluded that green portfolios had superior performance to non-green portfolios, making them a more secure choice for risk-averse investors during economic downturns and financial crises.

Due to the improvements in globalization, liberalization, and technology, economies worldwide have become more interconnected. The interconnectivity has not only enabled the expansion of countries but also created diverse prospects for worldwide investment, resulting in the accumulation of wealth. The financial market is an excellent choice for such investments due to its potential for significant returns within a very short period, as well as its ability to provide liquidity to investors, which is sometimes lacking in other investment options such as real estate. Hence, investors, financial institutions, and governments must comprehend the interdependent nature of diverse financial markets. Having a clear comprehension of this concept is especially crucial in emerging markets, as they are attracting interest from both local and global investors who are looking for greater financial gains. These markets are emerging as attractive investment destinations, driven by the worldwide economic interconnectedness (Zhou et al., 2012; Henry, 2000).

Furthermore, portfolio managers often view emerging markets as attractive opportunities for diversifying assets (Kumar et al., 2017), to capitalize on the benefits of portfolio diversity (Vo and Ellis, 2018). However, there is a clear pattern in which international investors have a limited comprehension of the complexities of emerging market dynamics. The lack of understanding in this area often leads to collective behavior, which in turn causes fluctuations in stock returns (Watson and Wickramanayake, 2012). Stock market fluctuations can be influenced by events occurring at either the domestic or global levels, such as the worldwide financial crisis in 2008 or the COVID-19 pandemic in 2019. These occurrences provide spillover effects that can be observed in the volatility and returns, which are typically linked to increased risks (Diebold and Yilmaz, 2009). When investors perceive a higher level of risk, they frequently transfer their assets to less dangerous investment possibilities, which puts downward pressure on the values of the stock market. During periods of increased volatility, investors who choose to remain involved typically require larger returns to offset the additional risk linked to market changes.

Volatility is a statistical measure of the fluctuation in returns for a certain securities or market index. Heightened volatility generally signifies an elevated level of risk connected with the security. It is typically measured using either the standard deviation or variance of returns for a certain securities or market index. Volatility in financial markets sometimes correlates with substantial movements in either an upward or downward trend. A market is considered volatile when there are significant oscillations, with the stock market seeing both significant gains and losses exceeding one percent over an extended period. The pricing of options contracts heavily relies on the crucial factor of asset volatility. Forecasting stock market volatility is important because it provides useful information for investment choices and risk mitigation tactics. Generally, generalized autoregressive conditional heteroscedasticity (GARCH) models and their modifications are employed in volatility forecasting. In situations when there are notable data jumps, skewness, outliers, and extremely persistent volatility processes, the log-ARCH model should be used instead of the non-exponential GARCH model. Nonetheless, the relationships between stocks and their returns are crucial in the age of global trading systems and linked worldwide markets. Variations in the volatility of one or more stocks can spread quickly throughout the whole financial network, with closely related equities being the most affected. Financial network volatility predictions can also benefit from these interactions. In this work, we improve the out-of-sample volatility forecasting performance by introducing a network log-ARCH model and putting forth a novel modeling approach motivated by spatiotemporal statistics (Anderson and Bollerslev,1998; Bollerslev,1986; Franq and Zakoian,2019; Geweke,1986).

Piyush and Vasant (2000) performed an analysis on the subject of volatility in the Indian stock market. Their study examined the opinions of fundamentalist business experts who argue that the major market hypothesis can explain volatility. In addition, they examined the possible impact of psychological variables on market volatility. The study thoroughly analyzed the BSE Sensex and a selection of representative equities to identify any differences in their volatility patterns during the past two years. In addition, they evaluated the effects of stock market regulations, including the introduction of rolling settlement and dematerialization, as measures intended to reduce volatility. Hence, their discoveries provide valuable insights that can help investors and market regulators improve the effectiveness of market sectors. Huseyin and Stewart (2000) carried out a study to investigate the impact of the introduction of equity-index futures on the volatility of securities markets before and after their introduction. They employed diverse models that take into account elements such as fluctuating levels of volatility, uncorrelated data, unpredictable fluctuations in volatility, and the common characteristics of each country's international market portfolio index. Their analysis revealed a correlation between futures trading and an increase in conditional volatility in both the United States and Japan. However, they observed no significant influence or manifestation of the "Dampening-volatility" phenomenon in nearly all other countries. The importance of this outcome was crucial in establishing the parameters of the model, as it entailed analyzing the relationship between open stock futures interest, exchange volume, and volatility. Additionally, they observed an increase in country-specific and conditional covariance, as well as country returns, in the upcoming listing.

Hakan and Halil (2001) examined the impact of the day of the week on the level of fluctuation in the stock market, specifically focusing on the S&P 500 market index. Their research uncovered a day-of-the-week pattern in both the calculation of volatility and returns. Significantly, Monday and Wednesday displayed the largest and lowest returns, respectively, while Wednesday and Friday demonstrated an escalation and decline in volatility. Upon further analysis of sub-periods, their conclusions were substantiated, revealing a significant and persistent weekly pattern of volatility. William (2002) performed a study on the volatility of NASDAQ stocks, which are characterized by their smaller size and stronger growth potential in comparison to the more established companies in the S&P 500 portfolio. The years 1998 and 1999 witnessed significant volatility on the NASDAQ, which had an impact on the initial public offering (IPO) market. Empirical evidence suggests that the abnormally excessive level of volatility cannot be solely ascribed to the company's size or lack of experience. However, the rise of cutting-edge technology is recognized as a vital factor that explains this phenomenon.

Gamimi and Lakshmi (2004) emphasized the critical importance of identifying stock market volatility in determining the cost of capital and assessing investment speculation and leverage options, given the inseparable link between volatility and risk. They underscored the significant repercussions of major shifts in financial-market uncertainty, particularly for risk-averse investors. To investigate the co-movement of stock markets across countries such as Singapore, the US, Hong Kong, the United Kingdom, and Japan, they utilized daily returns data. Various econometric models, including Vector Autoregression, Univariate GARCH, GARCH models with GJR extensions, and Multivariate, and Asymmetric Multivariate models, were employed to measure volatility co-movement. The empirical findings revealed pronounced volatility co-movement among Singapore, Japan, the US, the UK, and Hong Kong. Furthermore, the results indicated a limited yet significant volatility spillover effect, particularly from the other three dominant markets. Contrary to previous studies suggesting unidirectional spillover effects, this investigation demonstrated the likelihood of spillover from smaller markets to the broader market in terms of volatility. Overall, the analysis of co-movement and spillover in studied volatility provided valuable insights for risk analysis at a significant level. Porwal and Gupta (2005) conducted a study on the volatility witnessed in the Indian stock market. Their investigation centered on examining the standard rates of the S&P CNX Nifty. It was observed that 1996 was the most unstable year in the past ten years, with the volatility being attributed to political instability and regulatory shortcomings. In addition, they noted a rise in volatility in 2004, which they attributed to the growth of speculation by Foreign Institutional Investors.

Frimpong et al. (2006) employed a modelling and estimation approach to analyze volatility, specifically focusing on "Conditional Variance Volatility," within the Ghana Stock Exchange (GSE). They utilized a random walk of GARCH family models for this purpose. The Databank Stock Index, covering three days per week, served as the dataset for examining stock market volatility elements spanning over a period exceeding ten years. By comparing various competing volatility models, they aimed to evaluate their effectiveness in predicting volatility. The study identified impacts such as "Leptokurtosis, Volatility

Clustering, and Asymmetry," which were associated with stock market returns in other developed markets. The findings from GARCH models indicated a significant and persistent level of conditional volatility in stock price returns within the GSE. In a study conducted by Sinha (2007), an analysis was conducted to investigate the volatility of the equities market in both developed and emerging nations, with a particular emphasis on India. He observed that Asian markets, especially India, had greater levels of competitiveness in comparison to well-established markets. The year 1987 was designated as the most turbulent in general. In emerging economies, the year 1997 experienced the greatest instability, maintained for Chile and India. India witnessed its highest level of volatility in 1992, which coincided with a key event in the financial sector that had a significant impact on the stock market.

Aman (2008) utilized GARCH family models to investigate the characteristics of stock market volatility in two major Indian Stock Exchanges, namely NSE (NIFTY) and BSE (SENSEX). His analysis uncovered notable ARCH effects within both exchanges, suggesting the appropriateness of employing GARCH/ARCH models to capture the mechanism, including leverage effects in these markets. This indicates that investors in these markets may not be responding optimally to new information, whether positive or negative, as it can swiftly influence them. Louis and Wei (2010) analyzed the fluctuations in the effect of significant positive and negative return shocks on the expected volatility of the entire U.S. stock market. Following substantial negative return shocks, researchers noted that both asymmetric time-series models and implied volatility projections accurately anticipated an increase in volatility, which subsequently stayed constant following the shock. In addition, the volatility that was observed after such events usually anticipated an extension of volatility. In contrast, following substantial positive return shocks, asymmetric time-series models predicted an increase in volatility. Nevertheless, both implicit and actual volatility declined in these cases. Surprisingly, although time-series models that are not symmetrical projected a decrease in the amount of variation after almost no returns, both the expected and actual amount of variation showed very little change relative to the levels seen before the market became stable.

Rakesh and Mohammad (2011) undertook an analysis of stock return volatility across regular, weekly, and monthly intervals in the context of economic development. They investigated the hypothesis that a robust economic growth rate tends to stabilize investment decisions and instill confidence among investors, thus minimizing abrupt changes in investment strategies in response to news, whether positive or negative. The analysis was conducted using data from the Bombay Stock Exchange-listed BSE 100, where various economic growth scenarios, ranging from upper to lower growth rates, were examined. Utilizing AR and GARCH models, the study aimed to dissect the volatility components stemming from anticipated and unforeseen fluctuations in stock returns. The findings indicated that investors were not significantly influenced by the economic growth rate itself; rather, they demonstrated inherent sensitivity to broader investment decisions. The immediate implication drawn from this observation is that while short-term volatility remains relatively stable in relation to the rate of economic growth, the economic growth rate predominantly impacts investors with longer investment horizons. Consequently, high volatility tends to be associated with low economic growth, whereas low volatility is typically correlated with strong economic growth.

Debesh (2013) examined the numerous characteristics of fluctuations in the stock market in his research. Through the analysis of comprehensive stock market indexes across several components, he saw a decrease in the unpredictability of volatility. Periods of economic downturn or recession are frequently accompanied by increased volatility in financial markets, which tends to remain in the short term. Furthermore, it was discovered that elements such as political instability or interruptions worsened the volatility in the financial markets. Additionally, discovered a negative correlation between stock market volatility and development rate, indicating that increased volatility was linked to decreased growth. He demonstrated a cause-and-effect relationship between them, emphasizing that fluctuations in the stock market might lead to financial crises, so adversely affecting economic progress, both inside a country and globally. Significantly, there was a negative correlation between worldwide exchange and stock market volatility. This means that as volatility grew, there was a fall in exchange activity and an expansion of deficits in both current account and capital account balances. Adam, Marcet, and Nicolini (2015) propose that time-based asset valuation models, which include separable inclinations, offer precise evaluations of stock market variance by taking into account minor deviations from projected values. They argue that prudent investors, guided by their perspectives, could benefit from information derived from past evaluations of assets, thus influencing the direction and conduct of stock markets. Their methodology assesses various variables, including return volatility, stock volatility, stock-dividend ratio stability, and long-term return stability. The approach employs a methodical mathematical study to assess the compatibility of a sequence of moments, while also constraining equity premiums.

Dennis et al. (2017) performed a study where they analyzed and compared the importance of Implied Volatility and Historical Volatility Models in predicting reliable Value-at-Risk (VaR). The researchers conducted an empirical analysis of the Nasdaq 100 indices, S&P 500, and Dow Jones Industrial Average utilizing time series data that covered more than 20 years. Their research suggests that VaR models based on implied volatility did not perform better than VaR models based on GJR-based GARCH, with the latter generally yielding superior outcomes. To mitigate the limitations of pricing volatility risk, the researchers incorporated parametric and non-parametric modifications. Nevertheless, these modifications effectively decreased prejudice without causing implied volatility models to outperform historical models in terms of prediction precision. Dohyunchun et al. (2019) analyzed different predictions regarding Historical and Implied Volatility. They assessed the informational value of various factors such as lagged realized volatility, volatility from the GARCH family, out-of-the-money and at-the-money implied volatility, as well as market index volatility. Their findings revealed that while historical and implied volatility exhibit considerable predictive capability, they tend to be biased estimators of potential volatility. The study concludes that GARCH family volatility emerges as a predictive model with the potential to enhance the predictive accuracy of the Korea Composite Stock Price Index.

Smit and Varsha (2020) examined the volatility of the Indian stock market during the COVID-19 epidemic, using data from both the NSE and BSE indices. The analysis utilized a descriptive research design and incorporated a blend of primary and secondary data sources. Their research uncovered that the volatility of the stock market during this era was impacted not alone by the COVID-19 problem, but also by a range of international factors. The study emphasized the correlation between investor sentiment and heightened stock market activity during periods of uncertainty. Surprisingly their investigation indicated that individual investors tended to participate in short-term trading in the stock market, motivated by a curiosity to evaluate its underlying principles. Hence, they determined that COVID-19 had no substantial influence on the volatility of the Indian stock market.

Green investing

Green investing is the practice of making investments in businesses that benefit the environment (Boulatoff & Boyer, 2009). The rapid expansion of the worldwide green energy sector can be attributed to technological improvements in biomass, geothermal, solar, and wind energy (Ng & Zheng, 2018). To meet the growing demand from investors for socially conscious investments like green investing, there has been a notable increase in the creation of funds and other investment options in recent years (Mallett & Michelson, 2010).Businesses that prioritise environmental protection usually see a rise in shareholder value. According to King and Lenox (2001), companies that do well in the environmental arena of their industry typically do well financially as well. Additionally, according to Boulotoff et al. (2013), a company's stock price might rise by approximately 8% when it takes part in programs like the emissions reduction programme of the Chicago Climate Exchange. Investors are becoming more focused on green initiatives due to concerns about climate change and the biological landscape. This greater awareness has led to an increase in the number of investors searching for green financial solutions (Inderst et al., 2012). Heinkel et al. (2001) highlight the significant impact that environmentally conscious investors have on the economy and investment patterns.

Ng & Zheng (2018) found that environmentally friendly businesses outperform non-green ones and even outperform the S&P 500 Energy Index. Similarly, green equities outperform the market portfolio as a whole Cohen et al. (1995). According to White (1996), a different study revealed that a portfolio made up of green stocks outperformed the market, but a portfolio made up of polluting stocks did not. On the other hand, Boulatoff & Boyer (2009) discovered that environmental companies originally underperformed the NASDAQ Index. But because they are spending more on capital, they believe that green companies will eventually beat the NASDAQ. All things considered, a large body of research suggests that green companies typically beat market portfolios or benchmark energy indices.

Traditional stocks and Green Stocks

Over the past few decades, there has been a notable increase in concern about the environment and its governance on a global scale. The performance of businesses is impacted by several environmental challenges, including the release of hazardous compounds into the environment, the use of natural resources, the actions taken to prevent environmental degradation, etc. Corporations are subject to social standards, including those related to worker and social health. Sustainability has become a buzzword in the corporate world, and almost every company has started building a sustainable reputation in the community to secure its long-term existence.

Stock exchanges and developing market systems are crucial in promoting economic growth and progress. Stock exchanges play a significant role in facilitating the development of sustainable indexes, which enable investors to transition their investments from polluting industries to environmentally friendly firms. The engagement approach prioritizes the development of sustainable and eco-friendly practices, with a particular emphasis on making environmentally conscious investments. Responsible investing, as defined by the World Economic Forum Report (2005), involves making investment decisions that take into account the impact on society and the environment in a sustainable manner. Socially responsible investing includes allocating investments to a reduced number of enterprises that generate toxins, actively working with environmentally sustainable companies, and investing in clean technologies.

India has established two sustainability indices to meet its commitment to promoting environmental responsibility and sustainable practices in the corporate sector. The BSE

Greenex, an initial index developed by the Bombay Stock Exchange (BSE), evaluates the carbon emission performance of prominent companies and encourages the adoption of energy-efficient techniques. The BSE Carbonex was created in 2010 to assess the risks linked to climate change, identify possible advantages, and gauge companies' capacity to decrease carbon emissions. Singh (2014) observed the substantial expansion of the Indian stock market in terms of market capitalization, trading volumes, investor engagement, and the proliferation of indices. This expansion highlights the market's ability to adapt and recover. By implementing sustainability indexes, India demonstrates its dedication to environmental stewardship and provides investors with vital assistance in directing investments towards environmentally responsible businesses. Moreover, these indexes function as indicators for government policymakers, allowing them to assess investor attitudes toward sustainable policies and efforts.

Compared to other areas of socially responsible investing (SRI), green investing is a relatively recent topic, with fewer studies done in this area. As a result, no formal definition has been created for it (Chang et al., 2012). Mallett and Michelson (2010) define "green" or "sustainable" investing as an investment strategy that appeals to people who care about the environment, climate change, and maintaining the economy. While Climent and Soriano (2011) give a more precise definition, defining green funds as those that aim for ecologically responsible investments, Sabbaghi (2011) broadens this concept by adding social and governance considerations. Boulatoff and Boyer (2009) defined green investment as buying stocks of businesses that have a positive environmental impact based on a survey of 310 green companies.

Initial studies have examined different aspects of socially responsible investing (SRI). Rahul (2016) conducted a comparative analysis between socially responsible investments and traditional investing. The study revealed that, except for the energy index, there is a slight variation in risk levels between the two investment categories. Giannarakis et al. (2016) conducted a study on 102 firms to assess how their environmental performance affects the disclosure of their environmental scores. Their research demonstrated a clear correlation between performance and disclosure scores on environmental matters. In a study conducted by Maji and Mondal (2015) on the performance of environmentally friendly organizations, it was discovered that over 50% of these companies exhibited poor performance. Moreover, their research suggests that the environmentally conscious actions taken by firms have a minimal influence on investment decisions.

Additional studies have aimed to explore the correlation between green investing and conventional investment techniques, specifically regarding financial performance. Multiple studies have found that sustainable enterprises tend to have higher returns and lower risks compared to non-sustainable firms (Chan & Walter, 2014; Bensen et al., 2010; Lesser et al., 2014). In contrast, other research (Chang et al., 2012; Climent & Soriano, 2011; Silva & Cortez, 2016) has shown that green indexes perform worse than market indices. However, specific research have produced neutral results, suggesting that investors achieve similar returns regardless of whether they invest in green indices or market indexes. The findings indicate that if green investment were to increase profits, it would probably also increase levels of risk (Mallet & Michelson, 2014; Dixon, 2010).

Extensive research has been conducted on sustainable and green investment, examining several aspects of environmentally sensitive financial practices. Researchers have analyzed the correlation between sustainable investing strategies and conventional investment methods, as well as their influence on financial performance.

Impact	Author	Method	Time	Country	results
Positive impact	Chan & walter (2014)	Examine the impact of socially responsible investment on the performance of stocks, initial public offerings, and seasoned equity issues.	1990 -2012	Australia	Companies that prioritize environmental sustainability have shown a notable increase in profitability and have performed better in initial public offerings (IPOs) and seasoned equity offerings (SEOs) compared to other enterprises.
	Bensen et al .(2010)	Conducted an analysis and comparison of the financial performance of sustainable companies and common companies. Additionally, assessed the potential difference in risk between the two.	1999-2009	France	Sustainable enterprises exhibit reduced risk and enhanced profits as compared to other firms. Furthermore, they offer a consistent and persistent increase in investment yields.

	Lesser et al (2014)	Analyze the relationship between green stocks and Socially Responsible Investments (SRI) in terms of their financial performance and the attributes of the companies involved.	2003 - 2012	Germany	From 2003 to 2007, green equities demonstrated greater performance, but their performance declined from 2008 to 2012.
Negative Effects	Chang et al (2012)	An evaluation of the financial efficacy of environmentally-focused mutual funds compared to conventional mutual funds.	1996 - 2012	USA	Empirical evidence has shown that green mutual funds have a lower rate of return in comparison to normal mutual funds. However, the amount of risk in both types of funds remains similar.

	Climent & Soriano (2011)	This analysis will evaluate the performance and risk of green mutual funds to other funds, as well as their relative performance compared to socially responsible investments.	1987 - 2009	USA	Environmental mutual funds had lower performance compared to other funds, and there is no notable disparity in returns between green mutual funds and socially responsible investments.
	Silva & Cortez (2016)	Assessed the effectiveness of US mutual funds and European green mutual funds using a conditional model.	1996 - 2014	USA & Europe	Green funds demonstrate lower returns during normal periods and higher returns during times of crisis, especially in Europe.

	Su, X. (2021).	The purpose of this article is to assess the financial performance of eco-friendly investments in China. This will provide sensible guidance to policymakers on how to optimise the returns on environmentally-friendly investments and foster the participation of the business sector in green initiatives.	2012 - 2017	China	The findings reveal that green investment equities have lower performance compared to conventional stocks and provide less protection against extreme downside risk. This suggests that investors must incur an additional cost or premium for choosing environmentally friendly investments.
Neutral Effect	Mallett & Michelson (2014)	Analysed the performance of green funds, sustainable investment funds, and index funds using both parametric and non-parametric testing.	1998 - 2018	USA	Parametric and nonparametric testing indicates that there is no observable difference in performance between socially responsible funds and green funds, as well as index funds.
	Dixon (2010)	An examination of the performance of sustainability	2010	USA	Sustainability investment not only enhances returns but

		investments in respect to the level of risk and potential return.			also increases risk for investors.

Source: review of previous studies

Environmental investment has been in existence for about 50 years, but its importance has notably increased in the last two decades. With the increasing popularity of ESG ratings for organizations, it has become much more convenient to do correlation-cause research on a company's environmental and sustainability characteristics. There exists a substantial corpus of academic literature regarding the subject, albeit with considerable variations in the findings. The increasing significance of corporate social responsibility (CSR) has led to a growing interest in evaluating the effectiveness of environmentally sustainable investments compared to conventional investments. Companies have extended their activities internationally in a globally interconnected marketplace, even before the formation of complete global regulations and institutions that seek to solve significant market shortcomings or negative external impacts. As a result, there is a growing public expectation for companies to demonstrate socially and environmentally responsible behaviour. Corporate Social Responsibility (CSR) refers to the actions and programs implemented by firms that exceed the basic legal obligations of the countries in which they operate.

Carbon emissions play a crucial role in worldwide initiatives to support eco-friendly and sustainable development, as well as to reduce the impact of climate change. Given its status as the largest developing nation and a primary contributor to global carbon emissions Wang and Pisarenko (2020), it is imperative to establish carbon trading markets and new energy markets as strategies to reduce reliance on fossil fuels and mitigate greenhouse gas (GHG) emissions. India ranks third internationally in terms of carbon emissions. The country's CO2 emissions in 2021 amounted to 2.7 billion metric tonnes, accounting for 7 percent of the worldwide aggregate. Projections suggest that India will become the most populous country in the world in the next ten years and is expected to become the second-largest economy by 2050. As a result, its energy consumption is predicted to increase at a rate 1.5 times faster than the global average over the next thirty years. Hence, the policy choices and goals for reducing emissions established by India carry substantial importance in the worldwide endeavor to comply with the 1.5°C trajectory and prevent exceeding the carbon allowance.

India's significant greenhouse gas emissions, high vulnerability to the impacts of climate change, and fast-paced development require for rapid innovation systems and timely, adequate, and targeted financial resources to unlock and bring climate action into the mainstream. The same also has to scale up and accelerate sustainable development. To achieve global climate goals, it is imperative to make significant investments in developing economies, such as India. Therefore, it is crucial to channel foreign capital from developed nations to emerging ones. Given India's present emission levels and developmental pattern, achieving climate ambitions may be unachievable without significant climate investments in the country. In light of this situation, India presents a substantial opportunity for international investors seeking to participate in environmentally friendly projects, especially in key areas such as cleantech, renewable energy, sustainable transportation, electric vehicles, industrial decarbonization, water management, and nature-based solutions.

The advancement of green energy firms to a certain degree indicates a nation's commitment to decreasing carbon emissions and managing associated costs. The stock market functions as a barometer as well as an alert mechanism for the economy, reflecting economic circumstances and the financial assets of corporations. Hence, there is a strong correlation between the performance of equities in the green and conventional energy sectors and the pricing of carbon. The stock market in all sectors can be affected differently by fluctuations in carbon emission trading prices due to the different characteristics of listed companies. Therefore, it is beneficial for portfolio risk management to examine how various energy sectors react to changes in carbon prices.

According to theory, a scenario known as "spillover" occurs when a system's changes in one variable that is subjected to an external shock spread outward and alter other variables or the system as a whole (Jin and Jin 2008). Two transmission channels which are return spillover (Kodres and Pritsker, 2002) and volatility spillover (Acharya and Pedersen, 2005) can be used to link the green stock to the stock market. According to Wang et al. (2023), the transmission of price information is influenced by effective demand, which initially influences price changes in various marketplaces. The shifting pattern of information flow between the markets is shown by the return spillover effect. As a result, the cross-market volatility spillover effect is our main concern. According to most theories (Ferrer et al. 2018; Foglia and Angelini 2020), there is a favorable correlation between the shares of gray and green energy companies. The link between the green and grey energy sectors should therefore change over time (Zhang and Sun 2016; Lin and Chen 2019).

The current course of investing is increasingly focused on sustainable stock markets, underscoring the imperative for substantial attention in this domain. Investors are incorporating environmental, social, and governance (ESG) factors into their investment choices, to achieve financial development while simultaneously fulfilling their responsibilities to society (Statman & Glushkov, 2008; Louche, 2004). They are assessing the feasibility of incorporating sustainable indices into their portfolios, irrespective of their long-term alignment with traditional indices. The research in the field of sustainable and responsible investments largely focuses on examining the long-term relationship between mutual funds that engage in sustainable or socially responsible investing (SRI) (Jain et al., 2019). Moreover, a substantial amount of the literature focuses on comparing the performance of sustainable indices with that of traditional indexes (Arias Fogliano de Souza Cunha & Samanez, 2013; Janik & Bartkowiak, 2015; Santis et al., 2016). Much of the existing research focuses on analyzing the financial performance of companies that are part of sustainable indices. However, there is a noticeable gap in studies investigating the relationship or interdependence between sustainable and traditional stock indices, which could address the concerns of investors and other stakeholders. Sustainable finance has the potential to offer diversification benefits in conjunction with conventional indices.

Commodity Market

The shift to a low-carbon or climate-resilient economy is a shared objective of environmental experts and governmental organizations. Several steps have been taken to achieve this goal, including cutting back on investments in fossil fuel energy and supporting green initiatives. One important way to finance these ecologically friendly initiatives is through the emergence of green bonds. These financial products make it possible for local and international environmental conservation organizations to raise cash by using fixed-income securities. After that, the money earned is given to environmentally friendly and sustainable projects (Park et al., 2020).In addition to its interactions with other financial markets, the green bond market's ability to spread and manage risks will play a major role in its future stability and sustainability. Environmental scientists, organizations, and investors who want to diversify their holdings and manage risk with sustainable decisions keep an open mind on how the green bond market develops. There is a small but increasing amount of study in the field of literature that examines the relationship between the green market and other financial sectors, specifically in terms of returns and risk transmissions. This research primarily establishes a connection between the green stock market and the energy markets especially Crude Oil, Gold, and Silver, as demonstrated by studies conducted by Nguyen et al. (2020), Reboredo et al. (2020), Reboredo (2018), and Pham (2016).

The study aims to examine the transmission of volatility from internationally traded commodities to environmentally friendly stocks. The analysis will assess the effects of these interactions on the long-term viability and economic prosperity of the environmentally friendly stock market in India. Recent studies highlight the increasing interconnectedness of global markets, as investors seek to improve their investment portfolios by diversifying and hedging with various sorts of assets. This trend indicates a possible convergence between the green bonds and commodity markets. Broadstock and Cheng (2019) highlight that the correlation between the green and traditional bond markets is influenced by various macroeconomic factors, such as market volatility, policy uncertainties, economic activity levels, and the influence of news on investor sentiment, among other factors.

At the same time, other markets were also researched in prior research to establish the correlation with the green bonds. However, little empirical evidence is available concerning the green bonds’ interaction with the entire commoditization of the sectors outside the energy market. What is more, recently, some precious metals have also been recognized by the investing community as alternative investment tools, alongside the previous investment assets such as crude oil, due to the increased financialization on the primary global stock exchange accounts, academic literature also lacks empirical evidence for associating these assets with the green investment. Prior research has explored the correlation between green bonds and other markets. However, there is a lack of empirical data about the interaction of green bonds with broader categories of commodities, extending beyond the energy sector. Significantly, valuable metals like gold and silver with energy commodities like crude oil, have become acknowledged as viable investment assets in recent years because of their heightened financialization on major global stock exchanges. Nevertheless, there is a lack of empirical research that establishes a connection between these commodities and green investment (Watkins and McAleer, 2008; Lucey et al., 2017; Adekoya and Oliyide, 2020a). All the above research has been done in developed countries. It is imperative to look into the connection between different commodities and the expanding green bond market because several studies have shown how well they can hedge against a variety of market risks (as evidenced by Albulescu et al., 2019; Antonakakis et al., 2019; Adekoya and Oliyide, 2020a, 2020b; Adekoya et al., 2020; Mensi et al., 2021). Therefore, the primary contribution of this study is to investigate the volatility spillover effects between green investments and various categories of commodity assets, encompassing precious metals (gold and silver) as well as energy (crude oil). Additionally, we enhance the existing literature in two other respects. Firstly, unlike the majority of studies in green investment literature, we consider asymmetric interconnectedness by decomposing the return series of each asset into positive and negative returns. This approach enables us to separate positive and negative return spillovers, thereby mitigating potential aggregation bias observed in prior studies. Secondly, we investigate the interconnectedness across both time and frequency domains.

Over the past 20 years, a growing quantity of research on green finance—with a focus on green bonds in particular—has been done. The increasing amount of research on green bonds can be attributed to two main sources. First of all, studies indicate that the need for the transition to a low-carbon and low-emission economy is growing on a worldwide scale (Shishlov et al., 2016; Flaherty et al., 2017; Flammer, 2021). Second, investment analysts and financial specialists are always looking for assets that might help investors diversify and hedge their portfolios, especially in volatile markets. Given that green bonds are financial instruments, a number of studies have determined that it is important to examine how they receive or transmit risk as well as how they relate to other financial and commodity markets (reflecting research by Reboredo and Ugolini, 2020; Reboredo, 2018; Tang and Zhang, 2020). Some research has shown that it is important to investigate the linkages between the green bonds market and other markets at different frequency intervals, in addition to looking at connectedness in the time domain. This strategy is justified by the possibility that the interdependence of the green bond market with other markets would change at various frequencies or under other market circumstances. Furthermore, determining the frequencies linked to increased risk requires knowledge of various frequencies as well as market conditions. For instance, Reboredo et al. (2020) use a wavelet approach to examine the connectivity between asset classes and green bonds over various time horizons.

For both the US and the EU, there is compelling evidence of the close relationship between green bonds and corporate and treasury bonds from both the short- and long-term perspectives, with notable spillovers from these assets to the green bond market. This is consistent with other research showing a weak relationship over a range of periods between high-yield corporate bonds, energy, and stock assets, and green bonds. Similarly, Nguyen et al. (2020) use the wavelet framework to show the time-frequency co-movement between green bonds and various asset classes. They find evidence for correlations between asset pairs that vary in frequency and time. The report also emphasizes how green bonds' low and negative correlation with equities and commodities may help with diversification. Leitao et al. (2021) did a study wherein they employed the Markov-switching model to demonstrate that the volatility of the carbon market is intensified by the green bond market, regardless of the volatility levels in the market. As previously said, there is a growing body of research on green investments and how they relate to different markets, but it is still somewhat limited in many ways. Firstly, the relationship between the green bond market and other financial markets has received much attention in empirical investigations, whereas the interaction with commodity markets has received less attention. In short, the literature lacks a study on the dynamics of spillover between this environmentally friendly asset and larger classes of commodity assets. Furthermore, to the best of our knowledge, no research has looked into the asymmetric connectivity between commodities and green stocks.In recent decades, crude oil has stood out as a primary energy source, yet concerns about climate change have prompted a significant shift towards clean, renewable energy sources such as solar and wind power (Bouri et al.,2019; Kazemilari et al.,2017). According to the previous year's report from the International Energy Agency (IEA), there is expected to be a notable decline in crude oil usage before the expiration of 2024, potentially leading to an increased reliance on renewable energies. Luqman et al. explore the various ways renewable energy can impact Pakistan's economic growth. Meanwhile, Razmi et al.(2019) investigate the relationship between renewable energy utilization and stock values, suggesting that stock values can influence the adoption of renewable energy in the long term. Additionally, Rahman and Velayutham (2020) analyze the connection between non-renewable and renewable energy consumption and economic growth, providing evidence of a unidirectional causality extending from economic growth to renewable energy usage.

Recently, companies in the clean energy industry have been receiving lots of attention from investors, not only because they offer higher yields than those on the general stock market, but also because investing in companies with green can have positive environmental and socioeconomic impacts which can ensure an overall level of sustainability. Kumar et al. (2012) assert their research shows that the renewable energy investment industry is rising due to concerns regarding climate change as much as the fluctuation of oil prices. Reboredo (2015) claims that the volatility of the oil market encourages investors to invest in green energy firms. Because of the strong relationship of natural gas to the renewable energy industry, a large portion of research studies the links between the two types of assets. Sadorsky (2012) has revealed that the rise in oil prices can raise the risk associated with the equity of the clean energy sector. Bondia et al. (2016) establish that there is a connection within the near-term time frame between renewable energy markets and market prices for oil. Additionally, demonstrates that the Granger causality runs from the market for stocks to the commodity markets. Using wavelets, Reboredo et al. (2017) show that even though the short-term link between energy prices and the stocks of clean energy does not appear to be able to hold, the connection is apparent over the long run.

Ahmad (2017) discovers that the price of oil as well as the returns for renewable energy companies increase simultaneously which indicates that the rising energy prices cause a rise in the value of stocks of firms that are built on renewable energy sources. More recently, Ferrer et al. (2018) have examined the effects of spillovers on the relationship between US sources of clean energy and the return of crude oil. They have found that spillovers are important in the short-term and fluctuate throughout. Kocaarslan And Soytas (2019) use an auto-regressive distributed lag model which is nonlinear. (NARDL) Model that gives proof of the nonlinear relation and the asymmetrical effect of crude oil price with the cost of the clean energy stocks. Xia et al. (2019) study the powerful connection between energy prices as well as indexes for stocks that measure renewable energy. They offer evidence of an association between the exchange of carbon-based fuels as well as renewable energies. Bouri et al. (2019) have proved that crude oil can be a great security for the stocks of clean energy in the event of dramatic price movement. However, the majority of these studies fail to provide an opportunity to study the impact that the value of oil has on eco-friendly indexes. It could be different based on the various dimensions that make up the spread.

As previously mentioned the literature on the risks associated with the socially accountable (SR) investment is scarce. To fill in the gap, Hoti et al. (2005) utilize a mixture of both symmetric and asymmetric GARCH techniques to analyze the volatility fluctuations in the Dow Jones Sustainability Indexes (DJSI). In their extensive analysis, they discover the pattern of clustering of volatility across these sectors. In addition, their findings point to the positive effect of an asymmetrical parameter, which suggests the existence of leverage influences within these sustainability indexes. This groundbreaking research illuminates previously unexplored aspects in the area of socially responsible investment. Another research that was conducted by Hoti et al. (2007) provides a wealth of information into the phenomena of clustering volatility and leverage effects seen within both Dow Jones Sustainability Indexes and the Ethibel Sustainability Index. Through the application of asymmetric GARCH models, their study delves into the complex dynamics of volatility within these indexes, further enriching our understanding of sustainability-focused investment markets. Schaeffer et al. (2012) analyze the value of the markets for particular energy companies that are part of the Dow Jones Sustainability Index. Their research reveals the pattern of volatility in the returns on stocks for the firms they choose over time. Contrary to expectations, they argue that the inclusion of these companies in the DJSI does not significantly alter their volatility behavior, challenging conventional assumptions about the impact of sustainability-focused indexes on market dynamics.

Furthermore, Sariannidis et al. (2013) assist in enhancing knowledge of the link to economic and environmental performance by studying the impact of the global emissions of CO2 on socially responsible (SR) companies. Based on an analysis of the GARCH model, the study exposes a troubling trend that increases as CO2 emissions grow and the financial performance terms for SR businesses are likely to decrease. This shows the intricate connection between the sustainability of the world and financial performance, which highlights the importance of incorporating environmental considerations into the decision-making process for investment. Another component of the study is to study the complex connection of the transfer of volatility between commodity markets as well as the Dow Jones Sustainability Indexes (DJSI). Sandusky (2014) was one of the key researchers in this area by using the DCC-GARCH modeling model, which permits the calculation of the spread effects between oil and gold markets, as well as the DJSI. His research shows that similar to traditional firms, are at risk in Socially Responsible (SR) firms can be reduced by diversifying portfolios of investments that span oil, gold, and DJSI markets. On this foundation, Mensi et al. (2017) study the time-dependent relationships between gold, oil, and their Dow Jones sustainability world indexes using the DECO-FIAPARCH model multivariate. The results reveal that these three indexes have significant intercorrelations. In 2008, the financial meltdown caused an abrupt increase in correlations. This highlights the complex interactions between commodities and markets and the index of sustainability, especially during periods of economic uncertainty or tensions in markets.

Dutta et al. (2020) investigate the sensitivity of the market for socially accountable investments by using two sustainability indexes that were recently introduced that comprise the MSCI Global Environmental Index as well as the MSCI Global Green Building Index. Employing the dual-state Markov strategy of changing the regime (2020) the authors conclude that the indexes aren't directly responsive to fluctuations in the global price of oil. However, they demonstrate the ability to respond to oil price volatility fluctuations that reveal the complexity of the link between the markets for energy as well as investment approaches that have social responsibility. We build upon these prior studies and expand our second area of study analysing the risk spillovers of commodities that are strategic as well as Indian green stock indexes. Our study has important implications for policymakers trying to gain a better understanding of the effects of green investments and develop strategies to promote sustainable business. Particularly, during times of recession in the oil market, the incentive for green investors may reduce and result in lower costs in green investing. When oil prices increase the incentive for eco-conscious investors will increase, resulting in the cost of green business equity. The positive correlation between changes in the price of oil and the cost of stocks of green stocks was discovered in the findings of Dutta, Jana et al. (2020).

Furthermore, taking into consideration the relationship that is inverted with West Texas Intermediate (WTI) price and the Oil Volatility Index (OVX) as outlined in Dutta (2019) in the article, any rise or decrease in the value of OVX could hurt green stocks. This demonstrates the necessity of taking into account not only the direct effects of price fluctuations but also the larger changes in the market and its dynamic in determining the effects of green investments. If we can discern these patterns and relationships then policymakers can devise strategies to reduce the negative effect of volatile markets for commodities on green assets and create a climate that encourages sustainable growth for businesses. The war between Russia and Ukraine began in February 2014 and was focused on the fate of Crimea as well as Donbas the tensions got worse on the 24th of February 2022. It was the most important war in Europe in the period following World War II Umer et al. (2022). The war has had major consequences for the global financial system. Investors' reactions to news of geopolitical risk and conflicts are usually overhyped Zarebma et al. (2022) and are not good for the safety of markets as a whole. As an example, Abbassi et al. (2023) have found that the market price is vulnerable to geopolitical risks as well as trade dependence and dependence on trade that highlight the danger that markets are subject to these kinds of incidents. The economic consequences of the Russia-Ukraine (RU-UA) conflict vary and include the issues of logistical chains (especially in the areas of food items and base metals) items) to the increasing pressure on inflation, slowing growth prospects, and numerous other consequences as the conflict becomes more and violent (KPMG). Since the start of the war in Ukraine and Russia (RU-UA) as well as Ukraine the world equity market has experienced negative returns with enormous impacts that were diverse and significant volatility Boubaker et al.,2022; Sun and Zhang(2022).

Inflation pressures are increasing and the conflict is showing no signs of abating as investor confidence is in danger. Bossman and Gubareva (2023) research into the financial effects of geopolitical risk that result from the ongoing war between Russia and Ukraine on the largest market players in emerging and developed economies has shown that the negative impacts are specific to markets when they are at their geopolitical hazard and specifically Brazil, China, Russia, and Turkey being more accommodating to geopolitical risk in bear markets. The RU-UA conflict as the lingering consequences of COVID-19 has compelled central banks to increase their rates of interest to ensure the overall stability of the social systems of the countries. This has caused concerns about the global economy and an abrupt slowdown or recession and, if combined with the rise in inflation could create a negative economic climate Bossman and Gubareva (2023).

Prices of gold and stocks are among the most crucial indicators of the state's economic health. The relationship between stocks and gold prices is not straightforward and may affect several factors. If the stock market is rising, investors tend to be positive about the year ahead and keen to invest in companies. When the market is falling investors are more cautious and may withdraw their funds from the market. In times of the possibility of economic instability, gold is generally regarded as a safe place for investors. If prices for gold increase in this way this implies that investors are anxious about the risk of inflation as well as other economic concerns that may impact how traditional investment portfolios perform like stocks. However, sustainable and green stocks are not as extensively researched in academic journals when opposed to traditional stocks, due to the changing nature that sustainability plays in the finance industry and corporate, environmental, and social (ESG) investing. The standard research on finance has been based on the traditional measures and analysis of traditional stocks. These are well-established and have reliable data sources as well as proof of their historical performance are in the right place. However, the sustainable and green stock market is situated amid environmental, financial as also environmental and social concerns. Since the demand for green and sustainable investing is growing, the research done by academics on these topics is expanding however it's not enough to bridge the gap between non-scholarly and academic research. Because sustainability as well as ESG aspects are becoming more important in investment decisions we anticipate further research that sheds some information on the performance as well as the potential risks and impacts of sustainable and green stocks.

Green stocks are those that are eco-friendly and wealthy. Environmentally conscious businesses can cut carbon emissions and improve their competitiveness (Green et al., 2012). Wind, solar, and other options for energy sources have also been included in Green stocks. Investors who invest in green stocks not only stand a chance to make a steady profit on their investment as well as in reducing pollution and general pollution of the environment. Finding a green-listed firm isn't hard. Most brokerages can access a wide range of sources, such as the market's ratings to locate Green stocks. Similar to all investment scenarios, investors are trying for ways to broaden their investment portfolios through investing in Green stocks. The green stocks that shield us from the ravages of global warming showed remarkable resilience during the crises between 2008 and 2020 (Chakrabarti and Sen 2021).

Gold was considered to be an unquestionably safe place to diversify risk throughout the ages, however, it has been reinterpreted in contemporary times. Choudhry et al. (2015); Boubaker and Raza (2017); Wen and Cheng (2018), and Iqbal (2017) have established convincing evidence to support the claim that gold can as a safe place to store securities and bonds during times of crisis. In particular, the value of gold can rise dramatically during the financial crisis sector, with a huge volatility (Hood and Malik 2013). In comparison against Dollar as well as Cryptocurrency the price of gold has lost its appeal as an investment that is secure (Choudhry et al., 2015). It's hard to distinguish between more risky investments in stocks and gold. The price of crude oil is controlled by OPEC as well as in the USA in both demand and supply (Behar and Ritz 2017.). To address the growing demand for the market, China built its crude Oil market for trading in Shanghai and renamed it INE. The volatility of crude oil has had an impact on the stock market, without question, and is highly connected to the economy (Ran and Voon 2012; Nazlioglu et al. 2013). The markets for every BRICS country are impacted by spillovers of the price of crude oil (Boubaker and Raza 2017). The effects of spillovers are well-known in the context of Globalization (He et al., 2022). Maghyereh et al. (2017) found minimal spillovers from gold to stocks and gold, however, large spillovers from oil to stocks. Cryptocurrency (Wang et al. 2019) along with the Crude Oil Volatility Index (Chen et al. 2018) have found the effect of spillovers in research done recently. Zhang et al. (2022) have studied the absorption capacity of indexes of prices during the Crisis of COVID-19, and their findings show that prices shifted by the country and sector in different ways. The green indexes of stocks provide an opportunity to diversify your portfolio of stocks with a strategic approach to risk mitigation.

Gold and prestigious precious metals are employed to guard against the risk of inflation. Ahmad et al. (2018) For instance they argue that inflation reduces the value of investments and the effects of inflation offer a good opportunity for those with the wisdom of investing in gold to be a secure hedge instrument. It is usually thought of as an asset that could be replaced to preserve its value. In addition, it has a major impact on the Indian economy because of the enormous demand for exports of jewelry and other valuable metals. It is among the industries that are growing fastest within India and is also the nation's most significant exporter of foreign currencies. Silver is a different precious metal that is a favorite among the masses of India as a material to be used in jewelry or as an investment option. In India, the idea of silver is that it represents luck and good fortune. Of luck. It is believed as a substitute for gold. Because of their low capacity for substitution and their strong similarity to platinum and gold as well, both precious metals offer arbitrage potential and are very low-risk spread characteristics when trading (Pradhan et al., 2020) which are frequently used in environmentally friendly businesses. For instance, the usage of silver in sectors that deal with clean energy has increased substantially due to its use in photovoltaic systems to generate solar energy. Dutta (2019) asserts that a rise in demand for silver may make the market for solar power to become more uncertain.

Forex and green investment

In the context of worldwide integration, it is commonly recognized that the importance of foreign exchange risk has been increasing. When engaging in international companies, investors must recognize this specific risk, as it can greatly affect the value of their investments, either positively or negatively. Although diversifying one's portfolio within a country can help reduce or eliminate unique risks, it still exposes investors to overall market risks. International diversification can effectively reduce overall portfolio volatility due to the variation in systematic risk across different markets. Therefore, foreign investments offer investors the chance to reduce risk by taking advantage of the low correlations between countries. However, it is important to acknowledge that internationalization also brings along the potential risk of foreign exchange risk. This risk necessitates a comprehensive assessment and integration into corporate strategy for all aspects of overseas investments, including the management of green innovation and technology.

Over time, a large number of academics have conducted in-depth studies on the impact of currency rates on stock market performance. The relationship has produced a range of arguments and results, making it a highly desired subject. There is significant importance for investors and policymakers to conduct additional research and analysis regarding the relationship between exchange rates and stock market performance. In general, as exchange rate variations have a substantial impact on several economic factors, it is imperative to examine them. The investor's return in a foreign country is determined by two factors: the local performance of the asset and the currency's volatility. Therefore, when the currency in which the investment is made appreciates, the investor's profits grow, whereas a depreciation reduces them. This study aims to determine the extent to which foreign exchange risk affects the stock market, specifically in green stock investment in India. Our objective is to conduct a comparative analysis to examine the relationship between stock prices and exchange rate movements.

Many studies have examined the impact of exchange rates on stock market performance. This section will contain the results of a few of these research. It will discuss research showing a positive correlation between exchange rates and stock market performance first, followed by research showing a negative correlation. The relationship between currency exposure and stock markets has attracted significant interest from both researchers and investors. Stavarek (2005) investigates the correlation between currency rates and equity prices in the United States, as well as in four established EU nations and four newer EU members. The study utilizes monthly data to analyze both the short-term and long-term links between these variables and categorizes his dataset into two separate periods: 1978-1992, specifically examining developed countries, and 1993-2003, including all countries. The results indicate that the relationship between these variables is strongest in nations with well-established foreign currency markets. Moreover, the significance of both short-term and long-term cause-and-effect connections has risen in the recent period, indicating that as financial markets have become more interlinked and limitations on capital have been lifted, the association between currency exchange rates and stock prices has become more robust. Additionally, (Doong et al., 2005) utilize weekly data to examine the correlation in Indonesia, Malaysia, the Philippines, South Korea, Thailand, and Taiwan from 1989 to 2003. Their research reveals a mutually influential connection between exchange rates and equity prices in Indonesia, Korea, Malaysia, and Thailand. Furthermore, apart from Thailand, the examined nations' stock values exhibit a negative correlation with the currency exchange rate. This implies that when the currency experiences a devaluation, there is a corresponding decline in the values of equities.

Inci and Lee (2011) investigate the correlation between stock returns and exchange rate variations in a selection of key European countries (France, Germany, Italy, Switzerland, and the UK), as well as the USA, Canada, and Japan. Their research suggests a significant influence of past fluctuations in exchange rates on the performance of stocks. Furthermore, they detect evidence of Granger causation in the reverse direction. In contrast, Mishra (2004) examines the relationship between the stock market and foreign exchange markets, specifically within the setting of India. In contrast to the conclusions the analysis of data from 1992 to 2002 shows that there is no discernible Granger causation between exchange rate returns and stock returns in the Indian market. Connectedness is a vital term in financial markets and has a substantial influence on the stability of the financial system. The connections between institutions (such as financial markets and financial institutions) in the financial system are typically intricate and multifaceted. The forex market is the largest financial market globally, characterized by significant transaction volume and high liquidity. Its volatility has wide-ranging effects on imports and exports, commodity prices, capital flows, economic output, and employment. The stock market is significant due to its direct correlation with the economy and commercial activity. According to the triennial central bank survey performed by the Bank for International Settlements, the global foreign currency (forex) market showed substantial activity, with an average daily trading volume of $7.5 trillion in April 2022. Simultaneously, as of June 2022, the market capitalization of U.S. stock markets experienced a significant increase, reaching roughly $43 trillion. The increasing tendency of cross-border transactions in financial markets across different areas is expected to enhance both the independence and the spread of instability within the financial system. It is anticipated that the interconnection and the transmission of risks between different financial markets will increase, especially during times of emerging crises and uncertainties, such as the COVID-19 pandemic and geopolitical tensions.

The relationship between the stock market and macroeconomic indicators has been widely explored in the domains of economics and finance literature, as evidenced by famous works such as Fama (1981) and Nelson (1976). A significant body of research in the field of international finance has been dedicated to assessing the impact of currency exchange rate variations on stock market volatility. In recent years, emerging economies have faced challenges in maintaining macroeconomic stability. Several nations have opted to enact deliberate economic changes, specifically targeting the enhancement of their stock markets, to foster heightened economic expansion. During the 1970s and 1980s, numerous countries took steps to enhance their financial markets, often by reducing government interference in the financial sector. The main anticipation was that these measures would foster economic expansion by encouraging greater utilization of savings or by attracting larger volumes of foreign investment (Rajan and Zingales, 2003).

Over the past twenty years, economists have closely examined the relationship between stock returns and currency rates due to the increased global financial integration and increased trade and money movements between countries. Maku and Atanda (2010) argue that fluctuations in exchange rates are likely to affect the performance of the stock market because they can have an impact on international competitiveness and trade balances between countries. Despite numerous studies on the correlation between exchange rates and stock returns, there remains significant disagreement and debate in the literature regarding the actual impact of exchange rate volatility on stock market performance (Aydemir and Demirhan, 2009; Carruth et al.,2000). Multiple theoretical and empirical studies suggest that changes in exchange rates have a substantial influence on stock market performance by affecting the cash flow, investment, and profitability of companies. However, there is no consensus on the correlation between stock market performance and exchange rate volatility (Bhunia, 2012; Vygodina, 2006). Frank and Young (1972) analyze the correlation between currency exchange rates and stock prices. The findings indicate that there is no statistically significant correlation between the two variables. The empirical studies conducted by Bartov and Bodnar (1994) and Bodnar and Gentry (1993) confirm the findings provided by Frank and Young.

Multiple studies indicate that there exists a negative association between exchange rates and stock prices. Ajayi and Mougoue (1996) examine the relationship between stock indices and currency rates in eight developed countries from 1985 to 1991. It has been found that the exchange rate has negative impacts on stock values in both the short and long term. The study conducted by Ibrahim and Aziz (2003) examines the dynamic correlation between stock prices and exchange rates in Malaysia from 1977 to 1998. They discover a negative correlation between the exchange rate and stock prices. Doong et al. (2005) discovered a significant negative correlation between stock returns and currency rates in five Asian nations from 1989 to 2000. In contrast, several research challenge this conclusion by providing evidence of a substantial and favorable correlation between stock returns and currency rates. Aggarwal (1981) looked into the impact of exchange rate fluctuations on the price of American stock markets between 1974 and 1989. He finds that the US currency and stock prices have a strong association. Additionally examining US stock prices and currency rates, Giovannini and Jorion (1987) found results consistent with Aggarwal (1981).

Using data on India, Korea, and Pakistan from 1985 to 1994, Abdalla and Murinde (1997) proposed that exchange rates Granger affect stock prices. Nonetheless, stock prices have a greater impact on currency rates in the Philippines. Shifting the focus to the Indian context, there hasn't been a lot of research done in this area about the Indian economy. Research on the relationships between stock prices and important macroeconomic indicators, such as the prime lending rate, the narrow money supply, the index of industrial production, and the rupee's value relative to the dollar, has been conducted by Pethe and Karnik (2000). The macroeconomic changes that have taken place in India during the early 1990s—particularly in the financial sector—are the background against which their analysis and discussion are placed.

The impact of currency rates on the main stock market index of five MENA countries was examined by Moussa and Delhoumi (2022). The cointegration of stock returns and exchange rates was confirmed by their findings. Furthermore, their findings suggested that the market index was more sensitive to declines than to rises in exchange rates, with this tendency being especially noticeable in Tunisia and Egypt in contrast to Morocco, Turkey, and Jordan. Overall, their analysis found that the Middle East and North Africa (MENA) region's stock market returns are probably going to increase when the local currency strengthens. Griffin et al. (2004) that foreign inflows are a strong predictor of returns in Thailand, India, Korea, and Taiwan. However, Doong et al. (2005) demonstrated that these financial factors are not cointegrated. There is a substantial negative correlation between stock returns and the contemporaneous change in exchange rates for all countries except Thailand, and bidirectional causality has been shown in Indonesia, Korea, Malaysia, and Thailand.

Mechri et al. (2018) examined the Tunisian and Turkish marketplaces and came to a similar conclusion. Their research demonstrated a significantly substantial positive association between exchange rates and stock market results in both nations. Additionally, they found that exchange rate volatility had a major impact on the stock markets in Turkey and Tunisia. It's interesting to note that they only saw volatility clustering in Tunisia, which suggests that exchange rate volatility has a big impact on price swings in the stock market there. Maysami et al. (2004) divided the market indices into three different sectors and investigated the relationship between different macroeconomic variables and market indices in their research done in Singapore. Their results showed that exchange rates and stock market performance were positively correlated. According to their interpretation of the data, a stronger Singapore dollar helps to limit import inflation, which raises stock returns and earnings. Furthermore, they proposed that a strong Singapore dollar is seen favourably by overseas investors, which causes more money to flow into the nation and boosts the stock market. Similarly, Hsing's (2011) research supported these conclusions by showing that an increase in the value of the Bulgarian currency had a beneficial effect on the stock market while a decrease had the opposite effect.

Khan (2019) noted a considerable negative influence of exchange rates on stock returns in both the short and long terms, which is consistent with the findings of Khan et al. (2012). Khan (2019) looked at the relationship between exchange rates and stock returns on the Shenzhen Stock Exchange in particular. He concluded that an increase in the value of the Chinese Yuan would hurt stock returns and vice versa. Similarly, Bahmani-Oskooee and Saha (2015) in the US supported the idea that exchange rates have a short-term negative impact on stock prices, but they were unable to present evidence for a long-term effect. Furthermore, research by Aftab et al. (2015, 2021) has revealed evidence in favor of a negative association between stock returns and currency rates. Agrawal et al. (2010) examined the relationship between the Indian Stock Index, or Nifty, and the Rupee/USD exchange rate. Their analysis revealed an inverse relationship between these two elements, as well as a negative association. They also found a one-way association between stock returns and currency rates. They found that a decline in Rupee/USD exchange rates was linked to an increase in Nifty returns, suggesting a strengthening of the Indian Rupee. Furthermore, Cakan and Ejara (2013) found a bidirectional causal relationship in most of the tested nations in their analysis of the relationship between exchange rates and stock prices across twelve emerging economies. Lakshmanasamy (2021) found different results when he used the BSE SENSEX index in his study, which was exclusively focused on the Indian market. He noticed that compared to changes or surprises in other parameters like currency rates, the volatility of stock returns showed more sensitivity to its own lagged values. Thus, in the Indian context and according to previous research, it seems that exchange rate changes might not have a major effect on stock market performance, whereas the opposite might be true.

Several scholars have examined these relationships using a variety of analytical models, such as GARCH, Granger Causality, Co-integration, and Quantile Regression. For instance, Liu and Wan (2012) looked at the connection between stock prices and currency rates in the Chinese economy. They were unable to discover any proof of a persistent relationship between currency rates and stock prices. Nevertheless, they noticed a cross-correlation between currency rates and stock prices. Furthermore, their analysis produced no evidence of a causal relationship between currency rates and stock prices. Similarly, Tsai (2012) used Quantile Regression to investigate the relationship between stock prices and currency rates. The results show that there is a negative relationship between six Asian countries' stock values and exchange rates. In addition, Yang (2017) found that stock prices in four Asian economies—Singapore, Hong Kong, Taiwan, and South Korea—have a long-term correlation with exchange rates.

The dynamics of exchange rate and stock price volatility spillovers were examined by Tule et al. (2018), who found that there are bidirectional spillovers in the Nigerian financial markets. A two-factor arbitrage pricing model was used by Mahapatra and Bhaduri (2019) to investigate the spillover effects of exchange rate and stock return volatility inside Indian financial markets. The results they obtained supported the hypothesis that fluctuations in exchange rates can affect stock returns as well as the foreign exchange market. Asymmetry in the relationship between exchange rates and stock prices has also been observed by certain academics. Kumar (2019), Sheikh et al. (2020), and Sikhosana & Aye (2018) propose that there is an asymmetrical relationship between exchange rates and stock prices. Kumar (2019), Sheikh et al. (2020), and Sikhosana & Aye (2018) investigated the transmission of volatility between stock prices and exchange rates in the financial markets of South Africa. They used an asymmetric GARCH model for their analysis. Their work provides evidence for the presence of reciprocal spillovers within the financial markets of South Africa.

Extensive research has been conducted to investigate the potential effects of the Covid-19 pandemic on financial markets and the relationship between volatility (Ali et al., 2022; Bouri et al., 2021; Fasanya et al., 2021; Li et al., 2021; Umar & Gubareva, 2021). For example, a study by Umar and Gubareva (2021) investigated how media attention affected the volatility of Islamic stocks. Li et al. (2021) presented convincing data on the consequences of Covid-19 deaths in a similar manner. According to their findings, the stock market reacts more strongly to patient deaths than to their recoveries. In addition, Ali et al. (2022) carried out a study on the transmission of volatility between oil and stock markets, uncovering a positive correlation between the returns of these two sectors.

Previous research conducted by Bashir et al. (2016) and Hussain et al. (2017) has also found evidence of a correlation between currency rates, stock markets, and oil markets. In addition, Fasanya et al. (2021) discovered substantial evidence of volatility interconnectivity and spillover in the worldwide exchange market.

After the Global Financial Crisis of 2008, there has been a significant increase in research in the literature that specifically examines the subject about BRICS countries. A prime example of this is the recent study conducted by Dahir et al. (2018), which examined the interconnectedness between stock markets and exchange rates in BRICS countries using the dependence-switching-copula method. Their research uncovered an inverse relationship between foreign currency rates and stock prices among BRICS nations. Chkili and Nguyen (2014) analyzed the relationship between exchange rates and stock prices in BRICS using the VAR model. Their findings indicate that there is no noticeable correlation between stock prices and exchange rates across these states. Huang et al. (2021) used the VAR model to investigate the correlation between exchange rates and stock prices in BRICS. Their research revealed the main factors that influence changes in exchange rates and stock prices in each BRICS country. More specifically, the researchers noted that the primary factor influencing the economic situation in Brazil is the financial account, but in Russia, it is the current account. However, in China, India, and South Africa, both financial and current account issues have substantial influence.

Interest rate and stock market

Interest rates, a fundamental aspect of finance theory representing the time value of money, are critical in shaping the landscape of stock prices within the economy. Serving as a pivotal macroeconomic indicator, interest rates delineate the cost of capital, thereby directly influencing the economic profitability of corporations. This, in turn, impacts investor behavior and precipitates variations in the equity market. The nexus between stock valuations and interest rate fluctuations has garnered substantial attention within the academic sphere, leading to a rich body of literature that elucidates this relationship through both theoretical constructs and empirical analysis. Across diverse geographical contexts, these scholarly investigations employ a variety of analytical frameworks, including both single-factor and multivariate methodologies, to dissect the mechanisms through which interest rate adjustments manifest in the equity market. This discourse aims to synthesize these theoretical and empirical insights, offering a comprehensive examination of the dynamics at play between interest rates and stock prices.

Lynge and Zumwalt (1980) identified a heightened sensitivity of bank stock returns to interest rate fluctuations compared to the stock returns of non-financial entities, yet they acknowledged the presence of significant influences beyond market and interest rate factors. They noted a differentiation in sensitivity across the spectrum of interest rate maturities, distinguishing between the effects of short-term and long-term interest rate movements on stock returns. Their research indicated an evolving nature of this sensitivity within bank stocks. Subsequently, Flannery and James (1984) corroborated the inverse relationship between both short-term and long-term interest rates and stock returns, delving into the underlying reasons for the pronounced susceptibility of bank stock returns to interest rate changes. They proposed that an understanding of the impact of unanticipated interest rate shifts on stock returns necessitates a thorough analysis of the composition of a bank's assets and liabilities in terms of their maturities.

Campbell (1985) posits that the term structure of interest rates holds predictive power over stock returns, laying a foundational premise for subsequent investigations into this dynamic. In a focused study on the United Arab Emirates banking sector, Bashir and Hassan (1997) explore the impact of interest rate fluctuations on the stock returns of commercial banks, delving into the nuanced relationship between interest rate sensitivity and equity performance. Further expanding the geographical scope, Hasan et al. (2000) assess the efficacy of Treasury bill rates of varying maturities as indicators of the anticipated monthly, quarterly, and annual stock returns in the Sri Lankan market over the period 1990 to 1997. Contrary to findings from international contexts, their analysis uncovers a distinctive positive association between short-term interest rates in Sri Lanka and subsequent stock returns, demonstrating a consistent ability to forecast returns across different temporal dimensions. This relationship notably intensifies and becomes more pronounced with the extension of maturity periods and the expansion of the return horizons into quarterly increments. Moreover, the predictive power of interest rates on stock returns appears to strengthen over longer durations, albeit with an exception observed in the annual return projections, suggesting a nuanced and complex interaction between interest rates and stock market performance that varies with time and geography.

The investigation into the interplay between stock returns and interest rate fluctuations has intensified, leading to the uncovering of substantive evidence that delineates a predominantly negative correlation between these variables. Bulmash and Trivoli (1991) illuminated a direct linkage between current and preceding month stock prices in the United States, alongside identifying an inverse relationship between stock prices and the Treasury bill rate. This notion of a negative association was further substantiated by Abdullah and Hayworth (1993), who pinpointed a discernible negative correlation between US stock returns and both short-term and long-term interest rates. Echoing this sentiment, Gan et al. (2006) proposed the existence of a persistent negative correlation between interest rates and stock prices over the long term.Liu and Shrestha (2008) employed heteroscedastic cointegration analysis to probe the enduring linkage between interest rates and stock indices in China, confirming a long-term relationship. Conversely, in the examination of more immediate effects, Pilinkus and Boguslankas (2009) observed a detrimental impact of short-term interest rates on stock market valuations. Collectively, these studies contribute to a nuanced understanding of the complex dynamics at play between stock performance and interest rate movements, highlighting both temporal and geographical variances in this relationship.

The challenge of optimizing investment returns while mitigating associated risks impacts financial institutions and individuals equally. Investors rely on diversification to reduce the risk in their portfolios. Diversifying their portfolio allows an investor to minimize risk and maximize returns. Using monthly data between stock index and interest rates for fifteen developed and developing countries, Alam and Uddin (2009) looked for evidence of share market efficiency. They found that interest rates had a significant negative relationship with share prices for all of the countries and that changes in interest rates had a significant negative relationship with share price changes for six of the countries. Additionally, they argue that these nations' stock exchanges will greatly benefit from interest rate controls since more investors will flock to the share market and businesses will increase their investment in extensional projects.

Financial institutions and people are equally impacted by the challenge of optimizing investment returns while lowering associated risks. Investors can reduce portfolio risk by using diversification as a technique. Investors can lower risk and boost returns by using a portfolio diversifier. Alam and Uddin (2009) looked for evidence of share market efficiency by analyzing monthly data for fifteen industrialized and developing countries' stock indexes and interest rates. They found that, for each of the countries, interest rates and share prices were highly linked adversely. Moreover, for six of the nations, changes in interest rates considerably correlated negatively with changes in share prices. In addition, they argue that interest rate controls will benefit these nations' stock markets greatly by drawing more investors to the share market and motivating businesses to increase their expenditures on extensional projects. Volatility is a key factor to consider when making investments because it is a measure of risk and is defined as the degree to which prices fluctuate over a certain period. Volatility and projected investment results are closely related since expected returns depend on associated risks. Elevated volatility in the stock market usually indicates a higher risk associated with equity investments, leading investors to reallocate their capital to less volatile assets. This change puts downward pressure on stock prices, requiring bigger expected returns in the future to make up for the increased risk. As such, volatility becomes a crucial variable in many aspects of investing decision-making, including portfolio construction, asset pricing, and derivative valuation, hedging strategy formulation, capital sufficiency assessment, margin requirements, and other risk management aspects.

The main source of volatility in financial markets is information flow, as changes in asset prices are triggered by the arrival of unexpected news. The effectiveness of the price discovery process and the speed at which securities prices adjust to new information also have an impact on the degree of volatility. When there are gradual price modifications, volatility is typically lower than when there are sudden fluctuations. On the other hand, circumstances that are marked by excessive reactions in the value of securities typically exhibit increased volatility. In market conditions where there is a lot of noise traders and investors with different opinions tend to have more volatile prices.

The long-term relationship between two different Indian capital markets and several macroeconomic variables, such as interest rates, inflation, currency rates, and gross domestic savings, was investigated by Pal & Mittal (2011). They used stringent statistical approaches, including unit root testing, co-integration analysis, and error correction procedures, using quarterly data from January 1995 to December 2008. Their analysis produced important results that showed interest rates and foreign currency rates affected just one of the two capital markets, but inflation rates had a considerable impact on both. Moreover, the examination showed that total domestic savings did not exhibit a noteworthy capacity for explanation concerning either market. Naik and Padhi (2012) examined the relationships that exist between the BSE Sensex, the index of the Indian stock market, and five macroeconomic indicators from 1994 to 2011. These indicators include the money supply, treasury bill rates, exchange rates, industrial production index, and wholesale price index. They sought to determine the long-term equilibrium link between the stock market index and the macroeconomic factors by utilizing vector error correction modeling in conjunction with Johansen's co-integration methodology. The macroeconomic factors and the stock market index showed indications of co-integration, according to their analysis, which points to a long-term equilibrium relationship. Interestingly, the study found that while there was an adverse link with inflation, there were positive associations with the money supply, industrial production, and stock prices.

On the other hand, short-term interest rates and currency rates were thought to have little bearing on stock values. Sulaiman et al. (2009) investigated how macroeconomic variables affected stock prices on the Pakistani stock exchange. Specifically, they looked into how stock prices related to several important macroeconomic variables between 1986 and 2008, such as foreign exchange reserves, foreign exchange rates, the industrial production index (IPI), the wholesale price index (WPI), gross fixed capital formation (GFCF), and broad money M2. The study yielded notable insights through empirical analysis, indicating that stock prices were significantly impacted by foreign exchange rates and foreign currency reserves. Other factors, such as the GFCF and IPI, were discovered to be statistically unimportant in explaining changes in stock prices.Using data from 1997 to 2010, Aurangzeb (2012) attempted to identify the factors influencing the performance of stock markets in three particular South Asian countries: India, Sri Lanka, and Pakistan. Regression analysis was used to reveal important findings from the study, which showed that exchange rates and foreign direct investment both had a positive and statistically significant impact on stock market performance in South Asian environments. On the other hand, the performance of the stock market in the area was significantly impacted negatively by interest rates. Additionally, the data revealed a statistically small but negative correlation between South Asian stock market performance and inflation. In a similar way Ahmed and Imam (2007) investigated the connection between stock markets and a number of macroeconomic variables, such as GDP, the money supply, interest rates, treasury bill rates, and the industrial output index. They examined monthly data from July 1997 to June 2005 using several tests, including unit root analysis, co-integration analysis, and vector error correction models. According to their findings, there is no sustained correlation between macroeconomic indicators and the stock market index. They did point out, though, that adjustments to Treasury bill growth rates or interest rates could have an impact on market returns.

An examination of the effects of various important macroeconomic factors on stock market returns was carried out by Chen et al. (1986). Short- and long-term interest rates, expected and unexpected inflation, industrial production, and the difference between high-grade and low-grade bond yields were included in their research. The researchers used twelve cross-sectional regression analyses with data from 1953 to 1972. The research findings indicate that a few macroeconomic factors specifically changes in the risk premium and industrial production, have a large and statistically significant impact on stock returns. Using the GARCH-M model, Fang and Miller (2002) investigated the impact of volatility in the Korean foreign currency market on the Korean stock market. They used daily data from

January 3, 1997, to December 21, 2000, for their analysis. The research revealed three discrete mechanisms by which the Korean foreign exchange market influences the stock market: initially, stock market returns were negatively impacted by the exchange rate; secondly, these returns were positively impacted by depreciation volatility. They also claimed that the volatility of stock market returns was sensitive to changes in the volatility of exchange rate depreciation. From 1985 to 1997, Bilson et al. (2001) examined the ability of domestic macroeconomic indicators—money supply, goods prices, and real activity—to explain stock returns in 20 developing nations. According to their results, the money supply is very important, and the exchange rate has the most impact of all these factors. Ibrahim and Aziz (2003) investigated using co-integration and vector autoregression models the link between four macroeconomic factors and the Kuala Lumpur Composite Index (KLCI) in a different research. The monthly statistics of the variables they were analyzing served as the basis for their study. From 1977 to August 1998, the chosen macroeconomic variables were real production, inflation rate, money supply, and exchange rate. According to the research, the KLCI is related to the macroeconomic factors both in the short and long run. In addition, they discovered that the stock prices were favorably affected by the other two factors, but the money supply and exchange rate had a negative association with the stock prices.

In light of the above discussion, we believe that our research has the potential to make numerous significant contributions to the empirical literature. First off, in contrast to previous research on the dynamics of traditional Equity risk, Commdity risk, Exchange rate risk and Interest rate risk towards Green stock market, we have used a novel strategy. We have shifted the focus towards volatility connectedness and spillover, in contrast to previous (Bashir et al., 2016; Hussain & Bashir, 2013; Pan et al., 2007; Phylaktis & Ravazzolo, 2005; Rai & Garg, 2021; Ülkü & Demirci, 2012; Wong, 2017) that primarily focus on causality. Quantifying the volatility of both the "Giver" and "Receiver" variables, our study explores the pairwise volatility spillovers and connectivity between green stock prices and market risk. Second, we have extended the methodology to measure volatilities, exploring potential links to financial markets, whereas previous literature tends to only explore either stock market connectedness or exchange market connectedness. Finally, our study explores a topic that has not received enough attention in the literature: the relationship between traditional equity risk. Commodity risk, exchange rate risk interest rate risk, and green stock price volatility.

The following gaps in the literature have been noted based on the analysis of the literature provided above:

1) The association between market risk, which includes equity risk, commodity risk, foreign exchange risk, and interest rate risk, and the green stock market has only been the subject of a few studies with minimal scope. Many of these additions were made at various points throughout the study.

2) The current study is being carried out to fill the gap in the updated dataset for the market risk proxies and the Green stock market.

3) The current work contributes to the existing literature about the methodological improvisations composed of Multivariate GARCH.

The next chapter presents a more comprehensive description of the methods developed to accomplish this primary objective of the research. This approach was established to address the study gaps stated earlier in a way that was compatible with the general objectives of the research. Consequently, the subsequent chapter will provide a more in-depth discussion of the procedures and data employed in this research.

CHAPTER 3

DATA AND METHODOLOGY

This chapter thoroughly explains the Research Gap and Objectives of the Study with data and research methodology employed to meet the study's goals. It is organized into two main sections. The first section outlines the data sources and the timeframe for data collection. The second section focuses on the various tools and techniques used in the study.

3.1 Research Gap

Among the various investments, one of the most rapidly expanding is investing in Green stocks. As the proportion of people interested in green stocks continues to rise, it is essential to have a deeper comprehension of the various risks and returns associated with green investing compared to other asset classes. Most other studies concentrate their attention primarily on the traditional stock, gold market, silver market, and oil market [Dutta et al.,2021; Zhanga et al.,2020; Yıldırım et al.,2020; Shafiullah et al.,2019; Mensi et al.,2021; Dutta et al.,2019]. The research in this area shows no prior studies about the linkages between market risk and green investment. Some significant research gaps were found while doing the literature review. In significant emerging markets such as India, where investment in green sectors is projected to reach $686 billion by 2031, the correlation between risk transmission involving green equities and other financial assets still needs to be understood. India has witnessed a substantial surge in green investment since the inception of the 'United Nations Framework Convention on Climate Change (UNFCCC) Paris Agreement' in 2016. Additional green initiatives and environmentally favourable infrastructure have been allocated financial support from the Indian government. However, considering the expansion, investments in environmentally sustainable initiatives in India are still in their infancy. The inherent novelty of Indian green companies' equities could render them exceedingly volatile and vulnerable to risk transmission from diverse assets and market uncertainties. This circumstance poses crucial considerations for investors and portfolio managers regarding asset pricing and volatility forecasting.

Another central gap is the lack of studies on the Absence of market risk, which includes (equity risk, commodity risk, forex risk, interest rate risk) and the Green Stock market. Most studies focused on investor attention on the stock market. However, the emerging Indian green stock market was ignored, and there is limited research related to the Indian green stock market. Therefore, this study has to be undertaken to analyze the price discovery and volatility spillover. Specifically, it aims to achieve the following objectives.

3.2 Objectives of the Study:

1. To study the price discovery function between market risk and green investment in India.

2. To analyze the volatility spillover between market risk and green investment in India.

3.3 Data and its Sources

Daily closing values of all the indices listed in Table (3.1) below were used to fulfil the study's objectives. These indices have been chosen based on existing literature about these markets. The U.S. stock market is represented by the S&P500, The Standard and Poor's 500, or simply the S&P 500, a stock market index tracking the stock performance of 500 of the largest companies listed on stock exchanges in the United States and The Russell 2000 Index comprises the smallest 2,000 stocks in the Russell Index and is a small-cap U.S. stock market index. The Frank Russell Company launched it in 1984. FTSE Russell, a London Stock Exchange Group (LSEG) division, maintains the index. The Nasdaq 100 Index is a composite of the 100 companies that are not only listed on the NASDAQ stock market but also have the highest volume of trading activity among all of the companies that are included in the index. Companies from various industries, such as manufacturing, technology, healthcare, and others, are included in the index, along with companies from other sectors that have been taken as equity market risk proxy.

As a measure of the performance of various commodities, the S&P GSCI Crude Oil, Aluminium, Gold, Silver, Copper, and Natural Gas indices are used to track the performance of these commodities. These indices come under the commodity market risk. Market participants and investors utilize them to obtain exposure to commodity markets, protect themselves against price changes, and evaluate trends in global commodity prices. In addition to supply and demand dynamics, geopolitical events, economic conditions, and industrial utilization, various other factors can affect the prices of different commodities.

Exchange rate, foreign exchange, currency, or F.X. risks arise when a financial transaction is expressed differently from the company's local currency. Other names for this type of risk are currency, exchange rate, and F.X. risks. This risk occurs due to the possibility that the exchange rate between the company's native currency and the currency in which the transaction is denominated will undergo an unfavourable shift before the transaction is completed. Currency, exchange rate, and foreign exchange risks are other names for this risk aspect. In this study, we used these exchange rates: EUR: USD, JPY: USD, GBP: USD, CAD: USD, AUD: USD. Finally, we used the United States 10-year, 5-year, and 3-year bond yields to calculate interest rate risk.

The study utilizes the Indian sustainability indices (S&P BSE CARBONEX and S&P BSE GREENEX) based on Daily closing prices. The empirical analysis encompasses the index above and covers Daily closing prices. Based on data about the volatility of the above markets, this study looks at how predictable the Indian Green Stock Index's volatility is. All the data has been collected from Bloomberg. Details on equity, commodities, foreign exchange indexes, and interest rates are presented in the following Table: Table 3.1

Table 3.1. Variables of the study

Equity risk	Commodity risk	Forex risk	Interest rate risk	Green stock
S&P 500 US2000 NASDAQ 100	S&P GSCI Crude Oil S&P GSCI Aluminum S&P GSCI Gold S&P GSCI Silver	EUR: USD JPY: USD GBP: USD CAD: USD	United States 10-Year, 5-Year and 3-Year Bond Yield	S&P BSE GREENEX S&P BSE CARBONEX

	S&P GSCI Copper S&P GSCI Natural Gas	AUD: USD		

3.4 Period of study

For this research, we analyzed closing values of data spanning ten years, from April 1, 2014, to December 31, 2023. This time interval enables the examination of the transmission of returns and volatility across markets. To ensure data consistency across various stock exchanges, we opted to commence with 2014, which encompasses the most significant Period. This analysis period also includes the Russia-Ukraine war and the COVID-19 pandemic, which began to have an unprecedented impact on significant economies worldwide.

The return will be calculated by taking the first difference of the natural logarithm (ln) of the price series and multiplying it by 100. This will be done to transform the price series.

$R_t = \ln[(p_{t+1}) - \ln(p_t)] * 100$ 3.1.

3.5 Methodology

This study's methodology is analytical and empirical, based on secondary data. Its purpose is to investigate the possibilities of price discovery and volatility spillover between market risk (Equity, Commodities, F.X., and Interest risk) and the sustainable equity markets of India (Carbonex and Greenex).

3.5.1 Descriptive Statistics

Descriptive statistics allows estimating a series mean log return and standard deviation. This is performed through the employment of statistical methods. In addition, it offers a reasonable comprehension of the variation of the mean return expressed in terms of the range. Regarding the study of volatility, skewness, and kurtosis, the two statistics are significant in their own right. These metrics are applied as diagnostic tests for volatility modelling with the GARCH method. This is because stock returns are typically skewed and leptokurtic, which is why this phenomenon exists. In addition, autocorrelation and partial autocorrelations are analyzed as diagnostic tests for every index.

3.5.2 Stationary test.

The stationarity condition serves as the foundation for most statistical analytical methods. In light of this, before analyzing the time-series data, we first conduct a test to determine whether or not the series is stationary. This is because most time series models require this condition to be met. A time series is said to be stationary when both the mean and the variance of the time series remain unchanged and when the value of the covariance between two periods is determined by the differences in the amount of time that has passed between the two time periods. Regarding testing stationarity, the Unit Root Test is utilized the most frequently. The straightforward model wherein the unit root of the Y series is examined as follows:

$$Y_t = \rho Y_{t-1} + \epsilon_t \qquad 3.2$$

Where ϵ_t is the error term

Mean $(\epsilon_t) = 0$ For all t

Variance $(\epsilon_t) = \sigma^2$ For all t

Covariance $(\epsilon_t \epsilon_{t-s}) = f(s)$ Where $s \neq 0$

Equation 3.2 shows the series is nonstationary and has a unit root when p=1. We can further evaluate the stationarity by regressing the series on its lagged value. This model can be expressed as:

$$Y_t - Y_{t-1} = (\rho - 1)Y_{t-1} + \varepsilon_t \qquad 3.3$$

Or we can also write this as

$$\triangle Y_t = \theta Y_{t-1} + \varepsilon_t \qquad 3.4$$

In the case where $\theta = (\rho - 1)$, the series is nonstationary, and $p = 1$ if we test that, which will yield an answer of $\theta = 0$ in favour of the null hypothesis. The research employed the Augmented Dickey-Fuller test to verify the unit root of various index series. The results of this test were further validated using the Phillips-Perron (P.P.) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) studies.

The best technique to determine whether a unit root exists is the Augmented Dickey-Fuller (ADF) Test. With one significant improvement, this test is similar to the Dickey-Fuller test: it incorporates lag-dependent variables into the model to account for any possible serial correlation within the disturbance term. When we run the ADF test, we get several model setups depending on whether an intercept and trend component is present. If there is a pattern, more questions come up about what kind of trend it is—deterministic or stochastic. The answers to these questions will determine which model is best suited for evaluating the unit root.

The whole ADF test equation is displayed below, considering each situation.

$$\triangle Y_t = \alpha + \beta_t + \theta Y_{t-1} + \sum_{i=1}^{m} \gamma \triangle Y_t + \varepsilon_t \qquad 3.5$$

Alpha equal to zero indicates the utilization of a model lacking drift or intercept. When beta equals zero, the trend is not evident. The ultimate model that needs to be implemented for unit root testing is series-dependent.

Phillips Perron (P.P.) test: Developed in 1998, the Phillips Perron (P.P.) test is a diagnostic examination. Compared to the ADF test, this test makes a less stringent assumption regarding the extent to which error terms are distributed. In the process of the P.P. test, the serial correlation of the error term is rectified by adjusting the computed value of the estimated coefficient, which is based on the ε-statistic. The final Equation for the P.P. test is the following:

$$\triangle Y_t = \alpha + \beta_t + \theta Y_{t-1} + \varepsilon_t \qquad 3.6$$

Where α and β depict the presence or absence of intercept and trend.

Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test: Similar to other tests, the KPSS test determines whether or not the time series is stationary around the mean or trend. Specifically, the most significant distinction lies in that in the KPSS test, the null hypothesis is that the series is stationary. In contrast, the alternative hypothesis is that the series is not stationary. Taking into consideration a series that is presumed to be devoid of a linear trend, we can characterize the process of data generation in the following form:

$$y_t = u_t + v_t \qquad 3.7$$

Where $u_t$is random is walk, $u_t = u_{t-1} + \in_t$ where $\in_t \sim iid)0, \sigma_\epsilon^2$ and $v_t$is a stationary process. Here, the null hypothesis is $H_0: \sigma_\epsilon^2 = 0$ against the alternative hypothesis $H_0: \sigma_\epsilon^2 > 0$. If H_0 is true, the y_t should include a constant term and a stationary process. The test statistics for KPSS are:

$$KPSS = 1/T^2 \sum_{t=1}^{T} \frac{s_t}{\sigma_\infty} \qquad 3.8$$

3.6 Estimating Models of the Study

3.6.1 ARCH effect

Applying GARCH models requires ensuring the data meets two key assumptions: stationarity (no unit root) and homoscedasticity (constant variance). The presence of heteroscedasticity (non-constant variance) motivates the use of GARCH to model conditional volatility, capturing the dynamic changes in volatility over time. To assess the presence of heteroscedasticity in the residuals of a time series model, the ARCH-LM test, also known as the autoregressive conditional heteroscedasticity–Lagrange multiplier test, is employed.

$$u_t^2 = \gamma_0 + \gamma_1 u_{t-1}^2 + \gamma_2 u_{t-2}^2 + \cdots + \gamma_p u_{t-p}^2 + v_t \qquad (3.9)$$

In the time series analysis, ‘u’ is the squared residuals of the mean regression model. The residuals are the differences between the observed values of a time series and the fitted values from the mean regression model. For ‘p’, it is the lag length in the residual regression model. For the residual, what happens is that ‘p’ is the number of the previous time steps that are needed to model the current residual. The ARCH effect is very important as far as the field of financial forecasting and risk management are concerned. For example, in a situation where the ARCH effect happens to the series of stock price, this implies that the volatility of the stock price is not the same. As a result, the accurate evaluation of how the conditional volatility is affected. We used the ARIMA model to fit the mean equation for asset returns. The main reason as to why we chose this model is that it outperforms the others in evaluating how past returns and residuals affect future returns.

Conditional Mean Equation and Conditional variance equation:

$$y_t = c + b_1 y_{t-1} + b_2 e_{t-1} + e_t \qquad (3.10)$$

$$h_t^2 = \omega + \alpha_1 \varepsilon_{t-1}^2 + \beta_1 h_{t-1}^2 \qquad (3.11)$$

y_t Is conditional mean is the intercept,b_1 is coefficient of AR(1), b_2 is coefficient of MA(1),and e_t indicates error term at time t.

Equation 3.11 presents two key parameters – α1 and β1. These parameters refer to the ARCH and GARCH terms, respectively. To be more precise, parameter α1 helps establish the ARCH effect, which, in its turn, is related to how much recent news or market shocks near the current time affect the volatility. It measures the period when volatility is sensitive to the. In contrast, parameter β1 is also associated with the GARCH effect and helps determine when slash of the volatility dies out, that is, how persistent the volatility is. It is evident that if α1 is large, then the news near the current time has a considerable impact on the volatility. Also, if β1 large, then the volatility is persistent, and it takes a considerable period for it to disappear (Chaudhary et al., 2020; Rastogi, 2014).

3.6.2 Dynamic Conditional Correlation-Generalized Autoregressive Conditional Heteroskedasticity (DCC-GARCH)

The DCC-GARCH model introduced by Engle (2002) is quite capable of capturing time-varying and dynamic relationships. As Celik (2012), Nguyen et al. (2022), Özdemir (2022), and Zhang et al. (2022), among others, demonstrated in their studies, the DCC-GARCH model has been widely used to investigate market contagion. To the extent that multiple time series variables are involved, the DCC-GARCH model, one type of multivariate GARCH models, offers a way to investigate their correlations by taking into account time. This is particularly useful in financial market analysis. In this field of study, different assets can have interrelated and intertwined behaviors. The model proficiently captures the dynamics of volatility and correlations. It can thus provide important clues about how various asset prices are related to one another.

The DCC-GARCH model comprises two main parts: the GARCH model and the dynamic conditional correlation model. The former estimates the conditional variance of a given asset, while the latter evaluates the time-varying conditional correlations between these assets. Because of these parts' combination, investors and financiers can understand all changes in volatility and correlation in financial markets. Meanwhile, the GARCH model is an improvement over the autoregressive conditional heteroskedasticity model that aims to model volatility on the basis of historical data of a time series. However, the first one does not include any element as additional to taking into consideration the previous volatility when it seeks to capture their fluctuations. Instead, the GARCH model applies one more component to predict the effect of prior shocks and residuals on the current values of volatility. In other words, the latter assumes that the conditional variance of at time t is a function of past variances and squared values of shocks or residuals from previous observations.

The model to be used in this study is The Dynamic Conditional Corelation model Engle (2002). The model builts on the Bollerslev Constant Conditional Correlation model Bollerslev (1990). The CCC model assumed that conditional correlations are constant whereas DCC is a generalization of the CCC model applied to the conditional variances but it now allows the conditional correlations to be time-varying. Unlike the assumption that existed in the CCC model, the DCC model allows conditional covariance matrices to be modelled in a more subtle fashion. This model is more specifically important because of the possibility of anticipating future changes in the flexibility of variance (Yan et al., 2022). Its effectiveness stems from its utilization of historical data and squared residuals, offering a more profound understanding of the constantly changing volatility dynamics. From two-time series datasets, $r_{i,t}$ and$r_{j,t}$, modeled using AR (1) models, we derive two sets of residual time series variables, $a_{i,t}$ and $a_{j,t}$. The matrix Ht represents the dynamic conditional covariance matrix calculated for these paired time series, $r_{i,t}$ and $r_{j,t}$.

The matrices H_t, R_t, D_t, and D_t^{-1} are interconnected in the analysis of dynamic conditional correlations and variances within time series data. H_t serves as the covariance matrix, R_t represents the dynamic conditional correlation matrix, D_t is derived from $H_t$and is a diagonal matrix, while D_t^{-1} stands as the inverse of the diagonal matrix D_t. These matrices collectively offer insights into the relationships and fluctuations among variables in the time series context.

The connections among the matrices H_t, R_t, D_t, and D_t^{-1} can be summarized as follows:

$$H_t = D_t R_t D_t \tag{3.12}$$

$$R_t = D_t^{-1} H_t D_t^{-1} \tag{3.13}$$

By implementing two GARCH (1,1) models, we derived two normalized residual variables, $\mathcal{E}_{i,t}$ and $\mathcal{E}_{j,t}$. The subsequent relationship is established by defining the following variables where Q_t stands as the Covariance Matrix, G_t represents the Diagonal Matrix extracted from the Covariance Matrix Q_t, $Q_t - 1$ denotes the inverse of Q_t, and C_t indicates the Correlation Matrix in this context.

The relationships between the matrices of Q_t, C_t, G_t and D_t^{-1} are :

$$Q_t = G_t C_t G_t \tag{3.14}$$

$$C_t = G_t^{-1} Q_t G_t^{-1} \tag{3.15}$$

Considering matrices of second order, namelyR_t, H_t andQ_t, let us assume:

$$R_t = \begin{pmatrix} P_{i,t} & P_{ij,t} \\ P_{ji,t} & P_{j,t} \end{pmatrix} \; H_t = \begin{pmatrix} \sigma_{i,t} & \sigma_{ij,t} \\ \sigma_{ji,t} & \sigma_{j,t} \end{pmatrix} \; Q_t = \begin{pmatrix} q_{i,t} & q_{ij,t} \\ q_{ji,t} & q_{j,t} \end{pmatrix} \tag{3.16}$$

$$\sigma_{ij,t} = \sigma_{i,t} P_{ij,t} \sigma_{j,t}, \qquad \sigma_{ji,t} = \sigma_{i,t} P_{ji,t} \sigma_{j,t} \tag{3.17}$$

The evolving correlations under conditional dynamics between these two series can be expressed as:

$$P_{ij,t} = \frac{q_{ij,t}}{q_{i,t},q_{j,t}}, P_{ji,t} = \frac{q_{ji,t}}{q_{j,t}q_{i,t}} \;\; Where\ P_{ij,t} = P_{ji,t} \tag{3.18}$$

Due to the consideration of the time variable t, the correlation variables $P_{ij,t}$ and P_{ji} depict fluctuating correlations.

The DCC GARCH model incorporates two parameters, (α) and (β), to capture the dynamic nature of correlations in assets market volatility. Both parameters are time-varying and reflect the evolving relationships between asset prices over time. Alpha specifically measures the short-term persistence of volatility shocks, showing how much today's volatility is affected by yesterday's surprising price moves. On the other hand, the beta coefficient can be somewhat seen as specifying how long the shocks in the past take to wear off in terms of correlation that exists conditional on these Asset prices. This is particularly crucial because it also means that the same two-day-old price information or events may have varied impacts on correlations, depending on the values of the daily. The constraint promotes its stability by essentially avoiding it from being able to set the correlation on too much of a fixed course as that of the past. Alpha specifically measures the short-term persistence of volatility shocks, showing how much today's volatility is affected by yesterday's surprising price moves. On the other hand, the beta coefficient can be somewhat seen as specifying how long the shocks in the past take to wear off in terms of correlation that exists conditional on these Asset prices. This is particularly crucial because it also means that the same two-day-old price information or events may have varied impacts on correlations, depending on the values of the daily. The constraint promotes its stability by essentially avoiding it from being able to set the correlation on too much of a fixed course as that of the past.

3.6.3 Time-varying parameter vector autoregressions (TVP-VAR)

The method developed by Diebold and Yilmaz (2009,2012,2014) is utilized in this research work to analyze the interconnection of the equities, commodities, foreign exchange, and interest rate markets in connection with green investment. The research investigates volatility spillovers between and within these markets by employing the FEVD inside a GVAR framework. This allows for the evaluation of volatility spillovers. A simultaneous analysis of how each variable affects spillovers across and within markets when shocks impact them is made possible because the GFEVD is order-invariant, which is not the case with conventional approaches. The spillover index that Diebold and Yilmaz (2009, 2012, 2014) developed is a tool that can be used to study the transfer of information and shocks across various market segments. The methodology utilized here uses a vector autoregressive (VAR) model to analyse the variance of prediction errors. Antonakakis et al. (2020) disclose two main merits of this technique. First, it helps to overcome the challenge of arbitrarily choosing the optimal rolling window size. Second, it circumvents the problem of loss of valuable observations, thus making it suitable for short samples. According to Kashyap (2023), this method makes it possible to examine directional spillovers, which involves determining the extent to which markets are influenced by information-sharing mechanisms originating from other regions. The net impact of information flow between the stock markets of the United States and India green stocks is evaluated to determine the extent of directional spillovers. It is necessary to analyze the directional returns and volatility of various markets to determine the importance of the spillovers between them. When these spillover effects are investigated, it is possible to gain significant insights into the interconnection and interdependencies between the various markets and locations.

$$Y_t = \sum_{i=1}^{q} F_i \, Y_{t-i} + \varepsilon_t \qquad 3.19$$

$$Y_t = \sum_{i=0}^{\infty} A_i \, \varepsilon_{t-i} \qquad 3.20$$

In Equation 3.20, $A_n = \sum A_{ij}$, an N × N coefficient matrix, where j ∈ {1, ..., q}. A_0 is N × N is an identity matrix, while $A_1 = 0$ for i < 0. A complicated issue is the necessity of special adjustments when analyzing the correlations between variables by interpreting many Moving Average (M.A.) coefficients. Impulse Response Functions (IRFs) and Variance Decomposition (V.D.s) are employed to comprehend the system dynamics better. When determining how various shocks within the framework contribute to each variable's forecast error variance (FEV), V.D.s are beneficial resources to have at your command. To be more specific, V.D.s make it possible to quantify the percentage of the FEV of a certain market (i) that is a consequence of shocks observed in another market (j). This analysis clarifies the interdependencies among variables, where j ≠ i, for each i.

$$\theta_{ij}^{g}(H) = \frac{\theta_{jj}^{-1} \sum_{h=0}^{H-1} (e_i' A_h \Sigma \, e_i)^2}{\sum_{h=0}^{H-1} (e_i' A_h \Sigma (A_h' e_i)^2} \qquad 3.21$$

Regarding statistical analysis, the symbol Σ denotes the covariance matrix of the uncertainty vector. The σjj represents the standard deviation of the error term for the jth Equation. The selection vector e_j is also defined with a value of 1 for the jth element and 0 for all other components. A_h is the numerical form of the coefficient matrix used for the infinite Moving Average (M.A.) representation.

Instead of assuming that shocks are parallel, the Generalized Forecast Error Variance Decomposition (GFEVD) considers the interconnectivity of shocks, giving it an edge over older methods. By taking this technique, one can better comprehend the interdependencies between the variables. However, one of the limitations of GFEVD is that the contributions from the jth market to the forecast error variance of the ith market might not add up to one. To tackle this problem, Diebold and Yilmaz (2012) suggest that the sum of the items in the respective row normalizes each Variance Decomposition (V.D.) matrix member. This procedure is described in Equation 4. This normalization contributes to preserving the proportionality and interpretability of the outcomes of the decomposition calculation.

$$\theta_{ij}^{g}(H) = \frac{\theta_{ij}^{g}(H)}{\sum_{j=1}^{N} \theta_{ij}^{g}(H)} \qquad 3.22$$

One column is assigned to each part of the V.D. matrix, denoted by the symbol $\sum_{j=1}^{N} \theta_{ij}^{g}(H) = 1$ and $\sum_{I,j=1}^{N} \theta_{ij}^{g}(H) = N$. When we talk about volatility spillovers, we refer to the degree to which shocks in the market "j" affect the volatility anticipated in the market "i." The total spillover index (TSI) is a collective term used to quantify this influence. It is calculated by adding up the shares of cross-variance accumulated over time. To calculate the Technical Strength Index (TSI), Equation (3.23) is utilized. This Equation determines the proportion of error variances that contribute to predicting volatility in one market due to shocks from another market.

$$S^{G}(H) = \frac{\sum_{i,j=1,i\neq j}^{N} \theta_{ij}^{g}(H)}{\sum_{j=1}^{N} \theta_{ij}^{g}(H)} \times 100 \qquad 3.23$$

The fact that Equation (3.24) depicts the directional volatility spillovers (V.S.s) that market i receives from all of the other markets j is an essential point to emphasize. Equation (3.25), on the other hand, provides information regarding the V.S.s that market i transmits to all markets j. Consequently, Equation (3.16) is used to compute the net directional V.S.s, the difference between the spillovers that the market i transmits and those it receives. This net spillover statistic is vital for determining whether a stock exchange functions primarily as a net donor or receiver of shocks. It provides critical insights into the stock exchange's role in the more significant market dynamics.

From others to market i:

$$S_{i.}^{g}(H) = \frac{\sum_{j=1,i\neq j}^{N} \theta_{ij}^{g}(H)}{\sum_{i,j=1}^{N} \theta_{ij}^{g}(H)} \times 100 \qquad 3.24$$

To others from the market, i:

$$S_{.j}^{g}(H) = \frac{\sum_{j=1,j\neq i}^{N} \theta_{ji}^{g}(H)}{\sum_{i,j=1}^{N} \theta_{ji}^{g}(H)} \times 100 \qquad 3.25$$

Net Volatility spillover

$$NS_{j}^{g}(H) = S_{.j}^{g}(H) - S_{i.}^{g}(H) \qquad 3.26$$

The net volatility spillover is the difference between the volatility shocks received from other markets and the volatility spillover from one market to all other markets. This difference is referred to as the disparity between the two. Additionally, the concept of the mutual volatility spillover between two markets can be expressed as follows:

$$S_{ij}^{g}(H) = \left(\frac{\theta_{ji}^{g}(H)}{\sum_{i,k=1}^{N} \theta_{ik}^{g}(H)} - \frac{\theta_{ij}^{g}(H)}{\sum_{j,k=1}^{N} \theta_{jk}^{g}(H)}\right) \times 100 = \left(\theta_{ij}^{g}(H) = \frac{\theta_{ij}^{g}(H)}{\sum_{j=1}^{N} \theta_{ij}^{g}(H)}\right) \times 100 \qquad 3.27$$

Specifically, the difference between the volatility spillover from market i to market j and the overflow from market j to market i is the difference between the two occurrences.

To arrive at an accurate estimate of the spillover, it is necessary to take into consideration three essential elements: (1) the particular variables that are being analyzed; (2) the H-step-ahead forecast horizon that is being utilized for error Variance Decompositions (V.D.s); and (3) a dynamic model (L) that is designed to take into account spillovers that change over time. The expansion of the forecast horizon (H) results in an expansion of the analysis window, which allows for the capture of spillovers that are not just immediate but also longer-term. The present study uses a ten-day forecast horizon (H), which follows the Value at Risk (VaR) metric often utilized for ten days. In addition, a rolling window approach with a width (W) of two hundred days is considered. Because this method is uncomplicated and can efficiently accommodate systems with parameters that change over time, it is particularly suitable for analysing data collected daily.

3.6.4. Quantile Vector Autoregression (QVAR)

The Quantile Vector Autoregression (QVAR) technique, described in Chatziantoniou et al. (2021), is utilized in estimations to ensure reliability.

$$\mathrm{yt} = \mu_t + \sum_{j=1}^{p} \phi_j(\tau) y_{t-j} + u_t(\tau) \qquad 3.28$$

Let yt and $yt{-}j$ be k×1 dimensional vectors of endogenous variables. The parameter τ represents the quantile of interest and ranges between 0 and 1. In this context, Ψ indicates the lag length of the Quantile Vector Autoregression (QVAR) model. The term μ(τ) is a k×1 dimensional vector representing the conditional mean, while ϕj(τ) is a k×k dimensional matrix of Quantile-VAR coefficients. The error vector (τ)ut(τ) is also k×1k×1 dimensional, with a variable-covariance matrix denoted by Σ(τ). Moreover, the impact that a shock in variable jj has on variable ii is described as follows:

$$\psi_{ij}^{g}(H) = \frac{\sum(\tau)_{ii}^{-1} \sum_{h=0}^{H-1} (e'_i \psi_h e\_j)2}{\sum_{h=0}^{H-1} (e'_i \psi_h(\tau) \sum(\tau) \psi_h(\tau)' e'_j} \qquad 3.29$$

$$\psi_{ij}^{g}(H) = \frac{\psi_{ij}^{g}(H)}{\sum_{j=1}^{k} \varphi_{ij}^{g}(H)} \qquad 3.30$$

Here, ei is a zero vector with a value of one at the ith position. Additionally, the total connectedness of variable i to all other variables j represents the overall impact that variable i has on the other variables.

$$C_{i \longrightarrow j}^{g}(H) = \sum_{j=1, i \neq j}^{k} \psi_{ji}^{g}(H) \qquad 3.31$$

Furthermore, to estimate the impact of shocks originating from all other variables b on variable i, the total directional connectedness FROM others is utilized:

$$C_{i \longleftarrow j}^{g}(H) = \sum_{j=1, i \neq j}^{k} \psi_{ji}^{g}(H) \qquad 3.32$$

A net total directional connectedness results from the disparities between the total directional connectedness TO others and the total directional connectedness FROM others. This net total directional connectedness is the outcome of the variable's net impact on the network being examined.

$$C_{i}^{g}(H) = C_{i \longrightarrow j}^{g}(H) - C_{i \longleftarrow j}^{g}(H) \quad 3.33$$

In addition, the Total Connectedness Index (TCI), modified by Chatziantoniou et al. (2021), is employed to evaluate market risk. Because higher TCI values indicate a greater network interconnection, this index, which has a range of [0,1], is employed.

$$TCI(H) = \frac{\sum_{i,j=1,}^{k} \psi_{ij}^{g}(H)}{K-1} \qquad 3.34$$

3.7. Wavelet analysis

3.7.1 Wavelet analysis in finance and economy

The Wavelet Analysis has seen significant development and is now applicable to a wide variety of fields, particularly in economics and finance, which are the primary topics of discussion in this article. In the past several years, the world of finance has entered an era of big data, in which financial variables such as stock prices are monitored on a minute-by-minute or even second-by-second basis, respectively. Consequently, this leads to the creation of enormous datasets that are not only vast but also very changeable and complicated. Right now, more than ever before, there is an urgent need for efficient data processing machines. To better understand the large quantity of data currently available, researchers and experts in the sector are looking for mathematical approaches and applications to assist them. They intend to utilize this knowledge to improve their understanding of financial systems or make judgments based on accurate information.

Due to the development of data analysis tools, traditional methods, and ways, such as time-series analysis and spectrum analysis, are being reconsidered. While spectrum analysis focuses on examining frequency patterns, time-series analysis looks at what pattern is changing over time. In addition, it is common for the latter and their combination in the former, to assume that the data come from an underlying process with constant mean and variance, known as it being stationary. Yet, it is hardly ever true when dealing with economic and financial statistics as with such data, complex patterns and trends such as abrupt changes, clusters and the week or month effects are common. Besides, it is also often hardly possible to confirm the assumption made in spectrum analysis that market activities were constant during the observed period. In reality, it is more common to see a very active market for a month as well as for a market only to be relatively calm for another, with all other months being far from these two.

Wavelet analysis does not necessitate making significant assumptions on the data generation process:

The Wavelet Analysis method is highly flexible and does not rely on rigid assumptions regarding how data is initially generated. The ability to manage complicated data does not need the user to have an understanding of the underlying patterns or rules. In economics and finance, where the precise nature of the data is only sometimes evident, this is a beneficial characteristic. The data do not need to be stable to use Wavelet Analysis. This contrasts traditional methods, which frequently fail when dealing with nonstationary data (data in which parameters such as mean and variance shift with time). In light of this, it is an effective instrument for dealing with the changeable and complicated data frequently seen in economic and financial time series.

Information obtained through wavelet analysis is derived from both the frequency and time domains:

Wavelet Analysis is unique in its capacity to jointly consider both time and frequency, unlike time-series and spectral analyses which distinctly focus on either dimension alone. This dual perspective renders it a singular method well-suited to investigate variations in economic and financial influences across changing timeframes. Stock prices may correlate closely in the long run yet diverge significantly in the near term, and Wavelet Analysis can partition such data into temporal scales to see how components interact level by level. Through decomposing information into frequency bands aligned with specific periods, it affords examination of how impacts ebb and flow over time, from lengthy investment horizons down to brief trading intervals. The technique enables tracing intricate connections between monetary elements as their interplay unfolds, from macroeconomic forces down to micro fluctuations. Owing to such features, Wavelet Analysis has proven a valuable tool for disentangling convoluted relationships in economics and finance.

The capability to identify discontinuities in the data is one of the capabilities that Wavelet Analysis possesses:

The Wavelet Analysis method can also precisely locate the system's discontinuities, a handy feature. This capability will help professionals and academics in Economics and Finance determine the specific periods when various regime adjustments are represented in the actual market data, which might be of great use to them. In addition, they can recognize particular shocks that they have introduced into the dynamic system.

3.7.2 Wavelet Transformation

When analyzing time series data in both the time and frequency domains, the wavelet method offers a method that is not only straightforward to understand but also highly effective. Wavelet analysis, and more specifically, the application of Morlet wavelets, is utilized for the goal of this inquiry to investigate the co-movements that take place inside the expanding Asian marketplaces. When using this method, which involves breaking down the time series into 108 separate components of the time series, the study of time series data is improved. This method is used to improve the use of time series. For the wavelet analysis, the vocabulary and methods are based on the frameworks that were built by Aloui and Hkiri (2014), Aloui et al. (2018b), and Aloui et al. (2016). These frameworks were established before the wavelet analysis was performed.

Furthermore, the analysis builds upon the ground-breaking work done by Grinsted et al. (2004). Applying their techniques allows for a decomposition that is thorough yet structured. This organization helps make the hidden dynamics underlying the time series more easily comprehensible. In closing, the main findings of this exploration regarding the Wavelet can be summarized as follows:

$$\psi(t) = \frac{1}{\sqrt{s}}\psi\left(\frac{t-u}{s}\right) \qquad 3.35$$

A mathematical technique known as the wavelet transform is utilized to analyze data that has been accumulated over some time for a variety of reasons. We are given a particular wavelet function with the equation psi $\psi(.)$. The Equation represents this function. A factor is the scale of this function, which is 1/sqrt(s), and the shift of this function, which is tau (τ). Both of these factors will be discussed more below. To effectively decompose the signal f(t) into its wavelet coefficients, denoted by the symbol W(s,τ), it is imperative to utilize this particular function. These coefficients are used to determine the extent to which the volatility of the signal may be attributed to various scales (s) and places (τ) in time. Their objective is to determine as much as possible. In the wavelet ψ, $(\cdot) \in L2(\mathbb{R})$ function is assumed to be square integrable. The factor of the normalization in the Equation is $1/\sqrt{s}$, that is, ensuring $\|\psi u,\|2 = 1$ for representing the position of the wavelet parameters for dilation of the scale. Morelet specification-based wavelet is given below:

$$\psi_0^M(t) = \pi^{-\frac{1}{4}} e^{i\omega_0 t} e^{\frac{-t^2}{2}} \qquad 3.36$$

Based on the findings of the research carried out by Grinsted et al. in 2004, Rua and Nunes (2009), and Baruník et al . (2011). it has been established that the symbol $\omega 0$ refers to the weightage sign that represents the central frequency. This results in an improvement to both the frequency location and the excellent balance of the frequency structure.

3.7.3 Continuous Wavelets

Furthermore, according to the findings of the research carried out by Rua and Nunes (2009) and Baruník et al. (2011) on the Wavelet, it is feasible to depict the continuous Wavelet by employing the following form:

$$W_x(u,s) = \int_{-\infty}^{\infty} x(t) \frac{1}{\sqrt{s}} \psi\left(\frac{t-u}{s}\right) dt \qquad 3.37$$

While inspecting the proffered wavelet, its signature is symbolized by the period in the overarching formula. Furthermore, as it is a worthwhile instrument, this indicant facilitates detecting the site and scale on the time sequence. How the persistent wavelet can break down the era row demonstrated by the role (t) ∈ L2(R) is what renders it an operational implement. The complex wavelet allows for the decomposition of the signals into different frequency components, providing good time and frequency localization. The capability of extracting both location and frequency information makes wavelet transforms an important signal processing tool.

$$x(t) = \frac{1}{c_\psi} \int_0^\infty \left[\int_{-\infty}^{\infty} W_{x(u,s)\psi_{u,s}(t)}\, d_u \right] \frac{d_s}{s^2}, s > 0 \qquad 3.38$$

One of the wavelet transformation's distinctive qualities is that it can protect the time series with its unique properties. The power spectrum variance can be calculated using the formula 2($\mathbb{R}$) here.

$$x(t) = \frac{1}{c_\psi} \int_0^\infty \left[\int_{-\infty}^{\infty} |W_x(u,s)^2|\, d_u \right] \frac{d_s}{s^2} \qquad 3.39$$

3.7.4 Wavelet power spectrum

Wavelet analysis proves a potent tool for visualizing variances across frequencies and time within time series data. This technique decomposes signals into time and frequency domains, illuminating how power, or variance, of diverse wavelengths evolves through the timeline. It permits isolating recurring motifs, undertows, and rhythms imperceptible through routine temporal examination alone. Some sentences elucidate intricate periodic patterns while others summarize overarching concepts. Following the findings of Aguiar-Conraria et al. (2008) and Ramsey and Lampart (1998a, 1998b), the power spectrum wavelet is helpful when determining each stock market's local variance. This is also the case when analyzing the correlation between the two variables. It is denoted by the symbol$\left|W_{nx}{}^2\right|$, which stands for this Wavelet. Torrence and Compo (1998) also applied the Monte Carlo white- and red noise to acquire the distribution corresponding to the parameter. This was done to get the distribution. Wavelet power spectrum can be represented as,

$$D\left(\frac{|W_{nx}(s)^2|}{\sigma^2} < p\right) \Rightarrow \frac{1}{2} P_f X^2 v \qquad 3.40$$

The value of v, which should be 1 or 2 for real or complex wavelets, respectively, is taken from the means of the spectrum Pf at Fourier frequency f on the wavelet scale ($s \approx$ one f).

3.7.5 Cross Wavelet and Wavelet Coherence were used to determine the phase difference

Time series analysis uses two cutting-edge techniques: Wavelet Coherence (WTC) and the Cross Wavelet Transform (XWT). Both of these techniques are referred to as innovative methodologies. Several tools are applied to investigate the link between two-time series in both the time and frequency domains. In general, wavelet analysis is utilized to study the power contained within a single time series. On the other hand, these methods extend the wavelet analysis concept to investigate the interactions between two series. Same, the Wavelet Coherence is utilized.

Arrows pointing to the right suggest a synchronous relationship between series, indicating they are in phase. When the arrow veers upwards to the right, it signifies that the first series lags behind the second. Conversely, if the arrow slopes downwards to the right, the first series leads the second. Conversely, arrows pointing to the left denote that the two series are out-of-phase. If the arrow angles upwards to the left, it indicates that the first series leads, whereas if it points downwards to the left, it suggests that the first series lags. Within the visual representation, a red hue within the white contour at the bottom (top) of the plots signifies a robust co-movement at low (high) frequencies.

Similarly, a red shade within the white contours on the left-hand (right-hand) side indicates a significant co-movement at the beginning (end) of the observed Period. The directional orientation of the arrows signifies the phase difference between the two series, with the order of the series corresponding to the headers in the plot. Moreover, the depiction of phase difference, especially in lead-lag relationships, varies across different pairs of indices and exchange rates, frequencies, and the observed Period (Roesch & Schmidbauer,2014).

The cross-wavelet transform, frequently abbreviated as XWP, is a handy tool for evaluating the degree of covariance between two-time series across a range of frequencies. This method is particularly significant in the time and frequency domains because it can identify areas of considerable co-movement in market prices (Aguiar-Conraria et al., 2008). However, this method is also relevant in the frequency domain. The wavelet spectrum of the cross-wavelet between two signals, written as $(Wn^{xY}(s))$, is determined by the following Equation:

$$W_n{}^{XY}(s) = w_n{}^{X}(s) w_n{}^{Y*}(s) \quad 3.40$$

The Equation presented above contains the complete conjugate of the function$W_n{}^{XY}(s)$. The representation of $W_n{}^{XY}(s)$is is achieved by utilizing$w_n{}^{Y*}(s)$, which assists the Wavelet in obtaining the variables' covariance. For the cross wavelet with strong power spectra, the two signals power, denoted by the symbols $P_k{}^{X}$ and$P_k{}^{Y}$, are expressed in the following representation:

$$D\left(\frac{|W_n{}^{X}(s)|\, w_n{}^{Y*}(s)}{\sigma X^{\sigma} Y} < p\right) \Rightarrow \frac{Z_{v(p)}}{v}\sqrt{P_K^X P_K^Y} \quad 3.41$$

The Equation that has been provided indicates the standard deviation of x and y, which is represented by the symbols. The Equation that has been provided is expressed in $Z_{v(p)}$ and X^2, where v represents the degrees of freedom for the Chi-square distribution and P represents the probability. Following the description supplied by Torrence and Webster (1999), the cross wavelet serves as the foundation for computing wavelet coherence. This constitutes the bottom line. The following Equation can be utilized to determine the absolute squared value of the Continuous Wavelet Transform (CWT) parameter.

$$R^2(u,s) = \frac{|S(s^{-1}W_{xy}(u,s)^2|}{S(s^{-1}|W_x(u,s)|^2).S\left(s^{-1}\left|W_y(u,s)\right|^2\right)} \quad 3.42$$

The letter s in the Equation above stands for the smoothing parameter. Since 0 < $R2(u,s) \leq$ 1, the coefficient of squared wavelet-coherence (CSWC) satisfies the inequality requirement. When $R2(u,s)$ approaches zero, there is a weak correlation between the chosen markets, and when it is near one, there is a significant correlation. Because wavelet coherence is the best approach for measuring the covariance of two markets at different frequency and time domains, our method is more robust due to this element. Furthermore, the function can be used for both time series to diagnose the phase relationship between X and Y. It is possible to define the location in the pseudo-cycle as the phase difference, which is mentioned in the Equation:

$$\phi_{x,y} = \tan -1 \left(\frac{\Im\{W_n^{xy}\}}{R\{W_n^{xy}\}} \right) \ with \ \phi_{x,y} \ \epsilon[-\pi, \pi] \quad 3.43$$

The Wavelet can be used to define the relationship or correlation that exists between the two-time series through the use of arrows. There are phase discrepancies between the two-time series, and the arrows in the Wavelet illustrate these differences. To demonstrate the positive and negative correlations between the two time series, the direction in which the arrows point is of utmost significance. If the arrows are pointing in the right direction, this indicates a positive link between the two variables. It is reasonable to assume that the arrow is heading upward and rightward.

3.7.6 Testing robustness

Partial wavelet coherence (WTC)

Partial wavelet coherence (WTC) is calculated by determining the wavelet coherence between two variables while removing the influence of a third variable. Specifically, it involves assessing the wavelet coherence between y and x1, y and x2, and between x1 and x2.

$$R^2(y, x_1) = R(y, x_1).R(y, x_1)* \quad 3.44$$

$$R(y, x_2) = \frac{s[W(y, x_2)]}{\sqrt{s[W(y)].S[W(x_2)]}}; \quad 3.45$$

$$R^2(y, x_2) = R(y, x_2).R(y, x_2)*; \quad 3.46$$

$$R(x_2, x_1) = \frac{s[W(x_2, x_1)]}{\sqrt{s[Wx_2].S[W(x_1)]}}; \quad 3.47$$

$R^2(x_2, x_1)R(x_2, x_1).R(x_2, x_1) *$ 3.48

The partial wavelet coherence (PWC) is given by:

$$Rp^2(y, x_1, x_2) = \frac{R(y,x_1) - R(y,x_2).R(y,x_1)*}{[1-R(y,x_2)]-2-[1-R(x_2,x_1)]-2} \quad 3.49$$

$$Rp^2(y, x_1, x_2) = \frac{R(y,x_1) - R(y,x_2).R(y,x_1)*}{[1-R(y,x_2)]^2[1-R(x_2,x_1)]^2} \quad 3.50$$

Wavelet correlation

Wavelet correlation is used to analyze the correlation between two-time series data sets at different time scales. It lets you see how the correlation between two variables changes over time, capturing short-term and long-term relationships. The wavelet correlation between two signals X (t) and (t) can be calculated using the Wavelet transform. Here is the basic Equation:

Let $W_{X(a,b)}$ $and\ W_{.X.(a,b)}$ be the Wavelet transforms of X(t)$Y(t)$, respectively, at scale a and time b. Then the wavelet cross-correlation $(a,)$ is defined as:

$$C(a, b) = \frac{\sum_{n=1}^{N} W_X(a,n).W_y(a,n+b)}{\sqrt{(\sum_{n=1}^{N}[W_{x(a,n)}]^2)((\sum_{n=1}^{N}[W_{y(a,n)}]^2}} \quad 3.51$$

Where W_x(a,b) is the complex conjugate of W_x(a,b)

N is the number of data points.

a represents the scale of the Wavelet.

b represents the time lag.

Conclusion

To give recommendations for the development of empirical procedures that can be used to evaluate the impact as well as the short-term and long-term interaction between markets, the objective of this chapter is to provide a guideline on the development of such approaches. To fill the research gap discovered during the literature evaluation carried out in Chapter 3, this instruction was prepared with the support of the investigation. It has been determined that research objectives have been prepared for the chapter currently being addressed in this study. Studying the volatility spillover and price discovery that impact both short-term and long-term connections are the two primary objectives of current studies that are now being conducted in the field of research. The research aims to select various econometric methodologies, and the findings obtained from the different techniques are provided in the following chapter.

CHAPTER 4

DATA ANALYSIS AND INTERPRETATION

Data Analysis and Interpretation for Volatility spillover and Price Discovery.

The purpose of this chapter is to offer a detailed description of the basic statistical and econometric approaches that were utilized in the analysis of the daily data that was obtained for this research across a wide range of markets, such as the stock market, the commodity market, the currency market, and the interest rates. Our purpose is to determine whether or not our study can significantly contribute to the price discovery process and improve our knowledge of the direction of volatility spillover. This will be accomplished by undertaking an in-depth investigation. Therefore, the chapter has been divided into multiple components to facilitate a better understanding.

4.1. Descriptive Statistics

A descriptive statistics analysis aims to get a more comprehensive knowledge of the dataset and provide an overview of its main characteristics. Statistics that summarize the data include the standard deviation, skewness, and kurtosis. These statistics are descriptive. Using the mean and median, these statistics provide insights into averages, and by utilizing the standard deviation, they make it possible to get insights into dispersion or variability. A detailed review of the descriptive data for the Index series in various kinds of markets is provided in the following table.

Table 4.1 Descriptive statistics

	Mean	Median	Stdev	Skewness	Kurtosis	J.B. p-value
Crude Oil	0.000	0.001	0.031	-2.651	62.127	0.000
Aluminum	0.000	0.000	0.013	0.054	2.425	0.000
Gold	0.000	0.000	0.009	-0.021	3.877	0.000
Silver	0.000	0.000	0.018	-0.407	5.874	0.000

Copper	0.000	0.000	0.013	-0.126	1.881	0.000
Natural Gas	0.000	0.000	0.033	-0.244	2.833	0.000
S&P 500	0.000	0.001	0.011	-0.806	15.961	0.000
Russell2000	0.000	0.001	0.014	-0.931	11.855	0.000
NASDAQ 100	0.001	0.001	0.014	-0.539	7.561	0.000
US Bond Yield(10)	0.000	0.000	0.054	-0.111	2.402	0.000
US Bond Yield(5)	0.001	0.002	0.054	-0.364	3.224	0.000
US Bond Yield(3)	0.001	0.002	0.052	-0.607	6.615	0.000
GREENEX	0.000	0.001	0.011	-1.138	12.132	0.000
CARBONEX	0.000	0.001	0.011	-1.437	17.436	0.000
EUR: USD	0.000	0.000	0.005	-0.009	2.494	0.000
JPY: USD	0.000	0.000	0.006	0.219	3.770	0.000
GBP: USD	0.000	0.000	0.006	-1.024	15.205	0.000
CAD:USD	0.000	0.000	0.005	0.064	1.023	0.000
AUD:USD	0.000	0.000	0.006	-0.057	1.127	0.000
The total Number of Observations are 2456						

Source: Author’s Computation

The fact that the dataset contains events that take place over time demonstrates the degree of integration or interconnectedness. Calculating the logarithmic returns (rt) for various indices requires utilizing the daily closing prices of stock market indices as the basis for the calculation. A concise summary of the log return series data is presented in Table 4.1, which provides an in-depth analysis of the daily stock index returns in several marketplaces as the average daily returns are considered. It becomes understandable that all the markets have positive mean values, indicating that the overall performance is positive. According to the findings of return variability analysis, also commonly referred to as volatility analysis, various markets exhibit variable degrees of risk. One example is that in the market for commodities, crude oil and natural gas have the most significant standard deviations (0.031 and 0.0331), which suggests that they are more volatile than other commodities. Compared to the commodities market, the stock market displays the lowest standard deviation, with all three indices having approximately (0.014) values. This implies that the equity market is less volatile than the commodities market. Using the skewness values, one can acquire a more profound comprehension of the asymmetry within the return distributions. In this case, all four markets exhibit negative skewness implying that the number of negative returns exceeds that of positive returns. This information is revealed for all markets. By using kurtosis, which is an information about the tails of the return distributions. It is known that information about the peaks is more than 3 for the majority of markets.

When using skewness values, one can learn more about the asymmetry of the various return distributions. In this case, every market is negatively skewed, suggesting that negative returns occur more frequently than positive ones. About every market. By employing kurtosis, which is a measurement of the peaks of the return distributions, it has been found that the Majority market has kurtosis values greater than 3. This was established through statistical analysis. Based on this, the tails are thick, and the distribution has thicker tails than those of a normal distribution.

Consequently, there is a greater probability that extreme events or outliers may define the returns on the stock market. The Jarque-Bera test is utilized to assess whether or not the data represents a normal distribution. Based on the extremely low P-values (0.00) for every market, it can be concluded that the null hypothesis of normality is not accepted. According to the findings of the P.P. test, which are presented in Table 4.2, all of the daily realized volatility series are entirely stationary. This satisfies the DCC-GARCH specification requirement. As shown in Figure 2, all variables are subject to volatility throughout the entire data sample, particularly during COVID-19.

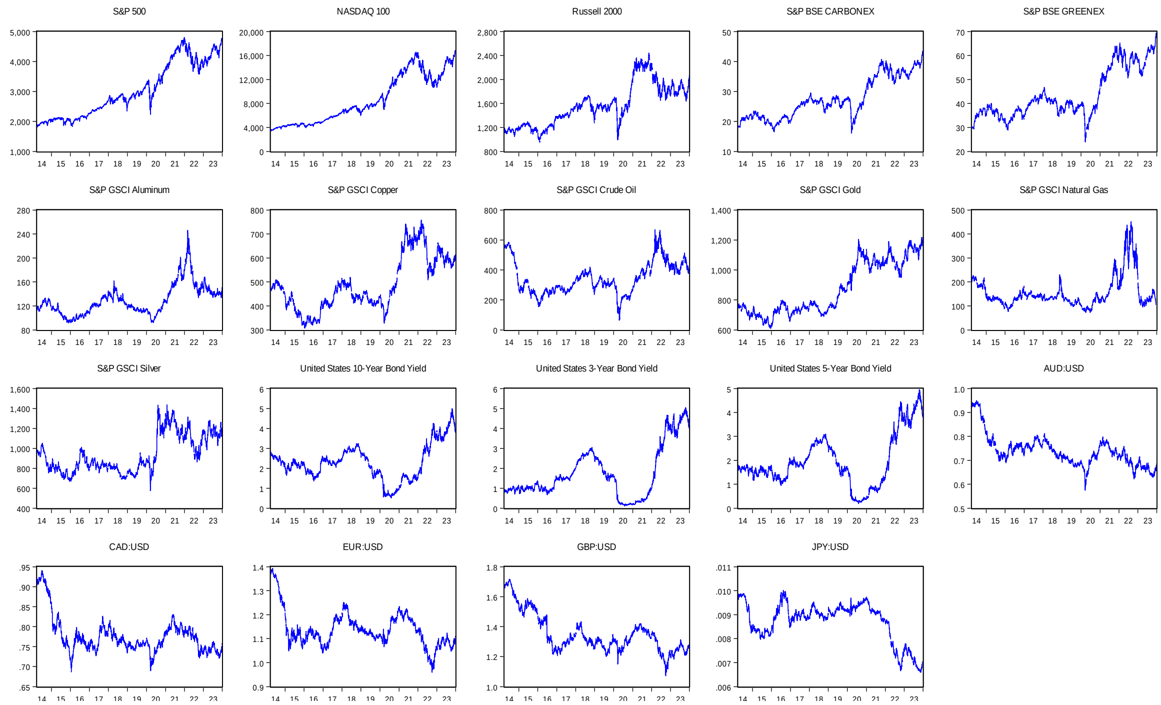


Fig 4.1 Graphical presentation of Price series of all the markets

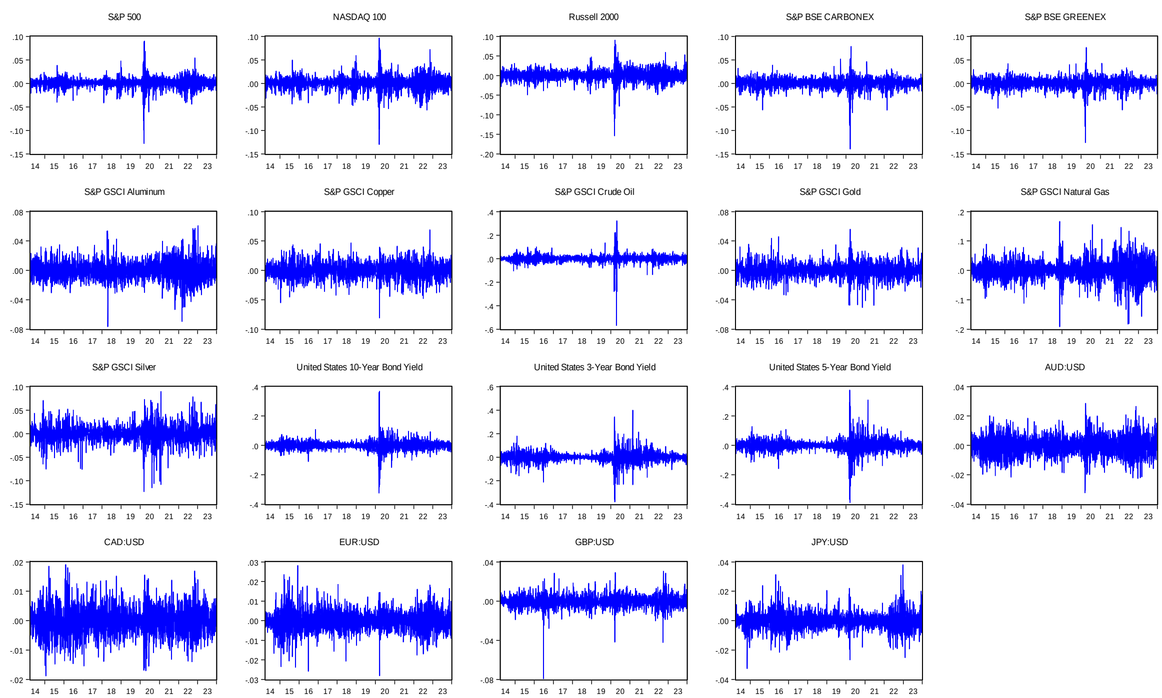


Fig 4.2 Daily realized volatility of each market.

4.2. Stationarity Test Statistics

It is necessary to determine whether or not the time series is stationary before carrying out any analysis of the data from the time series. This is because most time series models require the series to be stationary. This section contains the results of our examination of the series of markets for Unit Root. Within the scope of this investigation, the series is subjected to unit root tests to assess its stationary property. Table 4.2 indicates that all indices, the ADF test, the P.P. test, and the KPSS test statistics are lower than the critical values. This implies that these indices are likely stationary, indicating a relatively stable pattern.

The results of the stationarity tests at level and difference that were carried out on the series of different markets are provided in Table 4.2, which can be seen below. These tests were made on a series of different markets. When it came to conducting these stationarity-related examinations, the Augmented Dickey-Fuller (ADF) test, the Phillips-Perron (P.P.) test, and the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test were the ones that were employed.

Table 4.2 Stationary Test

Variables	ADF Test		P.P. Test		KPSS Test	
	At Level	At Diff	At Level	At Diff	At Level	At Diff
S&P 500	0.1482	0.0001	0.1581	0.0001	0.4499	0.0296
RUSSELL 2000	0.1994	0.0001	0.2220	0.0001	0.2279	0.0365
NASDAQ 100	0.4922	0.0001	0.4989	0.0001	0.4828	0.0496
S&P BSE GREENEX	0.7256	0.0001	0.7022	0.0001	0.7109	0.0478
S&P BSE CARBONEX	0.4077	0.0001	0.4635	0.0001	0.4511	0.0395
S&P GSCI Crude Oil	0.1478	0.0001	0.1750	0.0001	0.5685	0.0871
S&P GSCI Aluminum	0.4307	0.0001	0.4406	0.0001	0.3083	0.0522
S&P GSCI Gold	0.1372	0.0001	0.1690	0.0001	0.6248	0.0354
S&P GSCI Silver	0.1026	0.0001	0.0863	0.0001	0.5152	0.0313

S&P GSCI Copper	0.4105	0.0001	0.4269	0.0001	0.4921	0.0690
S&P GSCI Natural Gas	0.3369	0.0001	0.2530	0.0001	0.3582	0.0566
EUR.USD	0.1404	0.0001	0.1602	0.0001	0.2928	0.1164
JPY.USD	0.8500	0.0001	0.8490	0.0001	0.8867	0.0916
GBP.USD	0.3595	0.0001	0.4138	0.0001	0.7317	0.0451
CAD.USD	0.2096	0.0001	0.2178	0.0001	0.5205	0.0591
AUD.USD	0.1307	0.0001	0.1476	0.0001	0.3416	0.0585
US 10-Year Bond Yield	0.8903	0.0001	0.8805	0.0001	0.6856	0.0859
US 5-Year Bond Yield	0.9062	0.0001	0.9172	0.0001	0.6440	0.1193
US 3-Year Bond Yield	0.9425	0.0001	0.9452	0.0001	0.6070	0.1672
Critical values at the 5% significance level of 0.146 for all variables.						

We have examined the series to determine whether or not it possesses a trend and an intercept. If the trend was not observed, we performed an intercept test. The outcome is presented in the table provided above. The p-values of the first two tests at the level are not significant at a 5% significance level, as seen in Table 4.2. As a result, we discovered the statistical evidence in favour of the respective null hypotheses, which said that the series has a unit root, which indicates that it is a nonstationary series. The ADF and P.P. tests conclude that the log-transformed series is Stationary at the difference. This is the correct conclusion. However, the KPSS test show that the log-transformed series is not stationary. This is the conclusion that is reached. We will perform a log transformation, which is a possibility. In the context of return transformation, we discover statistical evidence supporting the hypothesis that the series is stationary. This evidence occurs by the 5% threshold of significance in the case of all the tests conducted to determine whether or not the series is stationary.

Table 4.3 clearly indicates the presence of an ARCH effect in all-time series. This implies that the variance of the residuals in these time series is different over time. In simpler terms, the magnitude of changes in these time series could be more consistent, with larger changes tending to be followed by larger changes and smaller changes tending to be followed by smaller changes. The ARCH effect has significant implications for financial forecasting and risk management. For instance, if the ARCH effect is present in a stock price series, it indicates that the volatility of the stock price is not constant. So necessitates the use of the GARCH model to assess the influence of conditional volatility accurately.

Table 4.3. ARCH effect

	Crude Oil	Aluminium	Gold	Silver	Copper	Natural. Gas	S&P 500	Russell 2000	NASDAQ100	US 10 YEARS	US 5 YEARS	US 3YEARS	GREENEX	CARBONEX	EUR.USD	JPY.USD	GBP.USD	CAD.USD	AUD.USD
F-static	143.1980	48.95321	33.49092	134.1502	26.08762	126.8033	435.4280	501.6783	471.3552	907.5539	961.0224	1073.294	80.61395	118.1865	37.57530	19.24813	12.98604	47.49023	35.75120
Prob	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

4.3. Empirical results and discussion on DCC-GARCH and TVP-VAR

4.3.1 DCC-GARCH Analysis on Market risk and Green investment

When employing the DCC-GARCH model to analyze the data for the entire period, as presented in Table 4.4, no evidence of short-term volatility contagion between crude oil, Aluminium, Gold, Silver, Copper, and Natural Gas with Carbonex and Greenex is observed. The significant $\alpha 1$ and $\beta 1$ values indicate a strong and persistent volatility spillover from commodities to both Carbonex and Greenex. The high $\beta 1$ suggests that the impact of volatility is persistent over time. The insignificant dcc $\alpha 1$ implies minimal short-term volatility spillover, whereas the significant dcc $\beta 1$ indicates a strong long-term persistence. During COVID-19, the Russo-Ukrainian War, and the Israel–Hamas War Increased $\alpha 1$ values during crises indicate heightened short-term volatility spillover from commodities to green stocks. The persistent $\beta 1$ values show continuous long-term spillover and Minimal short-term spillover (insignificant dcc $\alpha1$) persists, with strong long-term effects (significant dcc $\beta1$). The insignificant $\alpha1$ suggests weak short-term spillover from commodities to green stocks during crises, but the high $\beta1$ indicates persistent long-term spillover. Similar patterns of minimal short-term spillover with significant long-term persistence. Regarding the crisis period, our short-term results indicate volatility contagion between commodities and green stocks, with volatility following from commodities to green stocks. This implies the transmission of shocks from the commodities market to the stock market. Analyzing the pre-COVID-19 data we found that volatility does not transfer from commodities to green stocks in the short term. Significant $\alpha1$ and $\beta1$ indicate substantial short-term and persistent long-term volatility spillover from commodities to green stocks. Insignificant short-term spillover (dcc $\alpha1$) with strong long-term persistence (dcc $\beta1$) and Joint $\alpha1$ and $\beta1$ showing Minimal short-term spillover with strong long-term effects. Liu et al. (2021) examined the interconnectedness between green bonds, clean energy stocks, and traditional energy markets. They reported significant two-way volatility spillovers, particularly during market stress periods such as the COVID-19 pandemic. This study supports the conclusion that short-term volatility contagion is more pronounced during crises, affecting green stocks significantly. Furthermore, Dutta (2017) found that oil price uncertainty significantly affects clean energy stock returns, supporting the persistent volatility spillover observed in green stocks. These studies collectively validate the need for investors to consider commodity price dynamics when investing in green stocks, enhancing their risk management and strategic decision-making capabilities.

Table 4.4 DCC-GARCH results of Commodities with Green stocks

Panel A Whole Period April, 2014 to Dec, 2023									
		Crude Oil/Carbonex		Crude Oil/Greenex		Aluminum/Carbonex		Aluminum/Greenex	
		Estimate	Pr(>|t|)	Estimate	Pr(>|t|)	Estimate	Pr(>|t|)	Estimate	Pr(>|t|)
1	[A] $\alpha1$	0.148877	0.0000	0.148877	0.0000	0.062640	0.0002	0.062640	0.0002
2	[A] $\beta1$	0. 831194	0.0000	0. 831194	0.0000	0.916762	0.0000	0.916762	0.0000
3	[B] $\alpha1$	0.087701	0.0000	0.094145	0.0000	0.087706	0.0000	0.103037	0.0000
4	[B] $\beta1$	0. 886987	0.0000	0.870305	0.0000	0.886998	0.0000	0.856637	0.0000
5	[Joint]dcc$\alpha1$	0.002738	0.5810	0.001510	0.7197	0.001588	0.3859	0.000000	0.9999
6	[Joint]dcc$\beta1$	0. 976546	0.0000	0.974295	0.0000	0.995559	0.0000	0.932893	0.0073
Panel B During Covid-19, Russo-Ukrainian War and Israel–Hamas war (February 24, 2020, to Dec, 2023)									
1	[A] $\alpha1$	0.200780	0.0013	0.200780	0.001355	0.052511	0.1872	0.052511	0.1872
2	[A] $\beta1$	0.786798	0.0000	0.786798	0.000000	0.939362	0.0000	0.939362	0.0000
3	[B] $\alpha1$	0.093531	0.0145	0.107815	0.000714	0.093531	0.0145	0.107815	0.0007
4	[B] $\beta1$	0.891240	0.0000	0.865834	0.000000	0.891240	0.0000	0.865834	0.0000
5	[Joint]dcc$\alpha1$	0.004350	0.6822	0.000001	0.999770	0.000000	0.9914	0.000000	0.9986

6	[Joint]dcc$\beta 1$	0.949166	0.0000	0.961002	0.274973	0.919433	0.0000	0.916945	0.0000
Panel C Pre Covid-19 (April, 2014 to Feb 2020)									
1	[A] $\alpha 1$	0.073416	0.0000	0.073416	0.0000	0.101502	0.0000	0.101502	0.0000
2	[A] $\beta 1$	0.917188	0.0000	0.917188	0.0000	0.763687	0.0000	0.763687	0.0000
3	[B] $\alpha 1$	0.071499	0.0000	0.076075	0.0000	0.071499	0.0000	0.076075	0.0000
4	[B] $\beta 1$	0.884534	0.0000	0.865775	0.0000	0.884534	0.0000	0.865775	0.0000
5	[Joint]dcc$\alpha 1$	0.003896	0.4522	0.002665	0.4826	0.003738	0.4268	0.000721	0.8630
6	[Joint]dcc$\beta 1$	0.980125	0.0000	0.987720	0.0000	0.978681	0.0000	0.983906	0.0000

Based on the DCC-GARCH analysis, several key findings emerge regarding the volatility spillover between commodities (crude oil, Aluminium, Gold, Silver, Copper, Natural Gas) and green stocks (Carbonex and Greenex). Over the whole period from April 2014 to December 2023, the significant $\alpha 1$ and $\beta 1$ values indicate a strong and persistent volatility spillover from commodities to green stocks. The high $\beta 1$ values suggest that this impact is persistent over time, demonstrating a lasting relationship between the two asset classes. However, the insignificant DCC $\alpha 1$ values imply minimal short-term volatility spillover, while the significant DCC $\beta 1$ values point to robust long-term persistence in these effects. During the crisis periods, such as the COVID-19 pandemic, the Russo-Ukrainian War, and the Israel–Hamas War (February 2020 to Dec 2023), there is an increased $\alpha 1$ value, indicating heightened short-term volatility spillover from commodities to green stocks. The persistent $\beta 1$ values continue to show a long-term spillover effect. The minimal short-term spillover (insignificant DCC $\alpha 1$) persists alongside strong long-term effects (significant DCC $\beta 1$). The data suggests that during crises, short-term volatility contagion is more pronounced, implying the transmission of shocks from the commodities market to the stock market. In the pre-COVID-19 period (April 2014 to February 2020), the analysis reveals that volatility does not transfer significantly from commodities to green stocks in the short term. The significant $\alpha 1$ and $\beta 1$ values still indicate substantial short-term and persistent long-term volatility spillover, with joint dcc $\alpha 1$ and $\beta 1$ showing minimal short-term spillover but strong long-term effects. These patterns suggest a complex interplay between commodities and green stocks, influenced by external economic conditions.

There are several important implications for investors in green stocks regarding the DCC-GARCH analysis. The most crucial is the fact that there is persistent volatility spillover from commodities to green stocks. As a result, those investors who make long-term investments should take better account of the relationship and include it in their portfolios. Short-term investors, in turn, may have an easier time predicting the results as changes in commodity prices have no short-term impact during stable times. However, crises exacerbate short-term spillovers, so it is necessary to be more cautious when trading green stocks.

Table 4.5 DCC-GARCH results of Commodities with Green stocks

		Gold/Carbonex		Gold/Greenex		Silver/Carbonex		Silver/Greenex	
		Estimate	Pr(>|t|)	Estimate	Pr(>|t|)	Estimate	Pr(>|t|)	Estimate	Pr(>|t|)
Panel A Whole Period April, 2014 to Dec, 2023									
1	[A] $\alpha 1$	0.024639	0.0000	0.024639	0.0000	0.031041	0.0000	0.031041	0.0000
2	[A] $\beta 1$	0.965727	0.0000	0.965727	0.0000	0.963583	0.0000	0.963583	0.0000
3	[B] $\alpha 1$	0.087706	0.0000	0.103037	0.0000	0.087706	0.0000	0.103037	0.0000
4	[B] $\beta 1$	0.886998	0.0000	0.856637	0.0000	0.886998	0.0000	0.856637	0.0000
5	[Joint]dcc$\alpha 1$	0.000000	0.9998	0.000000	0.9999	0.004849	0.8101	0.006988	0.6440
6	[Joint]dcc$\beta 1$	0.928390	0.0000	0.931350	0.0084	0.667489	0.0026	0.696230	0.1298
Panel B During Covid-19, Russo-Ukrainian War and Israel–Hamas war (February 24, 2020, to Dec, 2023)									
1	[A] $\alpha 1$	0.057081	0.0000	0.057081	0.0000	0.027913	0.0000	0.027913	0.0000
2	[A] $\beta 1$	0.876593	0.0000	0.876593	0.0000	0.959810	0.0000	0.959810	0.0000
3	[B] $\alpha 1$	0.093531	0.0145	0.107815	0.0007	0.093531	0.0139	0.107815	0.0006
4	[B] $\beta 1$	0.891240	0.0000	0.865834	0.0000	0.891240	0.0000	0.865834	0.0000
5	[Joint]dcc$\alpha 1$	0.000000	0.9971	0.000000	0.9968	0.012009	0.6764	0.015113	0.5562
6	[Joint]dcc$\beta 1$	0.921586	0.0000	0.916845	0.0000	0.754094	0.0000	0.712663	0.0000
Panel C Pre Covid-19 (April, 2014 to Feb 2020)									
1	[A] $\alpha 1$	0.012167	0.0000	0.012454	0.0000	0.020961	0.0019	0.020961	0.0019
2	[A] $\beta 1$	0.984190	0.0000	0.984620	0.0000	0.971212	0.0000	0.971212	0.0000
3	[B] $\alpha 1$	0.071499	0.0000	0.076075	0.0000	0.071499	0.0000	0.076075	0.0000
4	[B] $\beta 1$	0.884534	0.0000	0.865775	0.0000	0.884534	0.0000	0.865775	0.0000
5	[Joint]dcc$\alpha 1$	0.000000	0.9999	0.000000	0.9999	0.000000	0.9997	0.000000	0.9999
6	[Joint]dcc$\beta 1$	0.929506	0.0000	0.954308	0.0000	0.884592	0.0000	0.916659	0.0000

Table 4.6 DCC-GARCH results of Commodities with Green stocks

		Copper/Carbonex		Copper/Greenex		Natural Gas/Carbonex		Natural Gas/Greenex	
		Estimate	Pr(>|t|)	Estimate	Pr(>|t|)	Estimate	Pr(>|t|)	Estimate	Pr(>|t|)
Panel A Whole Period April, 2014 to Dec, 2023									
1	[A] $\alpha 1$	0.067917	0.0000	0.067917	0.0000	0.077583	0.0000	0.077583	0.0000
2	[A] $\beta 1$	0.874338	0.0000	0.874338	0.0000	0.919002	0.0000	0.919002	0.0000
3	[B] $\alpha 1$	0.087706	0.0000	0.103037	0.0000	0.087706	0.0000	0.103037	0.0000
4	[B] $\beta 1$	0.886998	0.0000	0.856637	0.0000	0.886998	0.0000	0.856637	0.0000
5	[Joint]dcc$\alpha 1$	0.000000	0.9984	0.000000	0.9983	0.002297	0.3286	0.002990	0.2726
6	[Joint]dcc$\beta 1$	0.926103	0.0000	0.927854	0.0084	0.991291	0.0026	0.989280	0.1298
Panel B During Covid-19, Russo-Ukrainian War and Israel–Hamas war (February 24, 2020, to Dec, 2023)									
1	[A] $\alpha 1$	0.117884	0.0142	0.117884	0.0142	0.054141	0.0000	0.054141	0.0000
2	[A] $\beta 1$	0.727579	0.0000	0.727579	0.0000	0.942566	0.0000	0.942566	0.0000
3	[B] $\alpha 1$	0.093531	0.0145	0.107815	0.0007	0.093531	0.0145	0.107815	0.0007
4	[B] $\beta 1$	0.891240	0.0000	0.865834	0.0000	0.891240	0.0000	0.865834	0.0000
5	[Joint]dcc$\alpha 1$	0.000000	0.9984	0.000000	0.9995	0.005988	0.2361	0.005388	0.3469
6	[Joint]dcc$\beta 1$	0.924762	0.0000	0.923633	0.0000	0.985043	0.0000	0.984001	0.0000
Panel C Pre Covid-19 (April, 2014 to Feb 2020)									
1	[A] $\alpha 1$	0.029268	0.0000	0.029268	0.0000	0.078260	0.0867	0.078260	0.0867
2	[A] $\beta 1$	0.957234	0.0000	0.957234	0.0000	0.909611	0.0000	0.909611	0.0000
3	[B] $\alpha 1$	0.071499	0.0000	0.076075	0.0000	0.071499	0.0000	0.076075	0.0000
4	[B] $\beta 1$	0.884534	0.0000	0.865775	0.0000	0.884534	0.0000	0.865775	0.0000
5	[Joint]dcc$\alpha 1$	0.000000	0.9999	0.000000	0.9991	0.000000	0.9999	0.000000	0.9999
6	[Joint]dcc$\beta 1$	0.915168	0.0000	0.919478	0.0000	0.916458	0.0000	0.915459	0.0000

The analysis indicates that S&P 500, Nasdaq 100, and Russell 200 all have significant and pervasive volatility spillover effects on Carbonex and Greenex across all periods. The spillover is most evident over the long run, as specified by high and significant values of $\beta 1$ the effect is highly persistent. Furthermore, during crisis periods, there is a noticeable increase in the short-run volatility spillover, particularly from S&P 500 to green indices. No spillover effects were detected in the DCC joint estimates, although the long-term persistence was present. It should be noted that investors should consider both short-term volatility behaviors and long-term dynamics when dealing with green stocks. For the S&P 500, Nasdaq 100 and Russell 2000, substantial measures on $\alpha 1$ and $\beta 1$ indicate strong and persistent volatility spillovers to Carbonex and Greenex. The high $\beta 1$ values show that the relationships are highly persistent in the long term. The results of the joint DCC analysis show insignificant values of dcc results meaning that the short run spillover is relatively low. However, the substantial results of the dcc values show that the long-term persistency of the results is strong since $p<0.001$ for both indices. Accordingly, during crises, high measures of both $\alpha 1$ and $\beta 1$ are evident with $p<0.0001$ for the S&P 500, Nasdaq 100 and Russell 2000 showing that there is increased rate in the short term and high persistency in the long run. Joint DCC results show insignificant values of dcc results meaning that the short run effects are not significant. Moreover, the strong results of the dcc values of the facilitates indicate that the long-term results are persistent. Notably, the results of the aclear demonstrate that there is an insignificant short-run spillover whereas the spillover is substantial in the long run. Similarly, the findings of the pre-Covid results show significant results of $\alpha 1$ and $\beta 1$ with $p<0.0001$ for both indices meaning that the short-term and long-term spillovers to Carbonex and Greenex are significant. The results are supported by the joint DCC results showing insignificant values of the short-term effect of dcc values.

Table 4.7 DCC-GARCH results of Equities with Green stocks

Panel A Whole Period April, 2014 to Dec, 2023

		S&P 500/Carbonex		S&P 500/Greenex		Russell 2000/Carbonex		Russell 2000/Greenex	
		Estimate	Pr(>|t|)	Estimate	Pr(>|t|)	Estimate	Pr(>|t|)	Estimate	Pr(>|t|)
1	[A] $\alpha 1$	0.199732	0.0000	0.199732	0.0000	0.120122	0.0000	0.120122	0.0000
2	[A] $\beta 1$	0.773539	0.0000	0.773539	0.0000	0.854957	0.0000	0.854957	0.0000
3	[B] $\alpha 1$	0.087706	0.0000	0.103037	0.0000	0.087706	0.0000	0.103037	0.0000
4	[B] $\beta 1$	0.886998	0.0000	0.856637	0.0000	0.886998	0.0000	0.856637	0.0000

5	[Joint]dccα1	0.014643	0.2256	0.018045	0.1690	0.000000	0.9904	0.000000	1.0000
6	[Joint]dccβ1	0.621338	0.0000	0.572768	0.0005	0.925325	0.0185	0.940707	0.5727
Panel B During Covid-19, Russo-Ukrainian War and Israel–Hamas war (February 24, 2020, to Dec, 2023)									
1	[A] α1	0.142269	0.0000	0.142269	0.0000	0.100169	0.0000	0.100169	0.0000
2	[A] β1	0.831169	0.0000	0.831169	0.0000	0.863301	0.0000	0.863301	0.0000
3	[B] α1	0.093531	0.0145	0.107815	0.0007	0.093531	0.0145	0.107815	0.0007
4	[B] β1	0.891240	0.0000	0.865834	0.0000	0.891240	0.0000	0.865834	0.0000
5	[Joint]dccα1	0.005501	0.6610	0.016747	0.2752	0.000000	0.9987	0.000000	0.9980
6	[Joint]dccβ1	0.831533	0.0216	0.441240	0.5066	0.909054	0.0000	0.913375	0.0000
Panel C Pre Covid-19 (April, 2014 to Feb 2020)									
1	[A] α1	0.223319	0.0000	0.223319	0.0000	0.118598	0.0000	0.118598	0.0000
2	[A] β1	0.725308	0.0000	0.725308	0.0000	0.814672	0.0000	0.814672	0.0000
3	[B] α1	0.071499	0.0000	0.076075	0.0000	0.071499	0.0000	0.076075	0.0000
4	[B] β1	0.884534	0.0000	0.865775	0.0000	0.884534	0.0000	0.865775	0.0000
5	[Joint]dccα1	0.026203	0.1676	0.020919	0.2682	0.000872	0.8900	0.001245	0.7900
6	[Joint]dccβ1	0.560916	0.0000	0.631123	0.0000	0.951997	0.0000	0.947193	0.0000

The DCC-GARCH results for equities paired with green stocks over different periods provide insightful findings. For the whole period from April 2014 to December 2023, both S&P 500 and Russell 2000 indices show significant α1 and β1 estimates, indicating strong volatility persistence and reactivity to market shocks. The joint dccα1 and dccβ1 parameters vary, with significant dccβ1 suggesting strong co-movement between the indices and green stocks. During the COVID-19 pandemic and subsequent geopolitical conflicts (February 2020 to December 2023), the estimates for α1 and β1 remain significant, indicating continued market volatility and persistence. However, the joint dccα1 and dccβ1 parameters show mixed significance, suggesting that the co-movement between indices and green stocks was less stable during this period.Pre-COVID-19 (April 2014 to February 2020), the α1 and β1 estimates for both S&P 500 and Russell 2000 paired with green stocks were again significant, reflecting high market reactivity and persistence. The joint dccα1 parameter was generally insignificant, while dccβ1 remained significant, indicating consistent co-movement before the pandemic. Overall, the analysis reveals that market volatility and persistence were high across all periods, with significant co-movement between indices and green stocks, especially pre-COVID-19 and during the whole period. However, the stability of this relationship was challenged during the COVID-19 and geopolitical conflict period.

Table 4.8 DCC-GARCH results of equities and interest rate with Green stocks									
Panel A Whole Period April, 2014 to Dec, 2023									
		Nasdaq 100/Carbonex		Nasdaq 100/Greenex		US 10-Year/Carbonex		US 10-Year/Greenex	
		Estimate	Pr(>|t|)	Estimate	Pr(>|t|)	Estimate	Pr(>|t|)	Estimate	Pr(>|t|)
1	[A] $\alpha 1$	0.152994	0.0000	0.152994	0.0000	0.137875	0.0000	0.137875	0.0000
2	[A] $\beta 1$	0.823251	0.0000	0.823251	0.0000	0.824217	0.0000	0.824217	0.0000
3	[B] $\alpha 1$	0.087706	0.0000	0.103037	0.0000	0.087706	0.0000	0.103037	0.0000
4	[B] $\beta 1$	0.886998	0.0000	0.856637	0.0000	0.886998	0.0000	0.856637	0.0000
5	[Joint]dcc$\alpha 1$	0.000000	0.9997	0.000000	0.9999	0.000000	0.8930	0.006293	0.5338
6	[Joint]dcc$\beta 1$	0.912211	0.0000	0.918080	0.0000	0.912450	0.0000	0.778068	0.0000
Panel B During Covid-19, Russo-Ukrainian War and Israel–Hamas war (February 24, 2020, to Dec, 2023)									
1	[A] $\alpha 1$	0.105779	0.0011	0.105779	0.0011	0.145423	0.0006	0.145423	0.0007
2	[A] $\beta 1$	0.881076	0.0000	0.881076	0.0000	0.832597	0.0000	0.832597	0.0000
3	[B] $\alpha 1$	0.093531	0.0145	0.107815	0.0007	0.093531	0.0145	0.107815	0.0007
4	[B] $\beta 1$	0.891240	0.0000	0.865834	0.0000	0.891240	0.0000	0.865834	0.0000
5	[Joint]dcc$\alpha 1$	0.000000	0.9966	0.000000	0.9998	0.058556	0.6294	0.020413	0.1386
6	[Joint]dcc$\beta 1$	0.916604	0.0000	0.927818	0.0000	0.802000	0.0000	0.803735	0.0000
Panel C Pre Covid-19 (April, 2014 to Feb 2020)									
1	[A] $\alpha 1$	0.165066	0.0000	0.165066	0.0000	0.043844	0.0265	0.043844	0.0265
2	[A] $\beta 1$	0.773994	0.0000	0.773994	0.0000	0.953173	0.0000	0.953173	0.0000
3	[B] $\alpha 1$	0.071499	0.0000	0.076075	0.0000	0.071499	0.0000	0.076075	0.0000
4	[B] $\beta 1$	0.884534	0.0000	0.865775	0.0000	0.884534	0.0000	0.865775	0.0000
5	[Joint]dcc$\alpha 1$	0.017219	0.2726	0.007613	0.5692	0.000000	0.9999	0.000000	0.9999
6	[Joint]dcc$\beta 1$	0.461218	0.0536	0.556534	0.0025	0.917072	0.0000	0.917919	0.0000

A joint beta ($\beta 1$) value above 0.9 indicates a strong long-term persistence in the volatility spillover from the US 10-Year Treasury bond yield to the Greenex index. This means that fluctuations in the bond yield have a significant and enduring impact on the volatility of Greenex. For the US 10-Year Treasury bond, the estimates for $\alpha 1$ (0.137875, $p < 0.0001$) and $\beta 1$ (0.824217, $p < 0.0001$) indicate strong short-term and long-term volatility spillovers to both Carbonex and Greenex. The joint DCC parameters show that dcc $\alpha 1$ values are insignificant, suggesting minimal short-term spillover. However, significant dcc $\beta 1$ values indicate strong long-term persistence in volatility for both indices. During crises, the estimates for $\alpha 1$ (0.145423, $p < 0.001$) and $\beta 1$ (0.832597, $p < 0.0001$) remain significant, indicating continued short-term and long-term spillover effects. The joint DCC parameters reveal minimal short-term spillover (insignificant dcc $\alpha 1$ values) but persistent long-term effects (significant dcc $\beta 1$ values for Greenex). Before the pandemic, the $\alpha 1$ values (0.043844, $p < 0.05$) indicate some short-term volatility spillover to both indices. The $\beta 1$ estimates (0.953173, $p < 0.0001$) confirm long-term persistence. Joint DCC parameters show minimal short-term spillover (insignificant dcc $\alpha 1$ values) but strong long-term persistence (significant dcc $\beta 1$ values). The US 10-Year Treasury bond exhibits significant long-term volatility spillover to Carbonex and Greenex indices, particularly highlighted by the $\beta 1$ values across all periods. Short-term spillovers, represented by $\alpha 1$, are generally minimal except during crises. These findings highlight the importance for investors to consider both short-term and long-term volatility dynamics in green indices, especially about bond market movements.

The estimates for $\alpha 1$ and $\beta 1$ across all bonds (US 5-Year and US 3-Year) and indices (Carbonex and Greenex) are significant ($p < 0.0001$), indicating strong short-term ($\alpha 1$) and long-term ($\beta 1$) volatility spillover from US Treasury bonds to green indices. The joint DCC parameters show that dcc $\alpha 1$ values are insignificant ($p > 0.1$), implying minimal short-term spillover, while significant dcc $\beta 1$ values indicate strong long-term persistence. During the crises, the estimates for $\alpha 1$ and $\beta 1$ remain significant ($p < 0.0001$), suggesting both short-term and long-term volatility spillovers persist. The joint DCC parameters reveal minimal short-term spillover (insignificant dcc $\alpha 1$ values) but strong long-term effects (significant dcc $\beta 1$ values for Greenex). Before the pandemic, the $\alpha 1$ values are generally insignificant ($p > 0.1$), indicating minimal short-term spillover. However, the $\beta 1$ estimates are significant ($p < 0.0001$), showing strong long-term volatility spillover. Joint DCC parameters confirm minimal short-term spillover and significant long-term persistence.

Table 4.9 DCC-GARCH results of interest rate with Green stocks

		US 5-Year/Carbonex		US 5-Year/Greenex		US 3-Year/Carbonex		US 3-Year/Greenex	
		Estimate	Pr(>|t|)	Estimate	Pr(>|t|)	Estimate	Pr(>|t|)	Estimate	Pr(>|t|)
Panel A Whole Period April 2014 to Dec 2023									
1	[A] $\alpha 1$	0.131497	0.0000	0.131497	0.0000	0.134925	0.0000	0.134925	0.0000
2	[A] $\beta 1$	0.859292	0.0000	0.859292	0.0000	0.864075	0.0000	0.864075	0.0000
3	[B] $\alpha 1$	0.087706	0.0000	0.103037	0.0000	0.087706	0.0000	0.103037	0.0000
4	[B] $\beta 1$	0.886998	0.0000	0.856637	0.0000	0.886998	0.0000	0.856637	0.0000
5	[Joint]dcc$\alpha 1$	0.000000	0.9995	0.013989	0.1223	0.000000	0.9991	0.000000	0.9997
6	[Joint]dcc$\beta 1$	0.917989	0.0000	0.780000	0.0000	0.920468	0.0000	0.915530	0.0000
Panel B During Covid-19, Russo-Ukrainian War and Israel–Hamas war (February 24, 2020, to Dec, 2023)									
1	[A] $\alpha 1$	0.125170	0.0007	0.125170	0.0007	0.114356	0.0022	0.114356	0.0022
2	[A] $\beta 1$	0.873830	0.0000	0.873830	0.0000	0.884644	0.0000	0.884644	0.0000
3	[B] $\alpha 1$	0.093531	0.0147	0.107815	0.0007	0.093531	0.0147	0.107815	0.0007
4	[B] $\beta 1$	0.891240	0.0000	0.865834	0.0000	0.891240	0.0000	0.865834	0.0000
5	[Joint]dcc$\alpha 1$	0.062281	0.2407	0.019488	0.1369	0.030844	0.3120	0.010981	0.3969
6	[Joint]dcc$\beta 1$	0.930001	0.0000	0.807941	0.0000	0.930001	0.0000	0.739592	0.0002
Panel C Pre Covid-19 (April, 2014 to Feb 2020)									
1	[A] $\alpha 1$	0.050077	0.2283	0.050077	0.2283	0.053947	0.278133	0.053947	0.2781
2	[A] $\beta 1$	0.948483	0.0000	0.948483	0.0000	0.945039	0.000000	0.945039	0.0000
3	[B] $\alpha 1$	0.071499	0.0000	0.076075	0.0000	0.071499	0.000000	0.076075	0.0000
4	[B] $\beta 1$	0.884534	0.0000	0.865775	0.0000	0.884534	0.000000	0.865775	0.0000
5	[Joint]dcc$\alpha 1$	0.000000	0.9847	0.000000	0.9999	0.000000	0.996743	0.000000	0.9968
6	[Joint]dcc$\beta 1$	0.925456	0.0000	0.927030	0.0000	0.925109	0.000000	0.926049	0.0000

The analysis of volatility spillover between the forex market for five pairs, EUR, JPY, GBP, CAD, and AUD, and green indices, Carbonex and Greenex, provides the following key insights. First, significant long-term volatility persistence is detected throughout a variety of periods, suggesting that the exchange rate movements have a long-run impact on the volatility of green stocks. Second, the short-term spillover effects are limited except for several cases before Covid-19. Throughout the whole analysis, both primary and secondary estimates suggest that most spillover effects are associated with forex markets, implying that the forex risk accounting and risk-reducing practices, such as diversification and hedging, should be considered to respond to the implications of exchange rate movements on the green stock market. In turn, these ideas suggest that investors willing to be resilient to the currency impact should align with the long-term implications. The expected implication for green stock portfolios is that the consideration of the long-term forex movements with a long-term investment horizon would guarantee that the portfolios are better prepared for the adverse impact of currency depreciation.

Table 4.10 DCC-GARCH results of Forex with Green stocks

		EUR: USD/Carbonex		EUR: USD /Greenex		JPY: USD/Carbonex		JPY: USD /Greenex	
		Estimate	Pr(>|t|)	Estimate	Pr(>|t|)	Estimate	Pr(>|t|)	Estimate	Pr(>|t|)
Panel A Whole Period April 2014 to Dec 2023									
1	[A] $\alpha1$	0.045281	0.0041	0.045281	0.0041	0.078885	0.6674	0.078885	0.6675
2	[A] $\beta1$	0.949589	0.0000	0.949589	0.0000	0.911332	0.0000	0.911332	0.0000
3	[B] $\alpha1$	0.087706	0.0000	0.103037	0.0000	0.087706	0.0000	0.103037	0.0000
4	[B] $\beta1$	0.886998	0.0000	0.856637	0.0000	0.886998	0.0000	0.856637	0.0000
5	[Joint]dcc$\alpha1$	0.007426	0.1972	0.008108	0.2136	0.005292	0.0475	0.017604	0.3584
6	[Joint]dcc$\beta1$	0.986228	0.0000	0.984627	0.0000	0.991359	0.0000	0.940514	0.0000
Panel B During Covid-19, Russo-Ukrainian War, and Israel–Hamas war (February 24, 2020, to Dec 2023)									
1	[A] $\alpha1$	0.038175	0.2161	0.038175	0.2161	0.086854	0.6206	0.086854	0.6242
2	[A] $\beta1$	0.953565	0.0000	0.953565	0.0000	0.903432	0.0000	0.903432	0.0000
3	[B] $\alpha1$	0.093531	0.0145	0.107815	0.0007	0.093531	0.0145	0.107815	0.0007
4	[B] $\beta1$	0.891240	0.0000	0.865834	0.0000	0.891240	.0000	0.865834	0.0000
5	[Joint]dcc$\alpha1$	0.000000	0.9999	0.000000	0.9709	0.000000	0.9946	0.010055	0.7650
6	[Joint]dcc$\beta1$	0.915695	0.0000	0.920602	0.0006	0.903082	0.0000	0.612981	0.0916
Panel C Pre Covid-19 (April, 2014 to Feb 2020)									
1	[A] $\alpha1$	0.035421	0.0418	0.035421	0.0418	0.067292	0.4786	0.067292	0.4775
2	[A] $\beta1$	0.962123	0.0000	0.962123	0.0000	0.923110	0.0000	0.923110	0.0000
3	[B] $\alpha1$	0.071499	0.0000	0.076075	0.0000	0.071499	0.0000	0.076075	0.0000
4	[B] $\beta1$	0.884534	0.0000	0.865775	0.0000	0.884534	0.0000	0.865775	0.0000
5	[Joint]dcc$\alpha1$	0.023244	0.0127	0.020324	0.1419	0.008437	0.2285	0.016967	0.6832
6	[Joint]dcc$\beta1$	0.940100	0.0000	0.951404	0.0000	0.985690	0.0000	0.956924	0.0000

In the case of the EUR: USD exchange rate, significant $\alpha 1$ estimates ($p < 0.01$) seem to indicate that the short-term volatility spillover to Carbonex and Greenex markets is prominent. The $\beta 1$ estimates ($p < 0.0001$) signalize the strong long-term persistence. As for the Joint DCC parameters, DCC $\alpha 1$ appears to be insignificant and thus signals small short-run spillover of only 0.9%. Unlike the unconditional standard deviation approach, the DCC approach's $\beta 1$ is significant and so securely establish long-term persistence. For the JPY: USD exchange rate, the insignificant $\alpha 1$ estimates would indicate that the short-term spillovers are, in fact, very small, while the significant $\beta 1$ estimates might mean sustained long-term volatility. The Joint DCC parameters confirm these results with significant DCC $\beta 1$.

During crises, the EUR exchange rate exhibits insignificant $\alpha 1$ values ($p > 0.1$), indicating minimal short-term spillover. However, significant $\beta 1$ values ($p < 0.0001$) suggest persistent long-term volatility. Joint DCC parameters indicate insignificant DCC $\alpha 1$ values but significant DCC $\beta 1$ values, confirming long-term persistence. For the JPY: USD exchange rate, $\alpha 1$ values remain insignificant ($p > 0.1$), showing minimal short-term spillover. Significant $\beta 1$ values ($p < 0.0001$) confirm long-term volatility persistence. Joint DCC parameters show significant DCC $\beta 1$ values, indicating long-term persistence. Before the pandemic, the EUR: USD exchange rate shows significant $\alpha 1$ estimates ($p < 0.05$) for Carbonex, indicating short-term volatility spillover, but not for Greenex. The $\beta 1$ estimates ($p < 0.0001$) confirm long-term persistence. Joint DCC parameters reveal minimal short-term spillover but significant long-term persistence. For the JPY: USD exchange rate, insignificant $\alpha 1$ estimates indicate minimal short-term spillover, while significant $\beta 1$ estimates ($p < 0.0001$) confirm long-term persistence. Joint DCC parameters show significant long-term persistence. Overall, the EUR: USD and JPY: USD exchange rates exhibit significant long-term volatility spillover to Carbonex and Greenex indices, particularly highlighted by the $\beta 1$ values across all periods. Short-term spillovers, indicated by $\alpha 1$ estimates, are generally minimal except for the EUR: USD exchange rate before COVID-19. The findings underscore the importance for investors to consider both short-term and long-term volatility dynamics when dealing with green indices, especially in the context of exchange rate fluctuations.

Table 4.11 DCC-GARCH results of Forex with Green stocks									
Panel A Whole Period April 2014 to Dec 2023									
		GBP:USD/Carbonex		GBP:USD /Greenex		CAD:USD/Carbonex		CAD:USD /Greenex	
		Estimate	Pr(>|t|)	Estimate	Pr(>|t|)	Estimate	Pr(>|t|)	Estimate	Pr(>|t|)
1	[A] $\alpha1$	0.098549	0.0019	0.098549	0.0020	0.038702	0.0423	0.038702	0.0423
2	[A] $\beta1$	0.860862	0.0000	0.860862	0.0000	0.953310	0.0000	0.953310	0.0000
3	[B] $\alpha1$	0.087706	0.0000	0.103037	0.0000	0.087706	0.0000	0.103037	0.0000
4	[B] $\beta1$	0.886998	0.0000	0.856637	0.0000	0.886998	0.0000	0.856637	0.0000
5	[Joint]dcc$\alpha1$	0.010025	0.1276	0.013943	0.0526	0.022775	0.0069	0.024309	0.0158
6	[Joint]dcc$\beta1$	0.957332	0.0000	0.923206	0.0000	0.904752	0.0000	0.873951	0.0000
Panel B During Covid-19, Russo-Ukrainian War, and Israel–Hamas War (February 24, 2020, to Dec 2023)									
1	[A] $\alpha1$	0.081483	0.144567	0.081483	0.144850	0.038622	0.2953	0.038622	0.2955
2	[A] $\beta1$	0.892236	0.000000	0.892236	0.000000	0.948815	0.0000	0.948815	0.0000
3	[B] $\alpha1$	0.093531	0.014688	0.107815	0.000702	0.093531	0.0146	0.107815	0.0007
4	[B] $\beta1$	0.891240	0.000000	0.865834	0.000000	0.891240	0.0000	0.865834	0.0000
5	[Joint]dcc$\alpha1$	0.013545	0.132928	0.016019	0.075399	0.034492	0.1648	0.055152	0.1970
6	[Joint]dcc$\beta1$	0.948399	0.000000	0.943866	0.000000	0.847653	0.0000	0.694221	0.0539
Panel C Pre Covid-19 (April, 2014 to Feb 2020)									
1	[A] $\alpha1$	0.105961	0.0000	0.105961	0.0000	0.029491	0.0004	0.029491	0.0004
2	[A] $\beta1$	0.838121	0.0000	0.838121	0.0000	0.969142	0.0000	0.969142	0.0000
3	[B] $\alpha1$	0.071499	0.0000	0.076075	0.0000	0.071499	0.0000	0.076075	0.0000
4	[B] $\beta1$	0.884534	0.0000	0.865775	0.0000	0.884534	0.0000	0.865775	0.0000
5	[Joint]dcc$\alpha1$	0.005271	0.3044	0.003805	0.5279	0.008846	0.4339	0.005771	0.5914
6	[Joint]dcc$\beta1$	0.981078	0.0000	0.976252	0.0000	0.915888	0.0000	0.926450	0.0000

For the GBP: USD exchange rate, significant $\alpha1$ estimates ($p < 0.01$) indicate notable short-term volatility spillover to Carbonex and Greenex. The $\beta1$ estimates ($p < 0.0001$) show strong long-term persistence. Joint DCC parameters reveal that dcc $\alpha1$ is generally insignificant ($p > 0.1$), indicating minimal short-term spillover, but significant dcc $\beta1$ values confirm long-term persistence. Similarly, the CAD:USD exchange rate shows significant $\alpha1$ estimates for both indices, suggesting short-term volatility effects.

The $\beta1$ estimates ($p< 0.0001$) point to a significant amount of long run volatility persistence. A new analysis based on joint DCC parameters also provides statistically significant dcc $\beta1$ values, indicating that long-term spillovers remain. In crises, the GBP:USD exchange rate have $\alpha1$ insignificant values ($p > 0.1$), meaning that there is no short-term effect Significant $\beta1$ values ($p < -0.0001$) illustarte however great long-term volatility remained. The common long-run persistence was confirmed with insignificant dcc $\alpha1$ values but significant dcc $\beta1$ values in joint DCC parameters. The patterns in the same data series under crises for CAD:USD exchange rate are the same, having irrelevant

$\alpha 1$ values ($p > 0.1$) that are not a short-term spillover, and a significant $\beta 1$ values, this showing persistence of long-term volatility. More importantly the joint DCC parameters provide further confirmation, as the estimated dcc b1 values are significant for long-term persistence. Both indices have very large $\alpha 1$ estimates ($p < 0.01$) for the GBP:USD exchange rate prior to the pandemic — indicative of short term spillover effects. These $\beta 1$ estimates show highly significant long-term persistence ($p < 0.0001$). DCC parameters for the joint model show low dcc $\alpha 1$ values suggesting weak short-term spillover, however the corresponding dcc $\beta 1$ values are highly significant, indicating strong long run persistence.The CAD:USD exchange rate is driven by significant $\alpha 1$ and $\beta 1$ ($p < 0.01$ and $p < 0.0001$estimates, with spillovers predicted both short-term and long-term. Both DCC parameters imply very little short-run spillover in contrast to quite significant long-run persistence. Long-term volatility spillover can significantly be influenced by volatility in GBP: USD and CAD: USD exchange rates to both Carbonex and Greenex indices as presented by the consistent $\beta 1$ estimates across all timeframes in the analysis. Short-medium-run spillovers, those related to $\alpha 1$ estimates, are predominantly larger in the pre-Covid era in both currency pairs. Long-term spillovers stay high during crisis, but short term impacts are minimal.

Table 4.12 DCC-GARCH results of Forex with Green stocks

Panel A Whole Period April 2014 to Dec 2023					
		AUD: USD/Carbonex		AUD: USD /Greenex	
		Estimate	Pr(>|t|)	Estimate	Pr(>|t|)
1	[A] $\alpha 1$	0.039592	0.5508	0.039592	0.5483
2	[A] $\beta 1$	0.952798	0.0000	0.952798	0.0000
3	[B] $\alpha 1$	0.087706	0.0000	0.103037	0.0000
4	[B] $\beta 1$	0.886998	0.0000	0.856637	0.0000
5	[Joint]dcc$\alpha 1$	0.002437	0.4971	0.024314	0.1689
6	[Joint]dcc$\beta 1$	0.990060	0.0000	0.579237	0.0000
Panel B During Covid-19, Russo-Ukrainian War, and Israel–Hamas War (February 24, 2020, to Dec 2023)					
1	[A] $\alpha 1$	0.035591	0.6721	0.035591	0.6741
2	[A] $\beta 1$	0.953164	0.0000	0.953164	0.0000
3	[B] $\alpha 1$	0.093531	0.0145	0.107815	0.0005
4	[B] $\beta 1$	0.891240	0.0000	0.865834	0.0000
5	[Joint]dcc$\alpha 1$	0.002570	0.4736	0.026823	0.3978
6	[Joint]dcc$\beta 1$	0.993641	0.0000	0.585481	0.0010
Panel C Pre Covid-19 (April, 2014 to Feb 2020)					
1	[A] $\alpha 1$	0.026579	0.0000	0.026579	0.0000
2	[A] $\beta 1$	0.970423	0.0000	0.970423	0.0000
3	[B] $\alpha 1$	0.071499	0.0000	0.076075	0.0000
4	[B] $\beta 1$	0.884534	0.0000	0.865775	0.0000
5	[Joint]dcc$\alpha 1$	0.000000	0.9999	0.000000	0.9997
6	[Joint]dcc$\beta 1$	0.948049	0.1046	0.913220	0.0015

The analysis reveals a mixed impact of the AUD: USD exchange rate on the volatility of Carbonex and Greenex indices. The estimates for $\alpha 1$ ($p > 0.5$) are insignificant, indicating minimal immediate volatility spillover. However, the significant $\beta 1$ values ($p < 0.0001$) suggest that any volatility present is highly persistent over time. For the joint DCC parameters, the insignificant DCC $\alpha 1$ values ($p > 0.1$) imply minimal short-term spillover, whereas significant DCC $\beta 1$ values ($p < 0.0001$) demonstrate strong long-term persistence in volatility. During the crises, the $\alpha 1$ estimates remain insignificant ($p > 0.5$), showing that short-term spillover from the AUD: USD exchange rate to green indices is minimal. However, the $\beta 1$ values are again significant ($p < 0.0001$), indicating the long-term persistence of volatility. The joint DCC parameters show similar patterns: insignificant DCC $\alpha 1$ values suggest minimal short-term impact, while significant DCC $\beta 1$ values ($p < 0.001$ for Carbonex) reflect sustained long-term volatility effects. Before the pandemic, the short-term spillover ($\alpha 1$) from AUD: USD to green indices is significant ($p < 0.0001$), indicating some immediate volatility effects. The $\beta 1$ values remain highly significant ($p < 0.0001$), underscoring long-term persistence. However, joint DCC parameters reveal that DCC $\alpha 1$ values are insignificant, showing minimal short-term spillover, while the dcc $\beta 1$ values are generally significant, confirming the long-term persistence of volatility. Across all periods, the AUD: USD exchange rate has a persistent long-term impact on the volatility of Carbonex and Greenex indices, as shown by the consistently significant $\beta 1$ values. Short-term spillover effects, represented by $\alpha 1$, are generally insignificant, except in the pre-COVID period, indicating that immediate impacts are minimal. The joint DCC parameters further confirm that long-term volatility spillover is robust, particularly during crisis periods, which is crucial for investors considering the long-term stability and risk associated with green investments.

4.3.2. TVP-VAR Total connectedness

During the past 10 years, one of the most popular areas of research within the field of network theory has been investigating the connections between different asset classes, indices, commodities, foreign exchange, interest rates, and other natural and financial variables, including green investment. This is possible because researchers now have a more significant opportunity to understand network theory. The Diebold-Yılmaz Connectedness Index (DYCI) concept, which Diebold and Yılmaz introduced in a series of papers in 2009, 2012, and 2014, is a consideration. The duration of both a rolling window and a forecast horizon (H) is one hundred days, which is approximately comparable to a quarter-year. The allotted period is adequate for the resolution of temporal inconsistencies. With the changing window strategy, it is not necessary to externally designate crises' beginning and ending dates. The spillover indices presented herein are the outcomes of the efforts to implement the suggestions by Yilmaz (2012) and Owusu Junior et al. (2020). Significant changes in the dynamics of spillover during the observed period can be identified by utilizing these indices.

To analyze the interconnections that exist between the marketplaces, this research study makes use of the methodology that was created by Diebold and Yilmaz (2012). Using the FEVD inside a GVAR framework to measure volatility spillovers, this study analyses the potential for volatility spillovers to impact both across and within markets. Specifically, the results of this investigation are presented in the form of a survey. The GFEVD is order-invariant, which, in contrast to more typical approaches, enables each variable to simultaneously explore the spillovers that occur across and within markets that are influenced by shocks to both itself and the primary variables. This is a significant advantage over other approaches. An approach that enables us to analyze the spread of information and shocks across several different markets is the spillover index, a tool developed by Diebold and Yilmaz (2012).

The overall average connection of the various financial markets is presented in Table 4.13. Tables 4.14 and 4.15 break down the connectedness into two categories: short-term components (one to five traded days) and long-term components (five to indefinitely). The initial value of the Total Averaged Connectedness Index (TACI) is 60.72, present in Table 4.3, which indicates that about 60.72 percent of the variance in forecast errors across this network of global financial markets is a result of shock transmissions between markets.

The remaining 39.29% of the variance can be attributed to unique characteristics specific to each market. This extreme level of volatility transmission during the COVID-19 pandemic is consistent with the findings that were uncovered by Ding et al. (2021) and Wang et al. (2022). According to their research findings, the total volatility transmission among energy and financial markets stayed greater than sixty percent throughout the pandemic. It continued to be greater than forty percent even after the declining epidemic. Consequently, this highlights the considerable influence the global crisis has had on the spread of risk across markets.

Finally, the last row in Tables 4.13, 4.14, and 4.15 provides the net total connectedness, which results from the difference between total connectedness TO other assets and total connectedness FROM other assets. The Variance Decomposition (V.D.) matrix is a 24x24 matrix in which the off-diagonal entries describe how shocks in one market contribute to the forecast error variance (FEV) of another market, omitting the impact of the first market. In this matrix, the "from others" column displays the total contributions from other markets to a particular market. In contrast, the "to others" row displays the total contributions from a specific market to other markets. To get the Net Volatility Spillovers (V.S.s), take the numbers in the "from others" column and subtract them from the values in the "to others" row. The total spillover index (TSI) is displayed in the top row of the table. This index provides a quantitative representation of the overall level of inter-market spillovers in both directions. The summary of the cumulative impacts of market shocks on its variance and on the variances of other markets can be found in the "total" row, located at the bottom of the table. The directional spillovers "to others" from each market are an excellent example of the significant differences in the transmitted volatility spillovers.

The total average connectedness among various financial markets is presented in Tables 4.13, 4.14, and 4.15, including short-run components comprising one to five traded days and long-run components comprising five infinite days. In the first place, the total averaged connectedness index (TACI) is 60.83, which indicates that, on average, 60.72 percent of the forecast error variance in this network of global financial markets can be attributed to the shock transmission among these markets. The distinctive factor in each market captures the remaining 39.17 percent of the variance. This significant intensity of volatility transmission during the COVID-19 outbreak is mainly consistent with the findings of Ding et al. (2021) and Wang et al. (2022), who observe that the total volatility transmission among energy and financial markets exceeds sixty percent with the COVID-19 outbreak and continues to be above forty percent after the outbreak has passed. This highlights the significant role of the global epidemic in spreading risk from one market to another. Furthermore, from the standpoint of frequency decomposition in tables 4.14 and 4.15, the Intermarket volatility connectivity is mainly driven by volatility transmission in the short term (48.54 percent), compared with uncertainty transmission in the long term (12.30 percent). Furthermore, the level of connection is mainly driven by advancements, namely the transmission of shocks, in the short period, which accounts for around 48.54% of the entire impact.

The estimates from the spillover analysis presented in Table 4.13 highlight three key aspects: unidirectional spillovers, the total spillover to and from each asset, and the net directional spillovers for each individual asset. The net directional spillover is calculated by subtracting the total contributions an asset receives from others from the total contributions it gives to others. A positive net spillover value indicates that the asset is a net transmitter of shocks, while a negative value indicates it is a net receiver. Summarizing the results, it is evident that there is a significant spillover effect among the assets, with all of them substantially contributing to and receiving shocks. On average, the stock and commodity markets are the highest transmitters of shocks. In the commodity market, the leading transmitters are Gold (78.39), Silver (69.36), Copper (50.23), Aluminum (40.12), and Crude Oil (37.4). In the stock market, the S&P 500 (136.65) is the highest transmitter, followed by the Russell 2000 (60.83) and NASDAQ 100 (57.33). In terms of interest rates, the US 10-year bond yield (87.47), US 5-year bond yield (96.43), and US 3-year bond yield (89.26) are significant transmitters. In the forex market, the AUD/USD (42.67) and EUR/USD (40.90) are the highest givers of shocks. Conversely, as net receivers of shocks in the commodity market, Natural Gas (-7.08) and Aluminum (-2.15) stand out. In the stock market, NASDAQ 100 (-17.03) and Russell 2000 (-9.44) are notable net receivers, followed by Carbonex (-5.93) and Greenex (-6.5). In the interest rate sector, all assets are net givers, whereas in the forex market, all are net receivers of shocks.

Taking into consideration the net total directional connectedness (NET) of every asset, it is evident that the S&P 500 (91.31), followed by gold (20.34), the yield with the U.S. 10-Year Bond (17.56), the yield on the U.S. 5-Year Bond (25.3), the yield on the U.S. 3-Year Bond (19.78), and Silver (14.6), are the most significant net-transmitter of volatility for both short run and long run. Three markets experience the highest degrees of volatility: Greenex, Carbonex, and the foreign currency market. The market that experiences the most volatility is the foreign currency market. Regarding frequency bands, it is clear that volatility transmission in connection to the SP 500, the U.S. 10, 5,3-Year Bond yield, foreign exchange, and gold is predominantly driven by both short-run and long-run components. The SP 500 is used as a benchmark for transmitting volatility. On the other hand, it is essential to highlight that Greenex and Carbonex display heterogeneous volatility transmission characteristics. This indicates that they are only a net recipient of volatility in the short-run period.

Table 4.13. Average volatility connectedness

	Crude Oil	Aluminum	Gold	Silver	Copper	Natural. Gas	S&P 500	Russell 2000	NASDAQ100	US 10 YEARS	US 5 YEARS	US 3YEARS	GREENEX	CARBONEX	EUR.USD	JPY.USD	GBP.USD	CAD.USD	AUD.USD	FROM
Crude Oil	63.99	3.7	1.66	2.83	4.71	1.4	4.3	3.79	2.55	2.31	1.67	1.45	0.72	0.75	0.85	0.81	0.76	1.05	0.7	36.01
Aluminum	3.46	57.73	1.88	3.63	14.32	1.46	3.81	2.12	1.76	1.35	1.29	1.4	0.72	0.79	0.9	0.4	0.83	0.96	1.2	42.27
Gold	1.29	1.4	41.95	26.72	2.5	0.46	1.57	1.34	1.23	5.28	6.12	5.74	0.67	0.68	0.69	0.72	0.38	0.62	0.63	58.05
Silver	2.11	2.82	28.79	45.24	5.53	0.67	1.35	0.97	0.69	2.22	2.64	2.39	0.75	0.76	0.7	0.46	0.53	0.7	0.69	54.76
Copper	4.12	13.55	3.2	6.79	53.13	0.89	3.66	2.43	1.47	1.83	1.81	1.65	0.84	0.86	0.8	0.42	0.76	0.73	1.07	46.87
Natural. Gas	1.84	2.01	0.91	1.16	0.93	80.39	2.03	0.94	1.13	0.92	0.74	0.9	0.92	0.95	0.76	0.82	0.73	1.13	0.78	19.61
S&P 500	1.51	1.25	1.24	0.97	1	0.5	54.66	11.41	13.15	2.45	2.47	2.28	1.34	1.52	0.82	0.48	0.9	0.91	1.13	45.34
Russell 2000	1.95	1.37	1.3	0.92	1.63	0.61	33.92	29.73	13.66	2.93	2.86	2.53	1.4	1.43	0.61	0.47	0.83	0.87	0.97	70.27
NASDAQ100	1.18	1.17	1.22	0.72	1.1	0.54	40.66	13.61	25.63	2.7	2.71	2.45	1.11	1.16	0.73	0.48	0.77	0.86	1.19	74.37
US 10 YEARS	1.43	0.91	3.55	1.39	1.03	0.44	4.15	2.52	2.61	30.09	26.22	21.85	0.5	0.49	0.61	0.36	0.6	0.65	0.61	69.91
US 5 YEARS	1.07	0.85	3.84	1.48	1	0.44	3.66	2.35	2.5	24.79	28.46	26.11	0.48	0.46	0.53	0.36	0.51	0.48	0.63	71.54
US 3YEARS	0.93	0.88	3.77	1.4	0.9	0.58	3.29	2.11	2.28	21.99	27.89	30.51	0.44	0.41	0.6	0.37	0.52	0.47	0.65	69.49
GREENEX	1.17	0.81	1.03	0.83	1.08	0.55	3.76	2.13	2.12	1.17	0.77	0.69	41.55	37.44	0.92	0.75	0.95	0.99	1.29	58.45
CARBONEX	1.21	0.86	1.03	0.82	1.11	0.53	4.08	2.25	2.25	1.11	0.76	0.66	37	41.53	0.84	0.69	0.86	1.13	1.29	58.47
EUR: USD	0.98	1.3	5.26	3.73	1.94	0.63	2.34	1.19	1.03	2.08	2.91	3.37	0.93	0.81	39.55	5.31	12.24	5.8	8.59	60.45
JPY: USD	1.21	0.72	7.89	3.58	0.8	0.68	5.66	3.87	3.84	9.89	11.27	10.52	0.75	0.68	4.19	27.98	2.49	1.34	2.63	72.02
GBP: USD	1.46	1.24	3.19	2.79	1.98	0.66	2.75	1.38	0.55	1.37	1.63	1.86	0.96	0.9	13.92	3.04	45.72	6.04	8.56	54.28
CAD:USD	8.31	2.55	3.51	4.42	4.13	0.81	8.85	3.62	2.21	1.39	1.06	1.21	0.99	1.09	5	1.57	4.83	34.38	10.07	65.62
AUD:USD	2.19	2.7	5.13	5.18	4.54	0.67	6.82	2.81	2.3	1.69	2.01	2.2	1.42	1.38	7.46	2.72	6.59	9.46	32.74	67.26
TO	37.4	40.12	78.39	69.36	50.23	12.53	136.65	60.83	57.33	87.47	96.83	89.26	51.94	52.54	40.95	20.25	36.08	34.18	42.67	TACI
Net	1.4	-2.15	20.34	14.6	3.36	-7.08	91.31	-9.44	-17.03	17.56	25.3	19.78	-6.5	-5.93	-19.5	-51.78	-18.2	-31.44	-24.59	60.83/57.63

Notes: The results are based on a TVP-VAR model with a lag length of order one (BIC) and a 100-step-ahead generalized forecast error variance decomposition.

Table 4.14 Averaged volatility connectedness in the short run (1–5 traded days).

	Crude Oil	Aluminum	Gold	Silver	Copper	Natural. Gas	S&P 500	Russell 2000	NASDAQ100	US 10 YEARS	US 5 YEARS	US 3YEARS	GREENEX	CARBONEX	EUR.USD	JPY.USD	GBP.USD	CAD.USD	AUD.USD	FROM.1.5
Crude Oil	52.48	2.95	1.33	2.22	3.78	1.07	3.27	3.05	1.98	1.9	1.36	1.19	0.53	0.53	0.74	0.67	0.63	0.81	0.56	28.57
Aluminum	2.75	46.64	1.44	2.79	11.81	1.15	2.67	1.65	1.32	1.19	1.15	1.28	0.56	0.6	0.76	0.33	0.7	0.74	0.95	33.83
Gold	1.09	1.21	34.57	22.03	2.12	0.38	1.3	1.07	1.02	3.91	4.45	4.13	0.52	0.53	0.61	0.58	0.31	0.54	0.54	46.34
Silver	1.74	2.37	23.69	37.19	4.7	0.57	1.01	0.74	0.53	1.63	1.93	1.75	0.58	0.59	0.62	0.37	0.42	0.58	0.57	44.4
Copper	3.33	11.36	2.56	5.36	43.84	0.73	2.66	1.84	1.16	1.53	1.56	1.45	0.7	0.72	0.65	0.35	0.65	0.58	0.82	38.01
Natural. Gas	1.58	1.77	0.76	0.9	0.78	65.86	1.63	0.8	0.93	0.76	0.6	0.75	0.71	0.73	0.64	0.7	0.62	0.96	0.64	16.27
S&P 500	1.21	1.03	1.02	0.77	0.81	0.42	43.6	9.48	10.84	2.08	2.1	1.94	1.11	1.25	0.74	0.37	0.74	0.8	0.92	37.63
Russell 2000	1.52	1.14	1.11	0.74	1.29	0.5	27.39	24.2	11.35	2.52	2.46	2.2	1.17	1.2	0.54	0.32	0.69	0.73	0.77	57.65
NASDAQ100	0.94	0.97	1.02	0.64	0.88	0.44	33.17	11.32	20.86	2.22	2.31	2.09	0.91	0.98	0.65	0.38	0.63	0.77	1.02	61.34
US 10 YEARS	1.1	0.7	3.06	1.21	0.78	0.33	3.53	2.17	2.22	24.5	21.36	17.62	0.43	0.41	0.5	0.27	0.48	0.51	0.53	57.21
US 5 YEARS	0.81	0.7	3.27	1.3	0.77	0.36	3.01	1.98	2.07	20.33	23.25	21.11	0.42	0.4	0.45	0.27	0.41	0.38	0.52	58.57
US 3YEARS	0.7	0.74	3.21	1.22	0.7	0.48	2.67	1.78	1.88	18.11	22.84	24.75	0.37	0.34	0.51	0.29	0.41	0.39	0.51	57.16
GREENEX	0.68	0.57	0.88	0.66	0.8	0.38	2.1	1.39	1.29	0.81	0.6	0.56	31.72	28.24	0.69	0.57	0.71	0.66	0.81	42.4
CARBONEX	0.69	0.6	0.86	0.64	0.82	0.37	2.31	1.46	1.35	0.79	0.6	0.53	28.01	31.26	0.63	0.54	0.63	0.75	0.83	42.42
EUR: USD	0.87	1.08	4	2.91	1.47	0.53	1.77	0.94	0.77	1.59	2.24	2.56	0.69	0.55	32.16	4.18	9.94	4.49	7.01	47.57
JPY: USD	0.98	0.6	6.36	2.95	0.62	0.54	4.53	3.28	3.14	7.74	8.72	8.07	0.64	0.57	3.27	22.34	2.09	1.11	2.27	57.48
GBP: USD	1.14	1.01	2.51	2.11	1.54	0.54	1.94	1.06	0.44	1.01	1.31	1.52	0.68	0.6	11.15	2.54	36.96	4.54	6.87	42.51
CAD:USD	6.57	2.1	2.72	3.43	3.29	0.68	6.46	2.83	1.79	1.19	0.88	1.03	0.67	0.69	4.19	1.3	3.92	27.43	8.03	51.77
AUD:USD	1.76	2.26	4.08	4	3.57	0.54	4.79	2.1	1.77	1.3	1.6	1.78	0.97	0.9	6.07	2.24	5.42	7.37	26.64	52.53
TO	29.48	33.14	63.89	55.89	40.53	10.02	106.2	48.93	45.86	70.61	78.07	71.56	39.66	39.84	33.42	16.27	29.41	26.71	34.17	TACI
Net	0.91	-0.68	17.55	11.49	2.52	-6.26	68.57	-8.73	-15.48	13.4	19.51	14.41	-2.74	-2.58	-14.15	-41.21	-13.1	-25.06	-18.35	48.54/45.98

Notes: The results are obtained using a generalized forecast error variance decomposition founded on a TVP-VAR model. The BK-18 method is utilized to depict the frequency spectrum of the data.

Table 4.15 Averaged volatility connectedness in the long run (5-infinite traded days).																				
	Crude Oil	**Aluminum**	**Gold**	**Silver**	**Copper**	**Natural. Gas**	**S&P 500**	**Russell 2000**	**NASDAQ100**	**US 10 YEARS**	**US 5 YEARS**	**US 3YEARS**	**GREENEX**	**CARBONEX**	**EUR.USD**	**JPY.USD**	**GBP.USD**	**CAD.USD**	**AUD.USD**	**FROM.5.Inf**
Crude Oil	11.51	0.76	0.32	0.61	0.92	0.33	1.03	0.74	0.57	0.42	0.31	0.26	0.19	0.21	0.11	0.13	0.13	0.25	0.15	7.44
Aluminum	0.7	11.1	0.44	0.84	2.52	0.31	1.15	0.47	0.44	0.16	0.14	0.13	0.16	0.18	0.15	0.06	0.13	0.22	0.24	8.44
Gold	0.2	0.2	7.38	4.69	0.38	0.08	0.26	0.27	0.21	1.37	1.67	1.61	0.15	0.15	0.08	0.15	0.07	0.08	0.09	11.71
Silver	0.36	0.45	5.1	8.05	0.83	0.1	0.34	0.23	0.16	0.59	0.71	0.64	0.17	0.17	0.08	0.09	0.11	0.12	0.12	10.36
Copper	0.79	2.19	0.64	1.42	9.29	0.16	0.99	0.59	0.31	0.31	0.25	0.2	0.14	0.14	0.15	0.07	0.11	0.15	0.25	8.86
Natural. Gas	0.26	0.24	0.15	0.26	0.14	14.53	0.41	0.14	0.2	0.16	0.14	0.15	0.21	0.22	0.12	0.12	0.11	0.17	0.15	3.34
S&P 500	0.29	0.22	0.22	0.19	0.19	0.09	11.06	1.92	2.31	0.38	0.37	0.34	0.24	0.27	0.08	0.12	0.16	0.11	0.2	7.71
Russell 2000	0.44	0.24	0.19	0.18	0.33	0.11	6.54	5.53	2.31	0.4	0.4	0.33	0.24	0.23	0.07	0.14	0.14	0.14	0.19	12.61
NASDAQ100	0.24	0.21	0.2	0.08	0.22	0.1	7.5	2.29	4.77	0.48	0.41	0.36	0.2	0.18	0.08	0.1	0.14	0.09	0.17	13.03
US 10 YEARS	0.33	0.21	0.49	0.18	0.25	0.11	0.62	0.35	0.39	5.59	4.86	4.23	0.07	0.07	0.11	0.1	0.12	0.13	0.08	12.7
US 5 YEARS	0.25	0.15	0.56	0.19	0.23	0.08	0.65	0.37	0.43	4.47	5.21	5	0.06	0.06	0.08	0.08	0.1	0.09	0.11	12.97
US 3YEARS	0.22	0.15	0.56	0.18	0.2	0.1	0.63	0.33	0.4	3.88	5.05	5.76	0.07	0.06	0.09	0.08	0.11	0.09	0.14	12.33
GREENEX	0.48	0.25	0.16	0.18	0.28	0.17	1.65	0.74	0.83	0.35	0.17	0.13	9.83	9.2	0.23	0.18	0.23	0.33	0.47	16.04
CARBONEX	0.52	0.26	0.16	0.18	0.29	0.17	1.76	0.79	0.9	0.32	0.16	0.13	8.99	10.26	0.2	0.15	0.23	0.37	0.46	16.06
EUR: USD	0.11	0.23	1.26	0.81	0.48	0.1	0.57	0.25	0.26	0.5	0.67	0.81	0.24	0.26	7.39	1.13	2.3	1.3	1.59	12.87
JPY: USD	0.23	0.12	1.52	0.63	0.18	0.14	1.13	0.59	0.7	2.15	2.55	2.45	0.11	0.11	0.93	5.64	0.4	0.24	0.36	14.54
GBP: USD	0.32	0.23	0.68	0.68	0.45	0.12	0.82	0.32	0.11	0.35	0.32	0.34	0.27	0.3	2.77	0.51	8.77	1.49	1.69	11.76
CAD:USD	1.74	0.45	0.79	1	0.85	0.13	2.39	0.79	0.41	0.19	0.17	0.17	0.32	0.4	0.81	0.28	0.91	6.95	2.04	13.85
AUD:USD	0.44	0.44	1.04	1.18	0.97	0.13	2.03	0.71	0.52	0.39	0.41	0.42	0.45	0.47	1.38	0.48	1.17	2.09	6.1	14.73
TO	7.92	6.98	14.5	13.47	9.7	2.51	30.45	11.9	11.47	16.86	18.76	17.7	12.28	12.7	7.52	3.97	6.67	7.47	8.5	TACI
Net	0.49	-1.46	2.79	3.11	0.84	-0.83	22.74	-0.72	-1.55	4.16	5.79	5.37	-3.76	-3.35	-5.35	-10.56	-5.1	-6.39	-6.23	12.30/11.65

Notes: The results are obtained using a generalized forecast error variance decomposition founded on a TVP-VAR model. The BK-18 method is utilized to depict the frequency spectrum of the data.

Total Dynamic Connectedness

Our investigation begins by examining how the links between volatilities change across time., We observe the dynamic changes in the total average connectedness index (TACI) depicted within the black-shaded region and distinguish its immediate, denoted by the red-shaded area, and its enduring, signified by the blue-shaded area, characteristics. This allows for a comprehensive understanding of how this index evolves, both in the short and long term, illustrated in the green-shaded area. As we observe the shifts in volatility connections over time, there is a noticeable surge in the total average connectedness index (TACI) in late February 2020. This surge coincided with the rapid spread of the COVID-19 pandemic across the globe. It correlates with four consecutive declines in the U.S. stock market, followed by a decline in the oil market, believed to have swiftly spread market instability throughout the global financial market. We commence by examining total dynamic connectedness (TCI), which represents the dynamic changes in connectivity throughout the study period. Figure 4.3 provides a comprehensive overview, depicting not only the overall TCI evolution (highlighted in black) but also its breakdown into short-term (shown in red) and long-term (in blue) components. It's crucial to highlight that in this study, heightened levels of connectedness signify two key aspects: firstly, a synchronized movement of various crude oil types, and secondly, an increased potential for risk contagion within the network. Thus, identifying such movement patterns is integral to gaining insights into price differentials.

Figure 4 .3 shows how volatility (i.e., the magnitude of price fluctuations) spreads from one financial market to another over time. The figure shows a significant increase in volatility transmission in late February 2020, as the COVID-19 pandemic began to spread rapidly worldwide. This is not unexpected, given the Four consecutive market crashes in February and March 2020 and the subsequent oil market slump. These events are believed to have caused market turmoil to spread quickly through global financial markets. Volatility transmission has fallen sharply since its peak in March 2020, even though the

COVID-19 pandemic still evolves and poses a significant threat to human health and economic recovery.

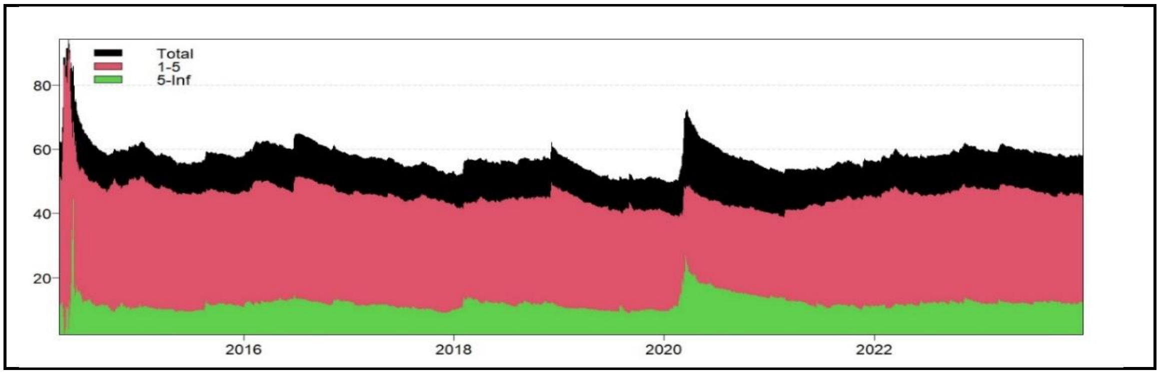


Fig 4.3 Total Dynamic Connectedness

The results shown in Figure 4.3 about the total TCI (highlighted in the black shaded area) demonstrate a significant reliance on events, with changing magnitudes ranging from around 50% to 75%. Significantly, there is a substantial surge towards the conclusion of 2014 and the commencement of 2015, accompanied by a noteworthy high in early 2020. The evidence indicates that markets remain highly integrated during these sample periods, with intermittent times of significant integration milestones. It is important to emphasize that when the high-frequency band controls the connection within the system, as is observed mainly during the sample period of our study, relevant markets quickly process information. Therefore, the transmission of shock within the network primarily happens in the immediate term, usually within a week.

Furthermore, research indicates that the lingering effects of previous shocks, specifically those that occurred within a timeframe of 6 to 100 days ago, do not have enough power to offset the impact of current market trends on interconnections. In contrast, if the low-frequency band controls the network's connectivity level, it is likely an indication of recent structural changes that occurred within a time frame of 6 to 100 days ago. Nevertheless, these alterations only become evident over a period when their consequences slowly emerge.

As we conclude this portion, it's essential to emphasize that while Figure 4.3 offers a valuable understanding of the prevailing dynamics linked to the dominance of either frequency band, the specific network variables driving shock transmission—whether in the short or long term—remain ambiguous. Hence, we aim to pinpoint the network elements acting as net transmitters and receivers in subsequent sections. Adopting this approach will enhance the clarity of the study's primary discoveries and streamline the derivation of insightful conclusions regarding the examined variables.

When volatility spillovers between markets are broken down into different periods, long-term spillovers have been the main driver during the global pandemic. This means that shocks to the financial system are taking longer to process and transmit, and investors' expectations about the future may have changed fundamentally (Wang et al., 2022). This finding is different from that of Ding et al. (2021), who found that short-term spillovers were the main driver, but it is consistent with that of Wang et al. (2022). According to Baruník and Krehlík (2018), uncertainty and systemic risk over the long term may increase.

Net Total Directional Connectedness

To summarize, Tables 4.13,4.14 and 4.15 and According to Figure 4.4, commodities like gold and Silver are responsible for more major market disruptions in terms of volatility than natural gas and oil are, which is true both in the short and long run. In the network of connectedness, these two commodities are responsible for transmitting a more significant number of volatility shocks to other commodities than they are receiving from other commodities. Moreover, the ongoing conflict between Russia and Ukraine has further strengthened the degree to which these two factors are tied. There are more significant market disruptions in terms of volatility in the equity market caused by the S&P 500 than by the Russell 2000 and the NASDAQ 100, both in the short and long run. This is because both the Russell 2000 and the NASDAQ showed significant disruptions in volatility before the COVID-19 event, as both of these markets transmitted volatility to others. However, after the COVID-19 event, the S&P 500 was the net receiver of volatility. While it is true that interest rates (the yield on U.S. bonds with maturities of 10, 5, and 3 years) are all transmitters of volatility, in the case of the foreign exchange market, all of the net receives the value of the volatility.

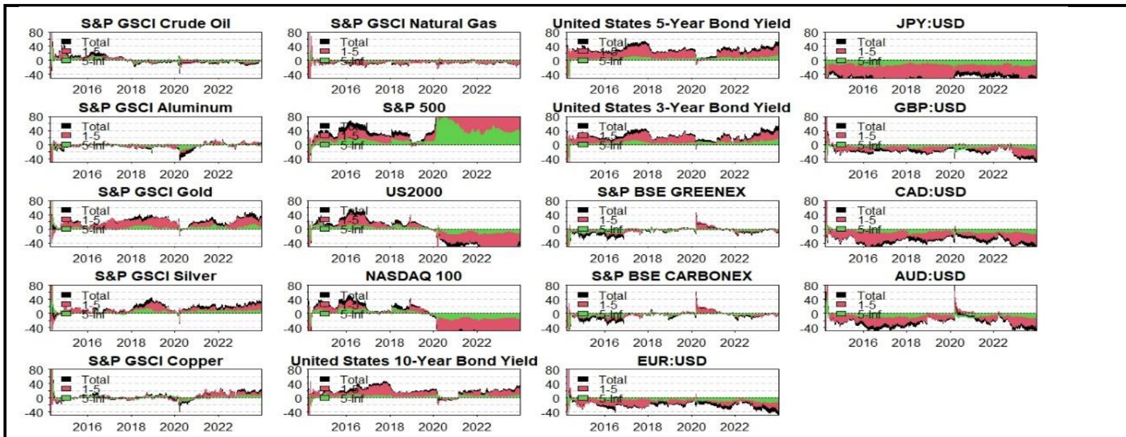
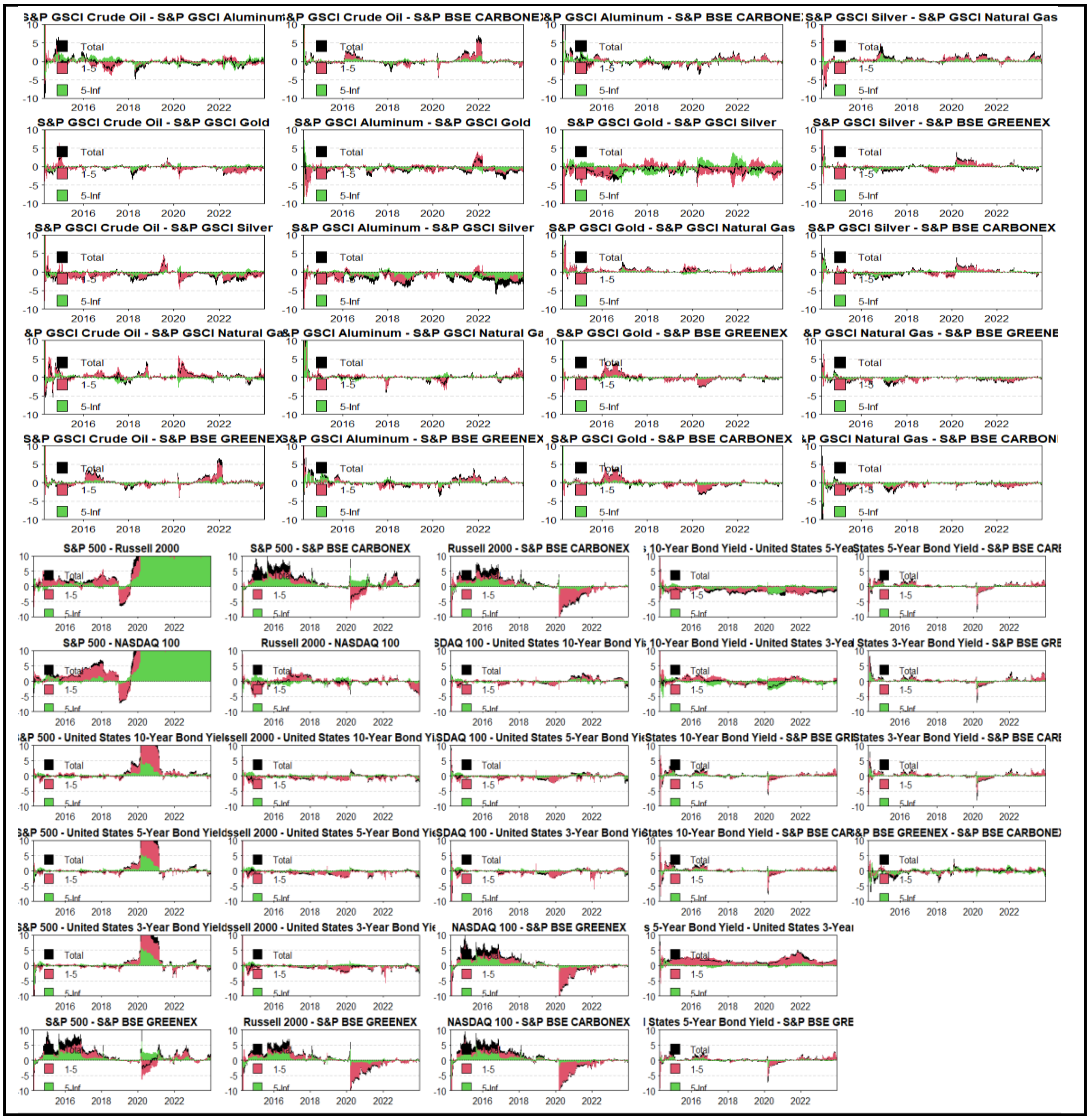


Fig 4.4 Net Total Directional Connectedness

Net Pairwise Connectedness

In times of uncertainty, such as the present COVID-19 epidemic and the conflict between Russia and Ukraine, it is essential to analyze the time variance of net pairwise directional interlinkages between different markets. In a significant way, the operation of these markets grows more constant over time. To conduct an in-depth examination of how the developments in the market influence the interdependence of short-term and long-term risks. An additional investigation into the interconnections, illustrated in Figure 4.5 using the net pairwise directional frequency connectedness, reveals that every variable is involved in trading operations. To evaluate the degree of pairwise connectivity, Gabauer (2021) developed a Pairwise connectivity Index (PCI), which assigns a number ranging from 0 to 100 to the degree of connectedness. Both the short-run and long-run connection may be detected with greater clarity when using the PCI. Fig. 4.5 presents these results. In commodities, crude oil was the net transmitter of volatility to Carbonex and Greenex during the crisis, especially during COVID-19, followed by copper, Silver, and gold as transmitters during the Chinese crisis. If we look at the equity market, all there are net transmitters during the crisis period. As per Tables 4.13,4.14, and 4.15, interest rates are the net transmitters, and forex are the net receivers of volatility spillover.


S&P GSCI Crude Oil - S&P GSCI Aluminum
S&P GSCI Crude Oil - S&P BSE CARBONEX
S&P GSCI Aluminum - S&P BSE CARBONEX
S&P GSCI Silver - S&P GSCI Natural Gas
S&P GSCI Crude Oil - S&P GSCI Gold
S&P GSCI Aluminum - S&P GSCI Gold
S&P GSCI Gold - S&P GSCI Silver
S&P GSCI Silver - S&P BSE GREENEX
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S&P GSCI Crude Oil - S&P GSCI Natural Gas
S&P GSCI Aluminum - S&P GSCI Natural Gas
S&P GSCI Gold - S&P BSE GREENEX
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S&P GSCI Crude Oil - S&P BSE GREENEX
S&P GSCI Aluminum - S&P BSE GREENEX
S&P GSCI Gold - S&P BSE CARBONEX
S&P GSCI Natural Gas - S&P BSE CARBONEX
S&P 500 - Russell 2000
S&P 500 - S&P BSE CARBONEX
Russell 2000 - S&P BSE CARBONEX
10-Year Bond Yield - United States 5-Year
States 5-Year Bond Yield - S&P BSE CARBONEX
S&P 500 - NASDAQ 100
Russell 2000 - NASDAQ 100
NASDAQ 100 - United States 10-Year Bond Yield
10-Year Bond Yield - United States 3-Year
States 3-Year Bond Yield - S&P BSE GREENEX
S&P 500 - United States 10-Year Bond Yield
Russell 2000 - United States 10-Year Bond Yield
NASDAQ 100 - United States 5-Year Bond Yield
States 10-Year Bond Yield - S&P BSE GREENEX
States 3-Year Bond Yield - S&P BSE CARBONEX
S&P 500 - United States 5-Year Bond Yield
Russell 2000 - United States 5-Year Bond Yield
NASDAQ 100 - United States 3-Year Bond Yield
States 10-Year Bond Yield - S&P BSE CARBONEX
S&P BSE GREENEX - S&P BSE CARBONEX
S&P 500 - United States 3-Year Bond Yield
Russell 2000 - United States 3-Year Bond Yield
NASDAQ 100 - S&P BSE GREENEX
5-Year Bond Yield - United States 3-Year
S&P 500 - S&P BSE GREENEX
Russell 2000 - S&P BSE GREENEX
NASDAQ 100 - S&P BSE CARBONEX
States 5-Year Bond Yield - S&P BSE GREENEX
Total
1-5
5-Inf

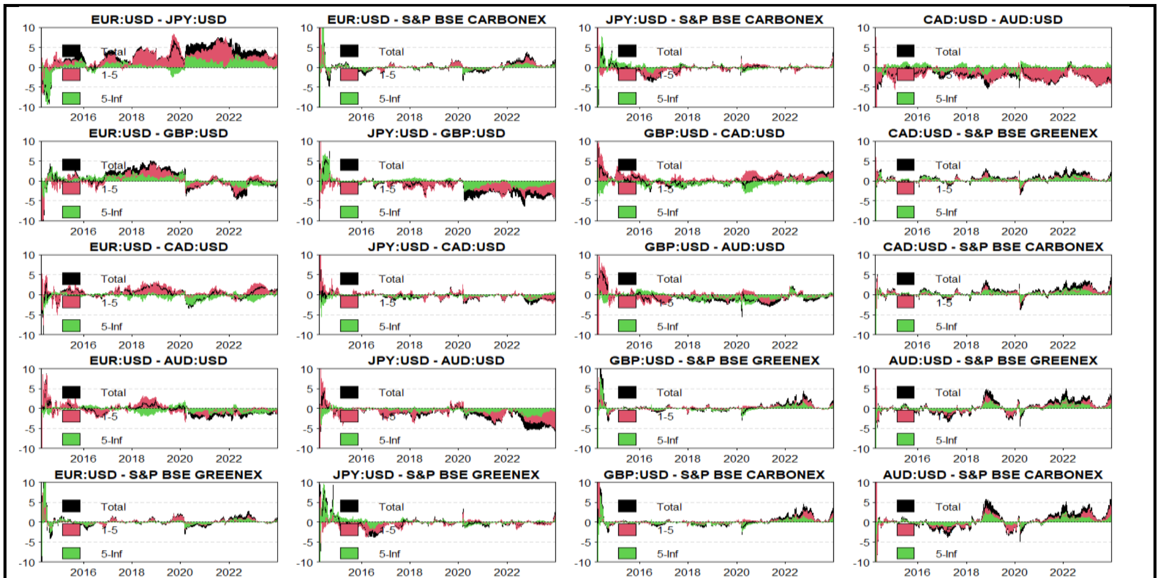


Fig 4.5 Net Pairwise Directional Connectedness

Conclusion

In the course of this investigation, we took into consideration the concept of a "common pool" for a variety of assets, including carbon and greens. Our goal was to do additional research into the degree of integration and the probability of risk-contagion within a network of factors. We implemented the dynamic connectivity technique predicated on a TVP-VAR model to accomplish this objective. The inspiration for this approach came from Antonakakis et al. (2020). We independently considered short-term and long-term network connectivity to identify events that had a moderately prolonged effect on the Carbonex and Greenex. This action was taken to ascertain occurrences that affected both of these systems. The authors, Barunık and Krehlık (2018), incorporated the notion of connectivity within two time periods: a low-frequency band, which spanned from 6 to 100 days, and a high-frequency band, which pertained to the course of five days. The primary results indicate that the market is highly integrated, as the overall dynamic connectedness consistently exceeds 50% and occasionally surges to approximately 70%.

Furthermore, the findings demonstrate that dynamic connectedness is exceedingly susceptible to external disturbances, suggesting that particular occurrences substantially impact it. The network of variables exhibits a relatively strong degree of interconnection, which indicates a considerable potential for risk-contagion. We established that, about the dynamics of both short-term and long-term connections, most of the connectedness during the study period occurred in the short term. This result suggested that variables, in addition to the network itself, respond rapidly to changes and rapidly process information pertinent to significant market developments.

On occasion, we noticed that short-term interconnectedness prevailed over the relevant underlying dynamics, including during specific periods spanning nearly the entire year of 2015, 2016 and 2020. The low-frequency band provided most of the network's overall connectivity, particularly around 2015, 2016 and 2020. Drawing upon these factors, we contend that the occurrences that transpired during that particular era were not merely developments that elicited a response (positive or negative) from all four markets; on the contrary, they significantly transformed the pre-existing interconnections and dynamics among the variables comprising the network. We subsequently analyzed net pairwise and net directional connectedness measures to determine the true nature of the interaction among the different markets. Every market variable can operate as a net transmitter or receiver within the network. An analysis of sporadic incidents that occurred during the study's sample period could offer valuable insights into the factors that influenced the gradual transition of different types between roles. Simultaneously, heightened ambiguity regarding the possible consequences of lockdowns on economic activity could account for the prevalence of long-term interdependence, which was emphasized by our net directional and net pairwise analyses.

4.3.3 Testing robustness by using Quantile frequency connectedness approach

In this analysis, we emphasize net connectedness outcomes to determine whether a typical market function as a net shock transmitter or receiver. This dynamic approach is distinct from earlier classifications, as it allows us to pinpoint shifts in each market's role over time. The roles of specific markets as net shock receivers or transmitters within the system vary based on the period and the particular market types within the studied network. In this study, we introduce a novel quantile frequency connectedness approach that facilitates the examination of propagation mechanisms by leveraging both quantiles and frequencies Presented in Table 4.16, Table 4.17 and Table 4.18. This innovative method enables the analysis of how various frequencies influence a given quantile, as well as how different quantile connectedness measures behave at specific frequencies. By integrating these two dimensions, the approach offers a more comprehensive understanding of the dynamic relationships between variables, capturing nuances that traditional models might overlook. This dual perspective is particularly useful for identifying and interpreting complex interactions and dependencies in time series data, thus providing deeper insights into the underlying economic or financial processes. We investigate the dynamic integration and volatility transmission among four well-established market risk indices: equity risk (represented by the S&P 500, NASDAQ 100, and Russell 2000), commodity risk (including crude oil, gold, silver, copper, natural gas, and Aluminum), forex risk (EUR: USD, JPY: USD, GBP: USD, CAD: USD and AUD: USD), and interest rate risk (represented by U.S. 10-year, 5-year, and 3-year bond yields), over the period from April 1, 2014, to December 31, 2023. This study aims to uncover the interconnections and the propagation of volatility across these diverse financial markets, with a specific focus on how these dynamics impact Green indices such as Carbonex and Greenex. By analyzing the interactions between traditional market risk indices and Green indices, we seek to provide a deeper understanding of how volatility in conventional financial markets influences and transmits to sustainability-focused indices over nearly a decade.

Net total and pairwise directional connectedness

In the equity market, the S&P 500 consistently acts as a net transmitter of shocks in both the short run and the long run. Conversely, the NASDAQ and Russell 2000 indices were net transmitters of shocks before the onset of the COVID-19 pandemic but became net receivers of shocks in the period following the pandemic. In the commodity market, crude oil was a net transmitter of shocks during the years 2014 to 2016 but transitioned to being a net receiver of shocks after that. Gold, copper, and silver consistently serve as net transmitters of shocks in both the short and long run. In contrast, aluminum and natural gas function as net receivers of shocks. Interest rates are net transmitters of shocks throughout the observed period. In the forex market, all currencies act as net receivers of shocks, indicating that they absorb rather than disseminate volatility within this market. This nuanced understanding of shock transmission across different financial markets and periods highlights the evolving nature of market dynamics, particularly in response to significant events such as the COVID-19 pandemic. At the same time, our main focus is on Carbonex and Greenex, as both are net receivers of shocks due to the Chinese crises and the Russia-Ukraine war.

Table 4.16 Average volatility connectedness

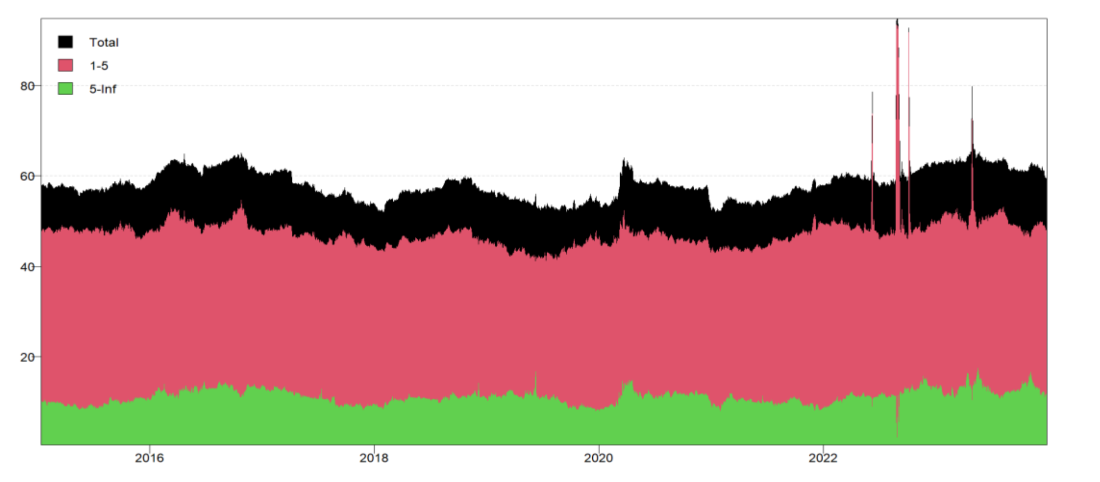
	Crude Oil	Aluminum	Gold	Silver	Copper	Natural Gas	S&P 500	Russell 2000	NASDAQ 100	US 10-Year	US 5-Year	US 3-Year	EUR:USD	JPY: USD	GBP:USD	CAD:USD	AUD:USD	GREENEX	CARBONEX	FROM.
Crude Oil	61.74	3.65	1.7	2.49	4.4	1.78	5.11	3.44	2.75	2.48	2.1	1.9	0.84	0.71	0.76	1.23	0.82	1.08	1.02	38.26
Aluminum	3.52	57.63	2.03	3.6	13.28	1.15	3.88	2.32	1.55	1.71	1.54	1.48	1.01	0.63	0.96	0.93	1.14	0.72	0.93	42.37
Gold	1.19	1.41	43.4	25.54	2.64	0.64	1.91	0.98	1.01	5.14	5.7	5.31	0.67	0.8	0.52	0.66	0.61	0.94	0.94	56.6
Silver	1.73	2.72	27.22	45.99	5	0.7	1.82	0.86	0.84	2.57	2.88	2.56	0.78	0.53	0.75	0.73	0.57	0.85	0.89	54.01
Copper	3.98	12.58	3.17	6.1	54.26	0.84	4.34	2.22	1.38	1.9	1.92	1.81	0.86	0.5	0.81	0.74	1.03	0.76	0.79	45.74
Natural Gas	2.11	1.64	1.37	1.5	1.39	76.41	2.4	1.05	1.18	1.3	1.38	1.37	1.02	1.17	1.15	0.84	0.75	0.98	0.99	23.59
S&P 500	1.73	1.4	1.4	1.02	1.27	0.59	54.86	11.03	12.36	2.43	2.38	2.39	1.19	0.73	0.98	0.81	0.96	1.19	1.28	45.14
US2000	1.94	1.52	1.39	1.03	1.61	0.63	37.31	27.84	11.51	2.89	2.78	2.47	0.93	0.64	1.08	0.86	0.94	1.29	1.34	72.16
NASDAQ 100	1.53	1.19	1.2	0.95	1.25	0.58	43.91	11.63	23.85	2.52	2.41	2.24	1.03	0.74	0.88	0.78	0.97	1.12	1.22	76.15
US 10-	1.44	0.9	3.75	1.62	1.06	0.55	4.68	2.43	2.18	30.32	26	21.27	0.63	0.39	0.65	0.44	0.5	0.58	0.6	69.68
US 5-Year	1.25	0.72	3.98	1.72	0.91	0.51	3.98	2.21	2.01	24.6	29.08	25.74	0.55	0.42	0.53	0.4	0.44	0.46	0.48	70.92
US3-Year	1.05	0.73	3.9	1.64	0.79	0.59	3.5	2.09	1.86	21.55	27.71	31.32	0.55	0.4	0.51	0.42	0.48	0.46	0.43	68.68
EUR:USD	0.91	1.45	6.56	4.77	2.49	0.83	4.06	1.63	1.2	2.53	3.85	4.23	36.81	3.94	10.24	4.85	7.36	1.17	1.1	63.19
JPY:USD	1.08	0.89	8.07	3.76	1.01	0.8	5.31	3.02	3.14	10.76	12.61	11.57	3.22	27.96	2.27	1.07	1.98	0.75	0.73	72.04
GBP:USD	1.17	1.24	3.92	3.29	2.33	0.82	4.02	1.67	0.75	2.08	2.6	2.84	11.82	2.71	44.74	4.78	7.01	1.12	1.09	55.26
CAD:USD	7.88	2.71	4.15	4.48	4.33	0.8	10.05	3.59	2.21	1.95	1.88	1.98	4.47	1.45	4.04	33.47	8.55	0.98	1.05	66.53
AUD:USD	2.55	2.81	5.83	5.64	4.65	0.75	8.92	3.02	2.45	2.32	2.78	3	6.37	2.14	5.35	7.84	30.4	1.59	1.58	69.6
GREENEX	1.22	0.86	1.27	0.97	1.27	0.61	3.36	1.71	1.94	0.79	0.87	0.81	1.04	0.79	1	1.16	0.84	42.79	36.69	57.21
CARBONEX	1.18	0.86	1.16	0.92	1.3	0.6	4.07	2.04	2.18	0.86	0.94	0.9	1.01	0.8	0.89	1.26	0.94	35.98	42.14	57.86
TO	37.45	39.3	82.07	71.06	50.98	13.76	152.64	56.93	52.5	90.39	102.33	93.88	38	19.51	33.37	29.78	35.89	52.01	53.16	1105
Net	**-0.81**	**-3.08**	**25.47**	**17.04**	**5.24**	**-9.83**	**107.49**	**-15.22**	**-23.65**	**20.7**	**31.42**	**25.21**	**-25.19**	**-52.53**	**-21.9**	**-36.75**	**-33.71**	**-5.21**	**-4.7**	**61.39/58.16**

Table 4.17 Averaged volatility connectedness in the short run (1–5 traded days).

	Crude Oil	Aluminum	Gold	Silver	Copper	Natural Gas	S&P 500	Russell 2000	NASDAQ 100	US 10-Year	US 5-Year	US 3-Year	EUR:USD	JPY:USD	GBP:USD	CAD:USD	AUD:USD	GREENEX	CARBONEX	FROM.1.5
Crude Oil	51.66	3.09	1.36	2.05	3.73	1.44	4.19	2.79	2.15	2.04	1.78	1.62	0.72	0.63	0.67	1.01	0.68	0.84	0.81	31.6
Aluminum	2.78	47.08	1.63	2.86	11.06	0.93	2.84	1.82	1.18	1.53	1.4	1.33	0.8	0.51	0.81	0.67	0.91	0.58	0.72	34.36
Gold	0.97	1.18	35.89	20.88	2.08	0.54	1.58	0.82	0.84	4	4.4	4.12	0.57	0.64	0.42	0.55	0.5	0.77	0.77	45.61
Silver	1.35	2.21	22.59	37.75	4.15	0.58	1.3	0.67	0.59	1.89	2.15	1.95	0.68	0.46	0.62	0.6	0.47	0.66	0.69	43.62
Copper	3.26	10.63	2.6	4.94	45.62	0.7	3.28	1.71	1.05	1.7	1.72	1.63	0.74	0.42	0.72	0.62	0.87	0.65	0.68	37.9
Natural Gas	1.81	1.39	1.11	1.14	1.17	63.47	1.98	0.9	0.98	1.09	1.2	1.18	0.86	1.01	0.96	0.72	0.63	0.75	0.78	19.64
S&P 500	1.44	1.15	1.14	0.81	1.04	0.52	45.58	9.2	10.25	2.06	2.08	2.08	1.05	0.6	0.79	0.7	0.86	1.05	1.15	37.96
US2000	1.62	1.29	1.17	0.79	1.3	0.54	30.92	22.43	9.31	2.5	2.44	2.17	0.84	0.5	0.89	0.75	0.82	1.12	1.18	60.13
NASDAQ 100	1.26	0.95	0.96	0.74	1.02	0.5	36.41	9.5	19.27	2.13	2.11	1.95	0.91	0.61	0.72	0.67	0.86	1	1.1	63.42
US 10-	1.15	0.71	3.17	1.34	0.82	0.43	3.98	2	1.83	24.88	21.54	17.45	0.53	0.33	0.5	0.33	0.43	0.48	0.49	57.52
US 5-Year	0.95	0.57	3.36	1.45	0.69	0.41	3.36	1.79	1.64	20.25	24.07	21.16	0.48	0.37	0.41	0.3	0.37	0.38	0.4	58.34
US3-Year	0.79	0.58	3.26	1.37	0.59	0.46	2.85	1.68	1.53	17.82	22.96	25.77	0.45	0.34	0.38	0.32	0.39	0.37	0.34	56.49
EUR:USD	0.8	1.18	5.1	3.72	1.93	0.75	3.03	1.26	0.93	2.06	3.1	3.34	30.09	3.14	8.44	3.72	5.89	0.94	0.85	50.18
JPY:USD	0.92	0.76	6.56	3.03	0.77	0.65	4.37	2.53	2.54	8.77	10.29	9.43	2.54	22.72	1.94	0.87	1.63	0.6	0.58	58.78
GBP:USD	0.93	1	3.12	2.52	1.9	0.7	3.14	1.25	0.58	1.69	2.27	2.45	9.59	2.29	36.61	3.64	5.74	0.81	0.8	44.42
CAD:USD	6.49	2.22	3.2	3.47	3.57	0.7	8.01	2.77	1.76	1.64	1.64	1.69	3.7	1.24	3.23	26.8	6.93	0.76	0.8	53.82
AUD:USD	2.08	2.33	4.59	4.27	3.7	0.64	6.87	2.22	1.86	1.89	2.3	2.51	5.18	1.77	4.48	6.03	24.86	1.22	1.2	55.14
GREENEX	0.91	0.63	1.08	0.76	0.99	0.51	2.12	1.05	1.18	0.61	0.72	0.67	0.8	0.63	0.81	0.83	0.61	33.13	28.17	43.09
CARBONEX	0.86	0.62	0.98	0.72	1.04	0.5	2.67	1.28	1.33	0.65	0.77	0.73	0.78	0.65	0.72	0.9	0.68	27.83	32.51	43.71
TO	30.37	32.46	66.97	56.87	41.54	11.5	122.89	45.27	41.53	74.32	84.86	77.49	31.23	16.12	27.51	23.2	29.27	40.81	41.52	895.74
Net	-1.22	-1.9	21.35	13.25	3.64	-8.15	84.93	-14.87	-21.89	16.81	26.52	21	-18.95	-42.66	-16.91	-30.62	-25.87	-2.27	-2.19	49.76/47.14

Table 4.18 Averaged volatility connectedness in the long run (5-infinite traded days).

	Crude Oil	Aluminum	Gold	Silver	Copper	Natural Gas	S&P 500	Russell 2000	NASDAQ 100	US 10-Year	US 5-Year	US 3-Year	EUR:USD	JPY:USD	GBP:USD	CAD:USD	AUD:USD	GREENEX	CARBONEX	FROM.5.Inf
Crude Oil	10.09	0.57	0.34	0.44	0.67	0.33	0.92	0.65	0.61	0.44	0.32	0.28	0.12	0.08	0.09	0.21	0.14	0.24	0.21	6.66
Aluminum	0.74	10.55	0.41	0.75	2.21	0.22	1.04	0.49	0.37	0.18	0.14	0.15	0.22	0.12	0.15	0.26	0.22	0.13	0.21	8.01
Gold	0.22	0.23	7.51	4.66	0.56	0.09	0.33	0.16	0.17	1.14	1.3	1.18	0.1	0.16	0.1	0.12	0.11	0.17	0.17	10.99
Silver	0.38	0.5	4.63	8.23	0.85	0.12	0.52	0.19	0.25	0.68	0.73	0.61	0.1	0.07	0.14	0.13	0.1	0.19	0.2	10.39
Copper	0.72	1.95	0.58	1.16	8.64	0.14	1.06	0.5	0.34	0.2	0.2	0.18	0.12	0.08	0.09	0.12	0.17	0.11	0.11	7.84
Natural Gas	0.3	0.26	0.26	0.37	0.22	12.94	0.42	0.15	0.2	0.21	0.18	0.19	0.16	0.17	0.19	0.13	0.12	0.23	0.21	3.95
S&P 500	0.29	0.25	0.27	0.21	0.23	0.07	9.27	1.83	2.1	0.36	0.31	0.32	0.14	0.13	0.19	0.12	0.1	0.14	0.13	7.18
US2000	0.32	0.24	0.22	0.24	0.31	0.09	6.38	5.41	2.21	0.39	0.33	0.3	0.09	0.14	0.2	0.11	0.13	0.17	0.17	12.02
NASDAQ 100	0.27	0.24	0.23	0.21	0.23	0.07	7.5	2.14	4.58	0.39	0.3	0.29	0.11	0.13	0.16	0.1	0.1	0.12	0.12	12.73
US 10-	0.28	0.2	0.58	0.28	0.24	0.12	0.7	0.43	0.35	5.43	4.46	3.81	0.11	0.06	0.15	0.11	0.07	0.1	0.11	12.17
US 5-Year	0.3	0.16	0.62	0.27	0.23	0.1	0.62	0.42	0.37	4.35	5.01	4.58	0.08	0.05	0.12	0.1	0.07	0.08	0.08	12.57
US3-Year	0.26	0.16	0.64	0.27	0.2	0.13	0.66	0.41	0.34	3.72	4.75	5.55	0.1	0.07	0.13	0.11	0.09	0.08	0.08	12.19
EUR:USD	0.11	0.27	1.46	1.05	0.56	0.09	1.03	0.37	0.27	0.48	0.76	0.88	6.72	0.81	1.8	1.13	1.47	0.23	0.25	13.01
JPY:USD	0.16	0.13	1.51	0.72	0.24	0.16	0.95	0.48	0.6	1.99	2.32	2.14	0.68	5.25	0.34	0.2	0.35	0.15	0.14	13.26
GBP:USD	0.24	0.25	0.8	0.76	0.44	0.13	0.88	0.42	0.16	0.39	0.33	0.39	2.23	0.42	8.12	1.14	1.27	0.31	0.3	10.84
CAD:USD	1.38	0.49	0.96	1.01	0.76	0.1	2.04	0.82	0.45	0.31	0.24	0.3	0.77	0.22	0.81	6.67	1.62	0.22	0.24	12.71
AUD:USD	0.47	0.48	1.24	1.37	0.95	0.12	2.05	0.8	0.58	0.43	0.48	0.49	1.19	0.37	0.87	1.8	5.54	0.36	0.39	14.46
GREENEX	0.31	0.23	0.19	0.21	0.28	0.1	1.24	0.66	0.76	0.18	0.16	0.14	0.24	0.16	0.18	0.33	0.23	9.65	8.52	14.13
CARBONEX	0.32	0.24	0.17	0.19	0.26	0.1	1.4	0.75	0.85	0.21	0.17	0.17	0.22	0.15	0.17	0.36	0.26	8.15	9.63	14.15
TO	7.07	6.84	15.1	14.18	9.44	2.27	29.75	11.67	10.97	16.06	17.47	16.39	6.77	3.39	5.86	6.57	6.62	11.19	11.64	209.26
Net	0.41	-1.17	4.11	3.79	1.6	-1.68	22.57	-0.35	-1.76	3.9	4.9	4.2	-6.25	-9.87	-4.99	-6.13	-7.84	-2.93	-2.51	11.63/11.01



Notes: The results are derived from a QVAR model that uses a rolling window size of 200 days, a lag length determined by the Bayesian Information Criterion (BIC), and a generalized prediction error variance decomposition for a 100-step-ahead forecast. The black region depicts the values of time dynamic connectivity, while the Red and blue regions illustrate the long-term and short-term outcomes, respectively. The provided lines depict the outcomes of the conventional VAR time and frequency domain connectivity technique.

Fig 4.6 Net Total Directional Connectedness

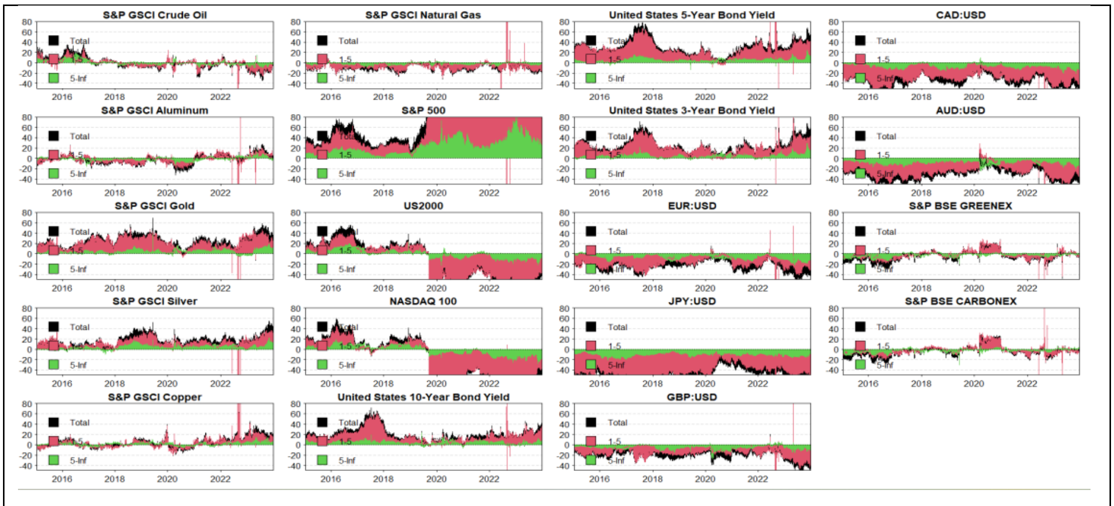


Fig 4.7 Net Pairwise Directional Connectedness

Conclusion

The robustness check conducted using Quantile Connectedness analysis confirms the findings of the Time-Varying Parameter Vector Autoregressive (TVP-VAR) model, highlighting the presence of short-run spillover effects from market risk variables to green stocks. This conclusion underscores the nuanced dynamics between these two entities, particularly in periods of market turbulence or uncertainty. By employing these sophisticated econometric techniques, we can draw several important insights that are pivotal for both investors and policymakers concerned with sustainable finance and market stability.

Firstly, the confirmation of short-run spillover effects suggests that green stocks, often perceived as relatively insulated due to their distinct market characteristics and investor base, are nonetheless susceptible to broader market risk fluctuations. This vulnerability indicates that green investments cannot be entirely decoupled from traditional market forces, contrary to some theoretical expectations. For investors, this finding underscores the importance of incorporating market risk assessments into their investment strategies for green assets rather than assuming an inherent buffer against market-wide shocks.

Secondly, the use of Quantile Connectedness analysis has provided a more granular understanding of the spillover dynamics across different market conditions. By examining the distribution of spillover effects across various quantiles, we gain insight into how extreme market conditions—both booms and busts—affect the relationship between market risk and green stocks differently. This aspect of the analysis reveals that during extreme market conditions, the spillover intensity can vary significantly, which has critical implications for risk management and portfolio diversification strategies.

Moreover, the confirmation of these spillover effects through two robust methodologies—TVP-VAR and Quantile Connectedness—adds a layer of reliability to our findings. It demonstrates the consistency of the results, reinforcing the credibility of the observed spillover phenomenon. This methodological rigor is essential for academic research and provides a solid foundation upon which subsequent studies can be built. For practitioners, this consistency enhances confidence in the application of these findings to real-world scenarios, aiding in the development of more resilient investment frameworks.

From a policy perspective, the observed spillover effects between market risk and green stocks highlight the need for regulatory frameworks that can mitigate the potential adverse impacts of market volatility on sustainable investments. Policymakers should consider these dynamics when designing regulations aimed at promoting green investments, ensuring that such regulations are robust enough to withstand market-wide disruptions. Additionally, the insights gained from this analysis can inform the creation of targeted financial instruments or support mechanisms to protect green stocks during periods of heightened market risk.

In conclusion, the combined use of TVP-VAR and Quantile Connectedness methodologies has provided a comprehensive and robust analysis of the short-run spillover effects from market risk to green stocks. The consistency of the results across these two approaches underscores the susceptibility of green investments to broader market dynamics, especially in the short run. For investors, this highlights the importance of integrating market risk considerations into their green investment strategies. For policymakers, it signals the need for regulatory measures that can shield green investments from market volatility, thereby fostering a more stable and sustainable financial environment. As the market for green stocks continues to grow, understanding and mitigating these spillover effects will be crucial f or achieving long-term sustainability and economic stability.

4.4. Wavelet Analysis

4.4.1. Wavelet Coherence

Wavelets are also known as discrete wavelets. This is one of the most exciting distinctions that can be made between the two. With the assistance of wavelet coherence, it is possible to analyze the coherence (correlation) between two time series at different frequencies. In this particular scenario, we can make use of it to determine whether or not the price movements in the four distinct markets (the equity market, the commodity market, the foreign exchange market, the interest rate market) and the green stock market (Carbonex and Greenex) correspond at multiple time scales (short-term versus long-term). When it comes to the frequency domain, typical correlation analysis only considers the general movement of the data. Wavelet coherence provides a more comprehensive perspective by drawing attention to how the interaction between the markets evolves across several periods (frequency ranges). When attempting to identify potential links, it is possible that the presence of solid coherence in particular frequency ranges could suggest a price discovery link between the markets in those periods. As an illustration, a high degree of coherence in the short-term frequencies would indicate that short-term price changes in markets contribute to the influence of green stocks.

One type of wave function is known as a wavelet, and it can be identified by the fact that it generally has a value of zero throughout its entire range. The duration of wavelets is finite, meaning they have a beginning and an end, in contrast to sinusoids, which have an infinite lifetime. Discrete wavelets are another name for wavelets at times. Among the many distinctions that can be drawn between the two, this is one of the most fascinating considerations. A valuable technique for extracting crucial features from signals to recreate them without maintaining or retaining the complete signal, wavelets are a strategy that can be utilized during this process. The utilization of wavelets is what allows for this to be performed. The non-stationarity associated with financial time series can be overcome with wavelets, which also offer additional benefits that help in this regard. According to A'Hearn and Woitek (2001) and Pakko (2004), adding the frequency component of time series data is essential to comprehend the co-movement at various frequencies. This can be accomplished by incorporating the frequency component.

Due to its significant feature extraction capabilities, the discrete wavelet transform (DWT) is employed in a wide range of applications, including signal processing and financial time series. Unlike the Fourier transform, the wavelet transform is distinguished because it enables simultaneous analysis of the frequency components of financial time series and the time component. This is in contrast to the Fourier transform, which only allows for the analysis of the time component. Considering this, a wavelet is an efficient instrument that may be utilized in the financial industry to deal with severely irregular time series. There are some benefits that can be gained from using wavelet analysis. Because of this, it is not essential to engage in the practice of making an informed assumption on the data generation procedure. In addition to its information, it also includes information in the frequency domain. The capability to discover any gaps or discontinuities in the data is another advantage of using this tool. Because of the increased volatility in the global financial market, there has been a greater emphasis placed on examining the links between financial markets and other factors during times of crisis. This is because these linkages have been found to exist during times of crisis. The introduction of shocks from one country to another leads to the formation of links between different markets. Because of the significant interdependence between the spot market and the futures market, this is especially true during times of difficulty within the market. The degree of dependency or contagion between various markets has increased from the time before the crisis to the time of the crisis. This rise can be attributed to the fact that the situation has occurred.

Even though it provides insights on similar series behaviors at various frequencies and time points, the Wavelet Power Spectrum (WPS) does not explicitly address the issue of contagion directly. A cross-analysis technique, Wavelet Coherence (WTC), has been developed to fill this existing hole. The WTC not only offers an estimate of the phase spectrum but also detects lead-lag correlations, which indicate which series affects another series. For example, the WTC can determine which series affects another series. 5% is the level considered necessary, and the white outlines reflect that level. A key element to remember is that the wavelet transform is performed to finite time series, which causes edge distortions. This is something that must be taken into consideration. However, during the analysis process, it is necessary to disregard these distortions, which are depicted in the areas of the image that are blurry on the extreme right and left. People mean this when they talk about the "cone of influence." Since the cone of influence represents the region affected by randomness, it is recommended that this region be excluded from consideration throughout the investigation.

There are variants in the series, which are shown by the color code in the graphic. In terms of the intensity of variations, the color red signifies a high level of power, whereas the color blue indicates a low level of control. The phase differences between the two series are represented by the direction in which the arrows point. The presence of arrows pointing to the right indicates that the variables are in phase, which suggests that information is being transmitted from one market system to another. The first market index is in the lead if the arrows point upward and to the right. If, on the other hand, the arrows point downward, the first index will be behind while the other variable will be ahead. Variables that are out of phase and have anti-cyclical effects are indicated by arrows pointing to the left. With the arrows pointing left and up, the first index is in the lead, while the arrows pointing left and down are in the lag.

Through the process of plotting the wavelet coherence results for each pair, we can investigate the dependency that already exists between the different marketplaces. The wavelet coherence analysis between the two signals is displayed concurrently in both the time and frequency domains. This analysis is performed simultaneously. One could consider coherence to be the same thing as a correlation. In contrast, a value of zero implies no correlation between the two signals, while a value of one suggests a strong connection between them. Something that needs to be deemed attractive exists between the two signals. The time and frequency scales are expressed along the Y and X axes, respectively. Both of these scales are expressed throughout time. In the context of the time-frequency domain, the cycles are typically categorized as follows: the short-scale (16-32 and 32-64 day cycles), the medium-scale (64-128 day cycles), and the long-scale (128-256 day cycles) cycles.

Right-Up (↗): This suggests that the first series leads the second series, but they are positively correlated (i.e., both move in the same direction).

Left-Up (↖): This suggests that the first series leads the second series, but they are negatively correlated (i.e., they move in opposite directions).

Right Arrow (→): This indicates that the two time series are in-phase, meaning they move together at the same frequency. When one series increases, the other series also increases, and vice versa.

Left Arrow (←): This indicates that the two time series are anti-phase, meaning they move in opposite directions at the same frequency. When one series increases, the other series decreases, and vice versa.

Right-Down (↘): This suggests that the first series lags behind the second series, but they are positively correlated.

Left-Down (↙): This suggests that the first series lags behind the second series, but they are negatively correlated.

Up Arrow (↑): This indicates that the first time series leads the second time series by 90 degrees.

Down Arrow (↓): This indicates that the second time series leads the first time series by 90 degrees.

4.4.2. Wavelet coherence of Commodity market with Carbonex and Greenex

According to the wavelet coherence plot, the red areas suggest a significant connection between the Crude Oil and Carbonex and Greenex indices at specific periods and frequencies. This connection is substantial enough to justify attention. Right-Up (↗): This suggests that the first series leads the second series in case of Crude Oil with Carbonex, but they are positively correlated (i.e., both move in the same direction).while as Right Arrow (→): This indicates that the two time series are in-phase, meaning they move together at the same frequency. When one series increases, the other series also increases, and vice versa in the case of crude oil with Greenex.. The middle frequencies are where these zones are found in exceptionally high concentrations. There are also blue regions on the wavelet coherence map, which indicates a little link between the Crude Oil and the Carbonex index and Greenex index. A substantial portion of the blue region is focused on the higher frequencies (about a period of 250) and is located on the left side of the plot. It may be argued from this that the two indices exhibit low coherence at those time scales, meaning their frequency content is dissimilar in the short term.

In the figure, the arrows represent the phase angle between the two-time series. Within the context of wavelet coherence plots, the arrows indicate the direction of progression from the lagging series to the leading series. According to the results of (Fig 4.4.1), the arrows appear to be heading from Crude Oil to Carbonex and Greenex in the medium and higher frequencies, which fall around 2020. This case shows that crude oil was ahead of Carbonex and Greenex during those eras. During COVID-19, the red regions that are concentrated around 1000 to 2000 indicate that the maximum degree of coherence(Highest Covariance Year) between Crude Oil with Carbonex and Greenex most likely happened between one and two years ago.

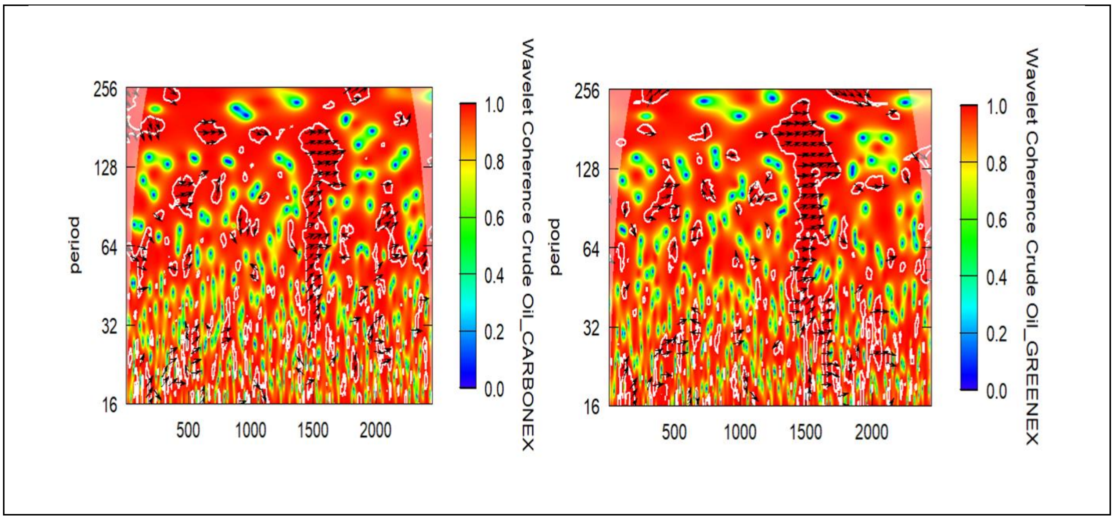


Fig 4.4.1. Wavelet coherence of Crude oil with Carbonex and Greenex

According to the wavelet coherence in Fig 4.4.2, the red areas suggest a significant connection between the Gold and Carbonex at specific periods and frequencies. This connection is substantial enough to justify attention. The blue color on the wavelet coherence map indicates a link between the Gold and Carbonex. A significant portion of the blue region is focused on the higher frequencies (about a period of 250) and is located on the left side of the plot. Right-Up (↗): This suggests that the first series leads the second series in case of Gold with Carbonex, but they are positively correlated (i.e., both move in the same direction).while as in case of gold with Greenex the relation exist in 2016 Left-Up (↖): This suggests that the first series leads the second series, but they are negatively correlated (i.e., they move in opposite directions).

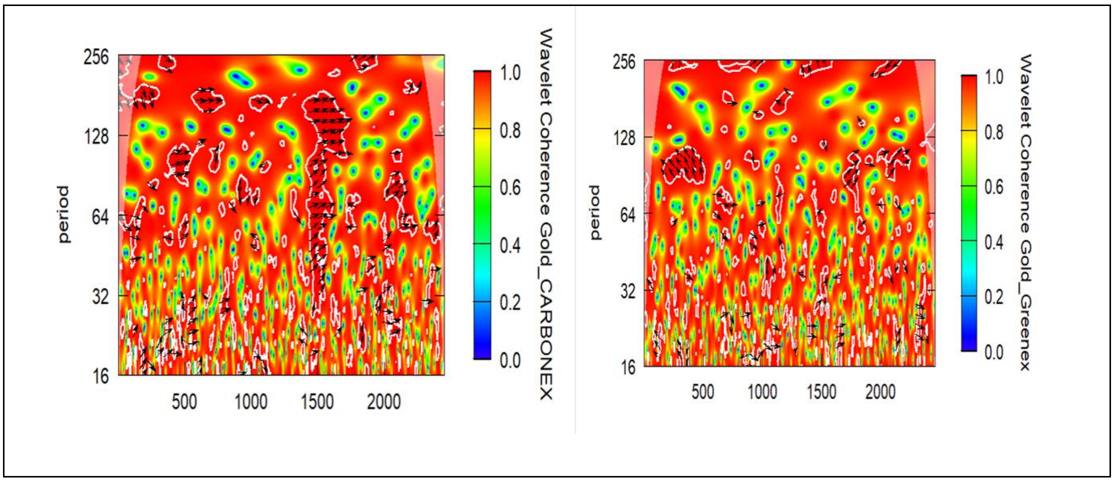


Fig 4.4.2 Wavelet coherence of Gold with Carbonex and Greenex

The utilization of wavelet coherence analysis between gold prices and environmental indices, more specifically Carbonex and Greenex, in (Fig 4.4.2) has yielded significant insights into the behavior of these markets during significant global crises, particularly the Chinese financial crisis that occurred in 2015 and the COVID-19 pandemic that occurred in 2020. During both crises, the coherence analysis demonstrates a significant volatility increase at medium and large-scale periods for both gold and Carbonex. This increased volatility reflects the severe economic uncertainty and market disruptions that these events have created. Interestingly, the analysis between gold and Greenex reveals no significant fluctuations, except for brief periods of high frequency in specific years. This contrasts the coherence between gold and Carbonex, demonstrating a transparent relationship with gold leading, indicating that gold plays a role as a safe-haven asset during economic turmoil. The evidence presented here suggests that while gold may be used as a hedge against the volatility of financial markets, its impact on markets focused on the environment, such as Greenex, is relatively minor. The short-term swings seen in the year 2020, notably in the aftermath of the COVID-19 breakout, help to highlight the rapid and severe reactions of financial markets to sudden disruptions that occur all over the globe. This highlights how important it is to have a profound understanding of the interrelationships and dynamics of markets, especially during volatility, to properly drive investment strategies and risk management approaches.

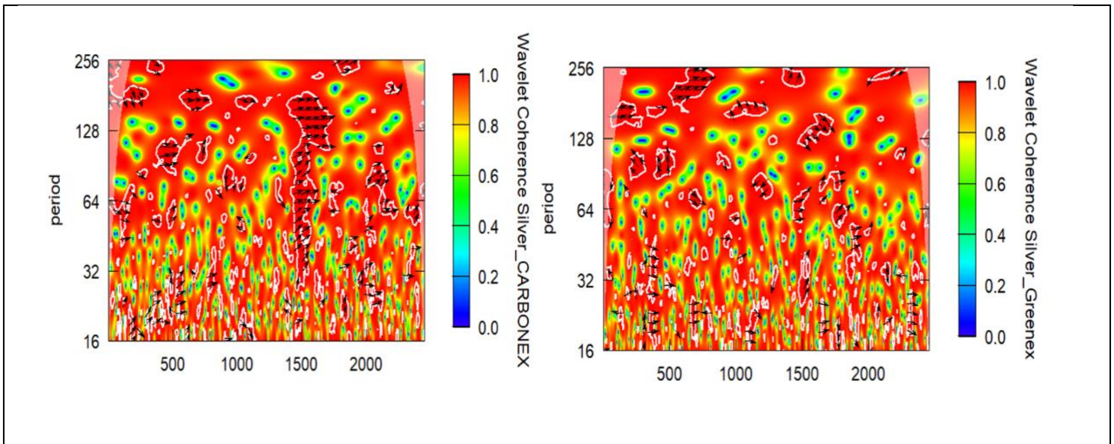


Fig 4.4.3. Wavelet coherence of Silver with Carbonex and Greenex

Right-Up (↗): This suggests that the first series leads the second series in case of silver with Carbonex, but they are positively correlated (i.e., both move in the same direction).while as in case of gold with Greenex the relation exist in 2016 In high frequency Right-Up (↗): This suggests that the first series leads the second series in case of silver with Carbonex, but they are positively correlated (i.e., both move in the same direction).otherwise there seems no relation of silver with greenex.The wavelet coherence analysis of Silver and two distinct indices—Carbonex and Greenex—in (Fig 4.4.3) during significant global events provides exciting insight into the relationship between Silver and these two indices. Silver and Carbonex exhibit substantial volatility over the medium and long term, particularly in 2015 and 2020, when the Chinese economic crises and the onset of the COVID-19 pandemic occurred, respectively. This indicates that fluctuations in these two assets are highly correlated during periods of financial uncertainty. Moreover, 2020 was marked by an increase in transient instability due to the COVID-19 pandemic, highlighting the significant impact that worldwide emergencies exert on market dynamics. It's also noteworthy that Silver appears to be leading Carbonex in the context of economic downturns, suggesting that Silver has a leading indicator role. The contrary is evident upon examining Silver's correlation with Greenex; aside from a few high-frequency intervals, there is no compelling indication of elevated volatility. This suggests that Silver's influence on Greenex is either very small or non-existent, which sharply contrasts Silver's relationship with Carbonex.

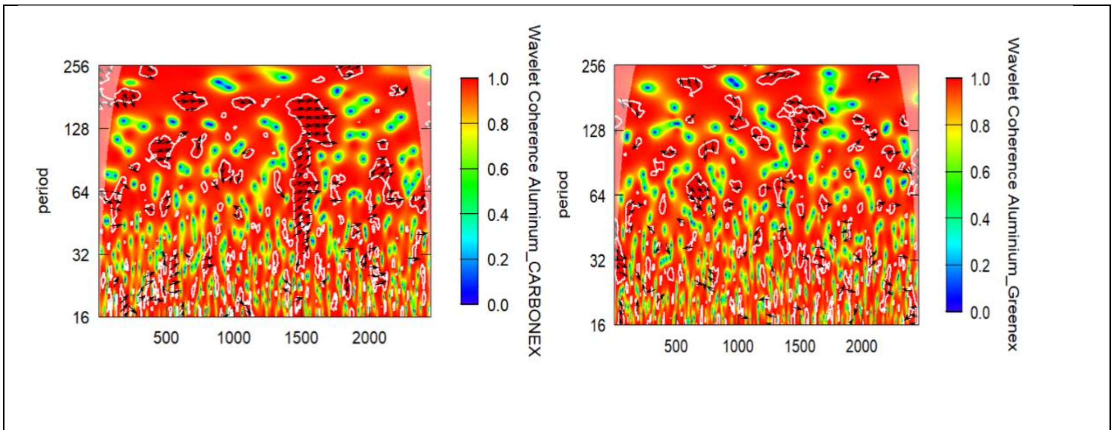


Fig 4.4.4 Wavelet coherence of Aluminium with Carbonex and Greenex

Fig 4.4.4 presents wavelet coherence analysis results that uncover fascinating patterns and correlations between two separate indices, Carbonex and Greenex and Aluminum. These patterns and correlations provide insight into the dynamic link between these indices during significant global events. During severe economic downturns, such as the Chinese financial crisis in 2015 and the COVID-19 pandemic in 2020, there was a notable rise in volatility over medium and long time horizons, according to an analysis of the relationship between Aluminium and Carbonex. This was most noticeable in 2015, particularly during the Chinese financial crisis. Aluminium is a crucial indicator of economic instability because of its susceptibility to shocks to the macroeconomics, which is highlighted by the circumstances described above. Right-Up (↗): This suggests that the first series leads the second series in case of Aluminium with Carbonex, but they are positively correlated (i.e., both move in the same direction).while as in case of Aluminium with Greenex the relation exist in 2020 In high frequency Right-Down (↘): This suggests that the first series lags behind the second series, but they are positively correlated.

Moreover, the analysis indicates that 2020 will witness a surge in short-term volatility coinciding with the onset of the COVID-19 issue, highlighting Aluminium's vulnerability to severe market fluctuations during uncertain times. Surprisingly, the Aluminium-Greenex relationship shows little sign of increased volatility other than sporadic high-frequency intervals. This demonstrates how little Aluminum affects Greenex and highlights how Aluminum affects other industries differently. Given that Aluminum is leading in Carbonex, the arrow's direction indicates that Aluminum serves as a leading indication of market movements, particularly in the industries that Carbonex covers. However, the fact that Aluminum has no discernible effect on Greenex shows its influence is restricted to particular economic sectors.

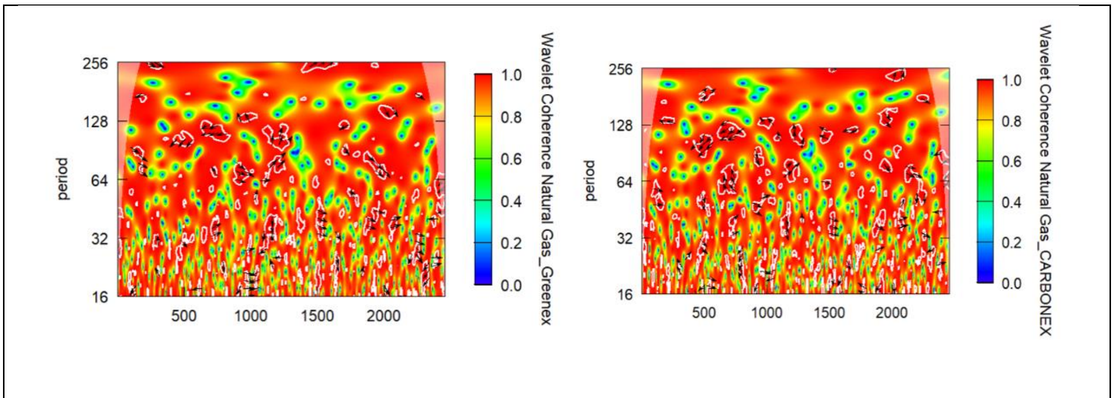


Fig 4.4.5 Wavelet coherence of Natural gas with Carbonex and Greenex

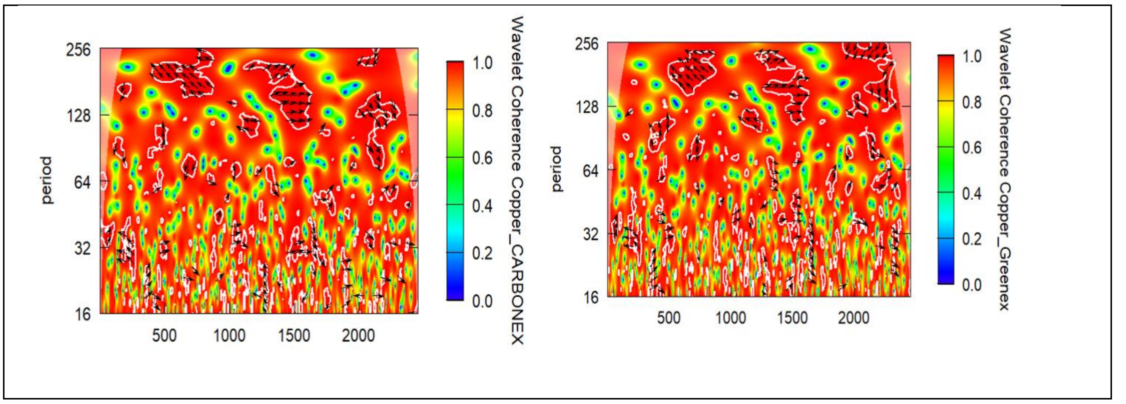


Fig 4.4.6 Wavelet coherence of Copper with Carbonex and Greenex

Regarding the dynamics of these interactions, particularly during significant global crises, wavelet coherence between copper with Carbonex and Greenex reveals some fascinating insights. The results in (Fig 4.4.6) demonstrate a substantial increase in volatility over long-term periods in the years 2015, 2020, and 2022, respectively. These years are characterized by the economic problems in China, the COVID-19 pandemic, and the conflict between Russia and Ukraine. The fact that this is the case indicates that the Copper-Carbonex-Greenex link is susceptible to disruptions in the macroeconomic environment, which may indicate the transmission of systemic risk. Furthermore, the increases in short-term volatility witnessed throughout these crises shed light on the acute reactions of the market and the fast modifications in investor mood that occur in response to shocks in the geopolitical and economic spheres. The increased volatility on both long and short scales during the COVID-19 epidemic and the conflict between Russia and Ukraine in 2022 further highlights the interdependence and fragility of global financial markets in the face of such turbulent occurrences. In case of copper with Carbonex and Greenexyears 2016 shows Left-Up (↖): This suggests that the first series leads the second series, but they are negatively correlated (i.e., they move in opposite directions).in year 2020 arrow direction Right-Up (↗): This suggests that the first series leads the second series, but they are positively correlated (i.e., both move in the same direction).during Israel-Hamas war direction is Right-Down (↘): This suggests that the first series lags behind the second series, but they are positively correlated.

4.4.3. Wavelet coherence of Equity market with Carbonex and Greenex

According to the wavelet coherence plotting (Fig 4.4.7), the red areas suggest a significant connection between the S&P 500 and Carbonex and Greenex indices at specific periods and frequencies. This connection is substantial enough to justify attention. The concentration of these regions can be seen in the middle and lower. This reflects the times when the two indices tended to travel together. The middle frequencies are where these zones are found in exceptionally high concentrations. There are also regions of blue color on the wavelet coherence map, which indicates a little bit of a link between the S&P 500 with the Carbonex index and the Greenex index. A substantial portion of the blue region is focused on the higher frequencies (about a period of 250) and is located on the left side of the plot. It may be argued from this that the two indices exhibit low coherence at those time scales, meaning their frequency content is dissimilar in the short term.

In (Fig 4.4.7), the arrows represent the phase angle between the two-time series. Within the context of wavelet coherence plots, the arrows indicate the direction of progression from the lagging series to the leading series. According to the results, the arrows appear to be heading from the S&P 500 to Carbonex and Greenex in the lower frequencies, which fall somewhere around observation 2000. This case shows that the S&P 500 was ahead of Carbonex and Greenex during those eras. During COVID-19, the red regions that are concentrated around 1500 to 2000 indicate that the maximum degree of coherence(Highest Covariance Year) between S&P 500 with Carbonex and Greenex most likely happened between one and two years ago. Right-Up (↗): This suggests that the first series leads the second series, but they are positively correlated (i.e., both move in the same direction) and Right Arrow (→): This indicates that the two time series are in-phase, meaning they move together at the same frequency. When one series increases, the other series also increases, and vice versa.

Interesting observations can be gathered from the analysis. Initially, the co-movement degrees between the S&P 500 and the Carbonex and Greenex markets were predominantly more vital. The presence of such dynamic correlation at high levels may indicate that shock transmission persists to a significant degree during turbulent periods. The same results are shown for Russell 2000 with Carbonex and Greenex as well as NASDAQ with Carbonex and Greenex in (Fig 4.4.8) and (Fig 4.4.9) as all three markets (S&P500, Russell 2000, and NASDAQ) are leading to Carbonex and Greenex during COVID-19. The short-term dependence is very low during the period under consideration. From these results, the magnitude of the integration of the GCC market with U.S. stock markets has changed over time. It is significantly affected by the occurrence of a crisis. Such results are supported by the results of previous studies by Brooks and Del Negro (2006), Madaleno and Pinho (2012), Graham et al. (2012), Akoum et al. (2012), Aloui and Hkiri (2014), Matar et al.(2021).

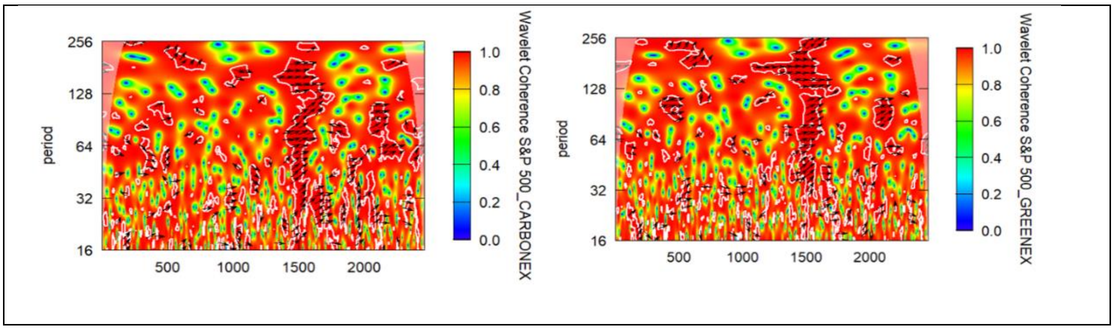


Fig 4.4.7. Wavelet coherence of S&P 500 with Carbonex and Greenex

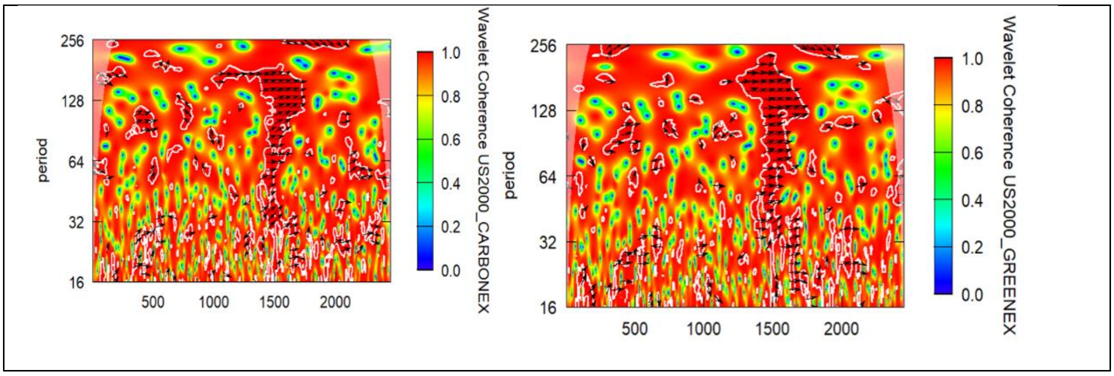


Fig 4.4.8. Wavelet coherence of Russell 2000 with Carbonex and Greenex

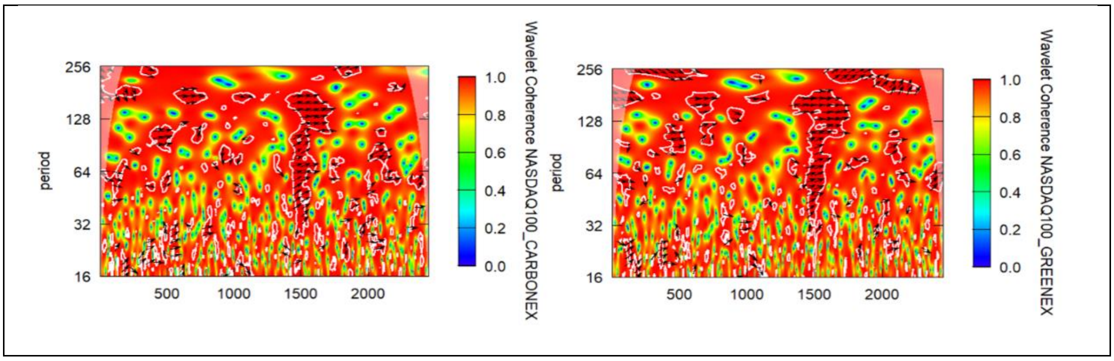


Fig 4.4.9. Wavelet coherence of NASDAQ-100 with Carbonex and Greenex

The wavelet coherence analysis between major U.S. stock indices (S&P 500, NASDAQ 100, Russell 2000) and Carbonex, Greenex reveals significant insights into market behaviors during major global crises. The analysis demonstrates patterns of high volatility across different time scales during the 2015 Chinese financial crisis and the 2020 COVID-19 pandemic. 2015, the Chinese financial crisis led to widespread economic perturbations that affected global markets. The wavelet coherence results show increased volatility at medium and long-term scales between the analyzed U.S. indices and Carbonex and Greenex during this period. This suggests that the impacts of the crisis were not only immediate but also had sustained effects over time, influencing investor behavior and market stability across these major indices and carbon markets. The prolonged volatility could be attributed to the global nature of the industries affected by these indices, which include sectors directly impacted by shifts in economic policy and international trade flows.

Conversely, the outbreak of COVID-19 in 2020 resulted in unprecedented short-term market shocks, reflected in the significant volatility at short-scale periods seen in the coherence analysis. This indicates the markets' rapid and volatile response to the immediate uncertainties and economic disruptions caused by global lockdowns and public health measures. The stark differences in volatility patterns during these crises highlight how different global events can distinctly influence market dynamics, affecting investment strategies and risk management across equity and carbon trading platforms.

4.4.4. Wavelet coherence of Forex rate with Carbonex and Greenex

In particular, using the technique of wavelet coherence between foreign exchange (forex) rates and Carbonex, Greenex in (Fig 4.5.10) has revealed intriguing insights into the behavior of these markets under global economic stresses. These insights have specifically highlighted distinct patterns during the Chinese financial crisis in 2015 and the COVID-19 pandemic in 2020. During 2015, China was going through a period of tremendous economic turmoil, characterized by significant currency devaluation and dramatic falls in the stock market. Both commodities and financial instruments all around the world were affected by these events, which caused ripples to spread across global markets. Over this year, the results of the wavelet coherence analysis reveal that there has been an increase in the volatility of the relationship between the currency exchange rates with Carbonex and Greenex at both medium and long scales. This may be due to shifts in economic expectations, policy reactions, and the global consequences of these factors. This indicates that there will be a more extended adjustment period and a high degree of interconnection between currency valuations and the green stock market. Majority of the currencies showing Right Arrow (→): during covid-19 in high frequencies, this indicates that the two time series are in-phase, meaning they move together at the same frequency. When one series increases, the other series also increases, and vice versa.

However, the COVID-19 pandemic dominated 2020, leading to unprecedented public health measures, such as travel restrictions and lockdowns, severely hampered global supply chains and trade. The wavelet coherence results during this timeframe showed notably substantial volatility between F.X. with Carbonex and Greenex at shorter scale periods. The financial markets reacted quickly and fiercely to the pandemic's beginning, as evidenced by this brief period of significant volatility. This also raised uncertainties about how the economy would recover. Volatility is typified by sharp declines in the stock market and substantial currency devaluation. These episodes knocked on global markets, impacting financial instruments and commodities worldwide. This suggests that there would likely be a long adjustment period and significant interdependence between currency values and sustainable stocks due to shifting expectations for the economy, governmental actions, and global consequences. Overall, this work highlights the interconnection and sensitivity of the F.X. with Carbonex and Greenex markets to international events. It also advances our understanding of market dynamics at different temporal scales during times of crisis. This knowledge is crucial for analysts, investors, and lawmakers navigating complex market behaviors during erratic times.

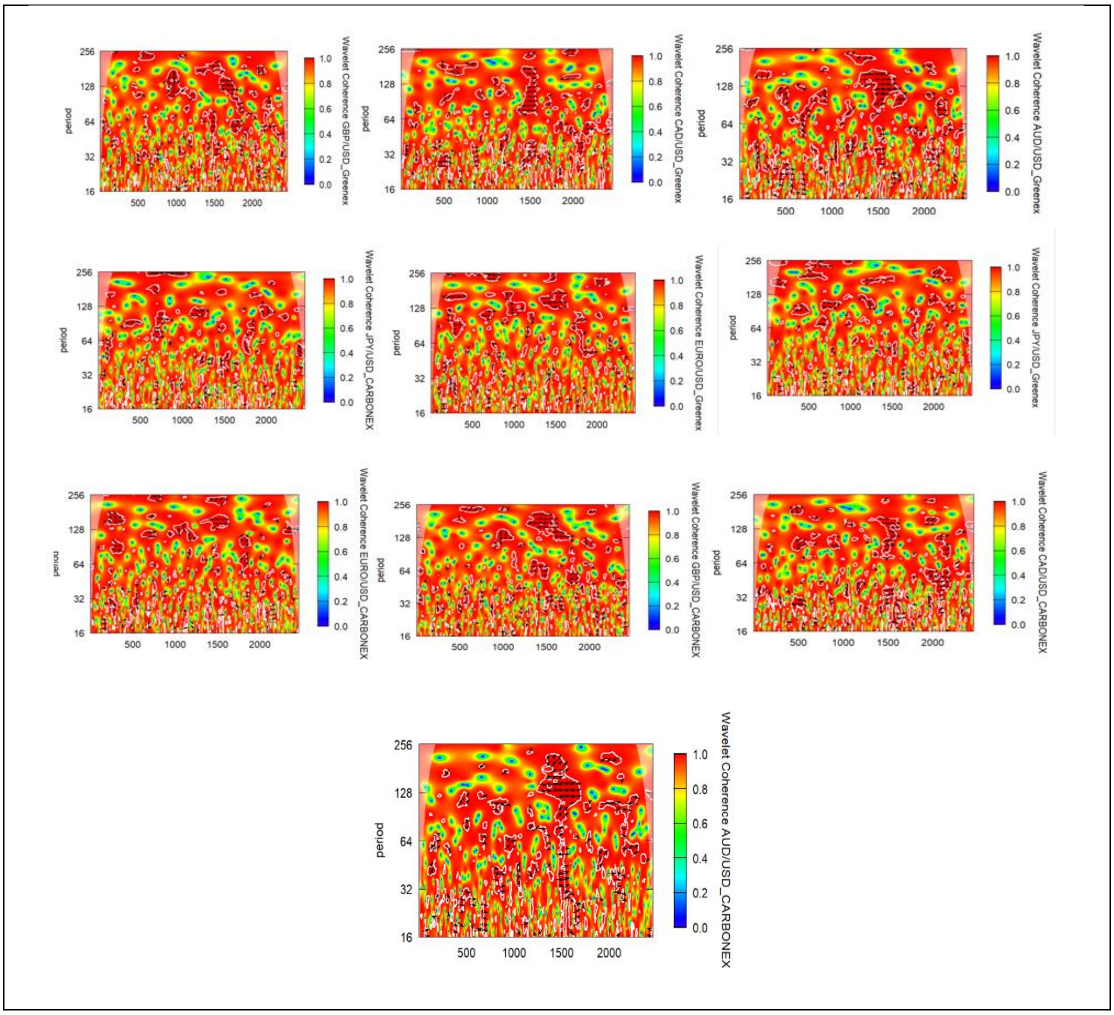


Fig 4.4.10 Wavelet coherence of Forex rate with Carbonex and Greenex

The efficacy of the wavelet coherence analysis between environmental indices such as Carbonex and Greenex and foreign exchange rates has been established to illustrate the substantial impact that global crises can have on market dynamics. The clear trends in volatility identified throughout the 2015 Chinese financial crisis and the 2020 COVID-19 pandemic emphasize the interdependence and receptiveness of these markets to significant economic disruptions. The direction of the arrows states that the Forex market is leading to sustainable stock. The Chinese financial crisis's medium- and long-term consequences point to a profound and ongoing influence on the world's financial and commodities markets. This implies that significant economic developments in critical nations like China may cause protracted periods of market adjustment and affect global economic expectations and governmental reactions. Such dynamics draw attention to the complex relationships between market indices sensitive to the environment and currency values.

On the other hand, The short-term volatility shown during the early stages of the COVID-19 outbreak reflects the rapid and acute reactions of markets to unanticipated and considerable global uncertainty. This volatility was seen throughout the early phases of the epidemic. It is evident that global supply chains are exceedingly fragile due to this rapid response, and it is also apparent that prompt public health measures play an incredibly essential role in companies' operations. These results contribute to a deeper comprehension of how various crises may have a distinct impact on the stability of the market and the behavior of investors. In addition to providing market analysts, investors, and policymakers with useful information, they highlight the need for solid financial plans that consider immediate repercussions and longer-term market changes in reaction to global events. During times of considerable economic hardship, having this expertise is necessary to navigate the intricacies of linked global markets successfully.

4.4.5. Wavelet coherence of Interest rate with Carbonex and Greenex

The recent financial crisis has proved that the interdependence of financial markets is more significant than ever. Changes in price in one market can quickly and readily impact another. To gain a deeper understanding of the dynamic structure that underpins markets and pricing, it is crucial to consider them together. As a result of the critical implications that it has for various aspects of finance, including asset allocation, portfolio management, risk management, and monetary policy transmission, investors, portfolio managers, corporate managers, and policymakers need to have a solid understanding of the interrelationships that exist between interest rates and stock prices. According to the principles of financial theory, a correlation exists between variations in interest rates and returns experienced by stock investors.

Furthermore, modern financial theory postulates that every firm generates a stream of future cash flows and that the stock value of that company is equal to the present value of all expected future cash flows discounted at the appropriate discount rate. This proposition is based on the assumption that every company generates a stream of future cash flows. It does not matter what kind of business it is; this truth holds. Regarding the impact of interest rates on stock prices, there are primarily two different channels through which this occurs. Interest rate changes directly influence the discount rate, which is a component of traditional stock valuation models. This is because the variations directly influence the discount rate in interest rates. Interest rate changes affect the expectations that companies have for future cash flows because they alter the cost of borrowing money. This is the second reason why interest rate fluctuations have an influence. Because of this, it is anticipated that interest rates will significantly impact the values of stocks. This is because of the circumstances described above.

Figure 4.4.11 shows that the co-movement patterns of the U.S. 10-year, 5-year, and 3-year bonds are remarkably comparable, particularly in the significance levels of each bond. This is particularly evident within the wavelet coherencies. It is important to note that data suggests that the movements of Carbonex and Greenex in the years 2015 and 2020 are led by the 10-year, 5-year, and 3-year bonds issued by the United States. The correlation between interest rates and the stock market has remained consistent throughout the data period. However, it has a propensity to be more evident at times of market instability, such as the Chinese crisis in 2015 or, more precisely, the recent worldwide pandemic issue that became apparent in 2020. Both of these examples are examples of market instability. In addition, it has been found that the significant association between changes in yields on bonds with maturities of ten, five, and three years, as well as returns on Carbonex and Greenex, is predominantly focused at investment horizons ranging from one to two years. Researchers established this. On the other hand, the correlation could be more robust regarding investment horizons that are less than a month and a half. Right-Up (↗): This suggests that the first series leads the second series, but they are positively correlated (i.e., both move in the same direction). Right Arrow (→): This indicates that the two time series are in-phase, meaning they move together at the same frequency. When one series increases, the other series also increases, and vice versa.

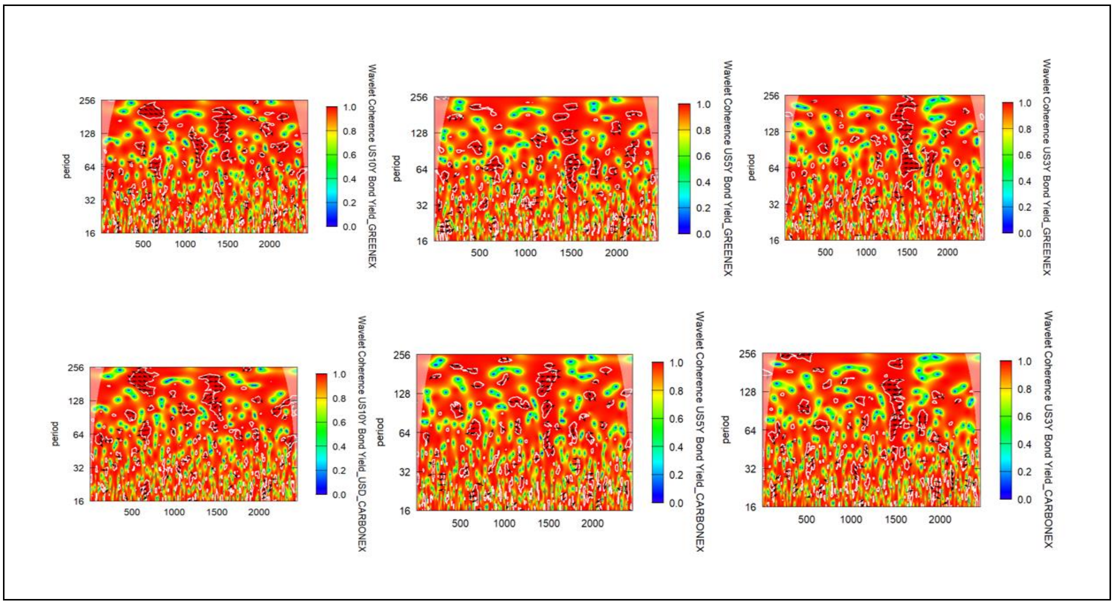


Fig 4.4.11 Wavelet coherence of United States 10-Year, 5-Year, and 3-Year Bond Yield with Carbonex and Greenex

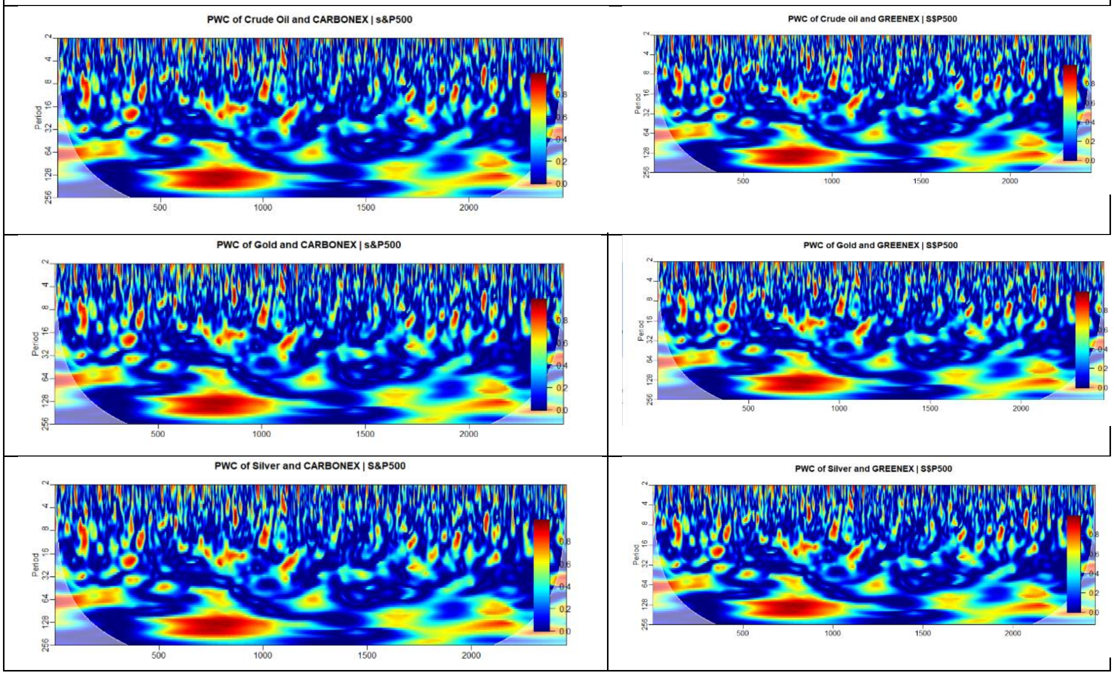
4.4.6. Robustness testing

To ensure the robustness of our findings, we use wavelet correlation and partial wavelet coherence (PWC) approaches in this research. As with partial correlation, partial wavelet coherence is especially helpful in removing the impact of shared elements that could influence the relationship between two separate data series. By eliminating other factors from the connection between the series, this technique allows us to concentrate more precisely on their direct relationship. The outcomes of our estimates of partial wavelet coherency can be seen in Figures 1 through 6. The thick white lines in these pictures show the "cone of influence." This cone shows parts of the data that might be impacted by edge effects, which can change the research close to the data set's edges. For a visual representation, we use a color transition from blue to red to show how strong the link is or how much power it has. Red areas show strong associations, which means that the factors being studied are strongly linked.

On the other hand, blue areas show weak associations, which means they have a weaker or non-existent link. This color coding makes it easy to find trends and see how strong the connections are across various periods and conditions in the data. Looking at these slopes helps us understand how associations change over time, which gives us more information about the processes we are looking into. This more nuanced method lets us look more closely at how variables affect each other and how they might change in response to different outside factors or over time.

For instance, in our analysis, we looked at how commodities behaved independently of the S&P 500's effect using PWC to examine the relationship between commodities and sustainable indices like Carbonex and Greenex. Figure 4.4.12 shows the outcomes of this analysis. Here, we can observe that there seems to be a considerable association between these indices—highlighted in red—during major global events like the COVID-19 pandemic and the Russia-Ukraine conflict. This implies a robust connection at these junctures. However, this association is not evident on other scales, suggesting that the relationship may be event-specific or impacted by outside political or economic forces. With the aid of PWC, we can extract more profound insights into the dynamics of various financial indexes and comprehend how significant events might impact their interrelationships while accounting for the more general market movements reflected in the S&P 500. Our research is strengthened by this methodological approach, which also offers a more precise picture of how these indices interact in different scenarios. Except for a few scales, the results produced via PWC are in excellent agreement with wavelet coherence.

Partial wavelet coherence (PWC) approaches between commodities and Carbonex, Greenex



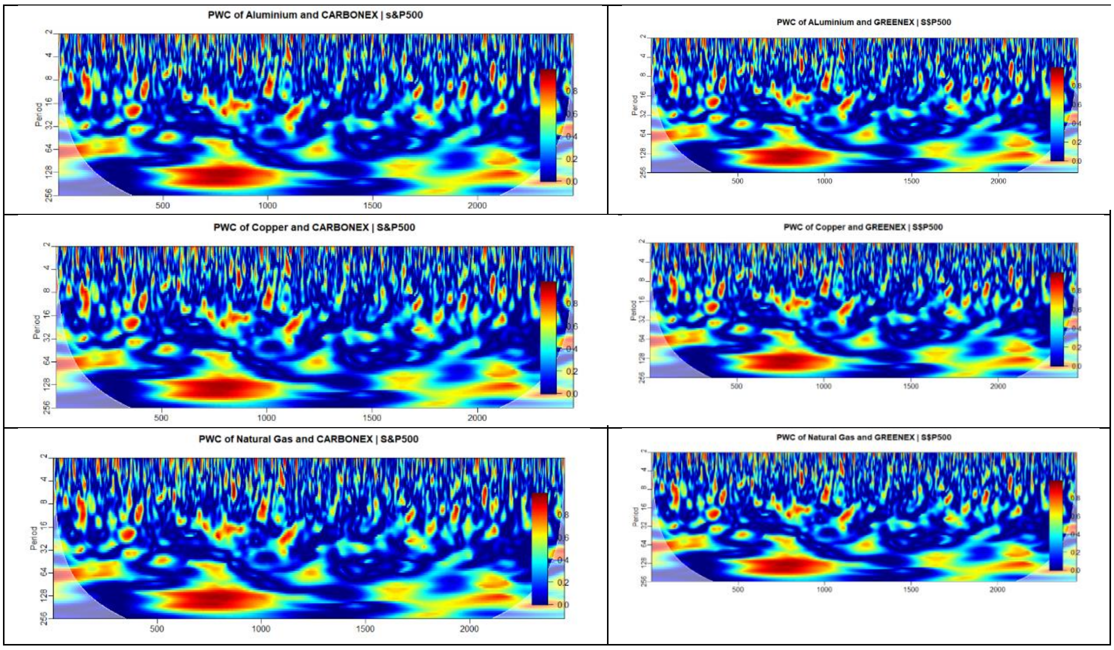


Fig 4.4.12 Partial wavelet coherence (PWC) approaches between commodities and Carbonex, Greenex

Furthermore, a graphic representation in Fig 4.4.13 provides the partial correlation between the equity markets (S&P 500, Russell 200, and NASDAQ 100) and Carbonex and Greenex. The NASDAQ 100 and the S&P 500 are not considered, which results in the correlation being spread across several scales. The partial association between the breakout of COVID-19 and Russia's invasion of Ukraine is diverse, which is a crucial point to keep in mind. It has been discovered that there is a correlation on a significant scale during the peak of the COVID-19 outbreak because the PWC of Equity markets (including the S&P 500, Russell 200, and NASDAQ 100) and Carbonex and Greenex are considered. Even with the COVID-19 outbreak and the invasion of Russia and Ukraine, however, other scales are not found to correlate with the outbreak. Identical results are obtained from partial wavelet coherence between interest rates (10-year, 5-year, and 3-year) with Carbonex and Greenex in Fig 4.4.14. Except for a few scales, the results produced via PWC are in excellent agreement with wavelet coherence.

Partial wavelet coherence (PWC) approaches between the Equity market and Carbonex, Greenex.

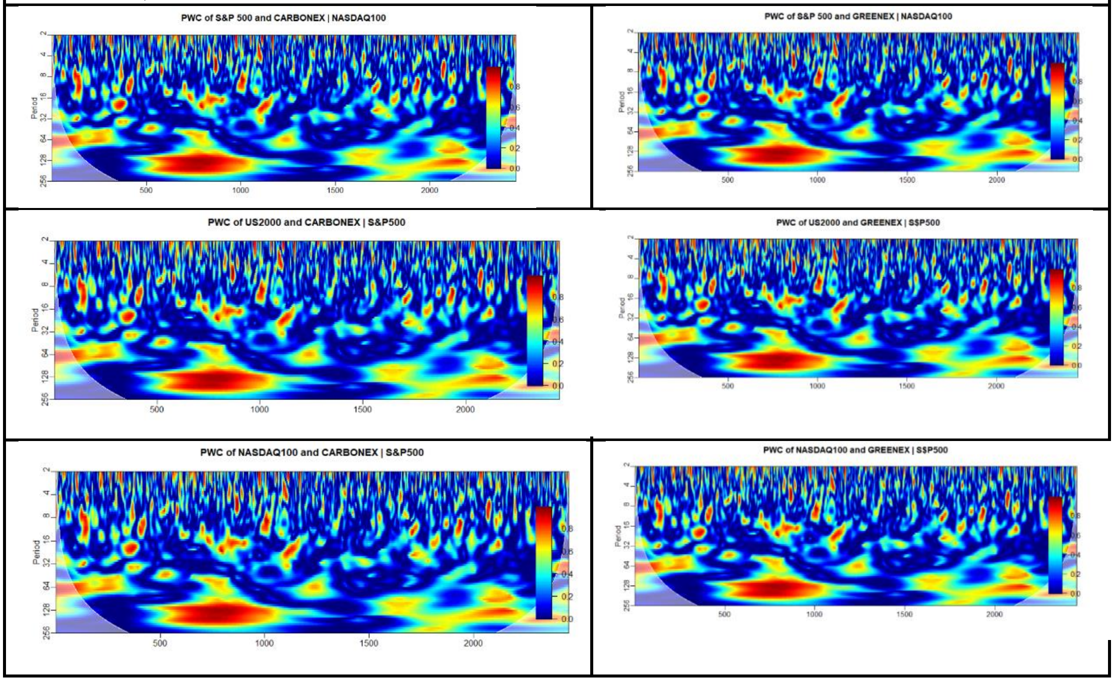


Fig 4.4.13 Partial wavelet coherence (PWC) approaches between the Equity market and Carbonex, Greenex

When applied between exchange rates and sustainability indices (GreenEx, CarbonEx), the partial wavelet coherence (PWC) analysis in Fig 4.4.15 reveals significant insights into frequency-domain relationships during specific global events, most notably the COVID-19 pandemic and the Russia-Ukraine war. This is accomplished by controlling for the influence of the S&P 500. According to the wavelet coherence plots, the highlighted red areas in the high-frequency bands show that short-term swings in the exchange rates and these environmental indices are more pronounced during these geopolitical and global health problems. This is demonstrated by the fact that the red areas are highlighted. This finding suggests that exchange rates are more sensitive to changes in environmental policy and economic expectations about Greenex and Carbonex markets when times are chaotic. More significant uncertainty and fluctuations in investor sentiment are characteristics of such periods mirrored in the volatility of financial markets. These periods are characterized by greater volatility. The redness observed in higher frequencies during COVID-19 indicates rapid adaptations to the sudden shifts in energy consumption patterns and participation in economic activities. Additionally, during the conflict between Russia and Ukraine, the dependence may be affected by worries regarding energy security and the anticipated modifications in industries highly dependent on carbon for their production.

Partial wavelet coherence (PWC) approaches between Interest rates and Carbonex, Greenex.

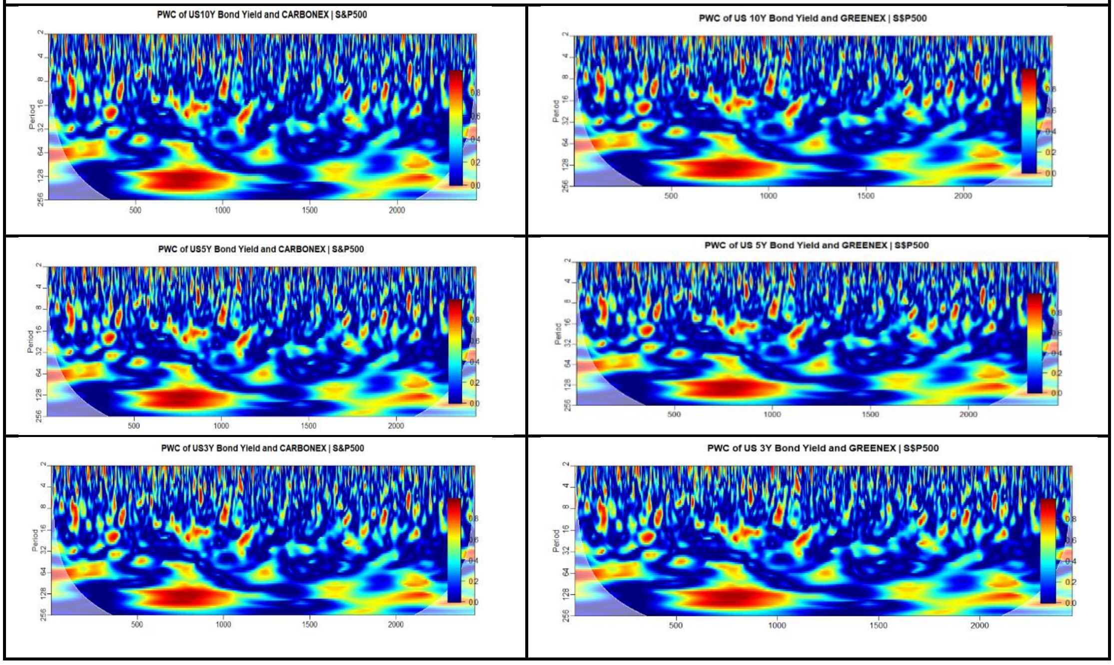
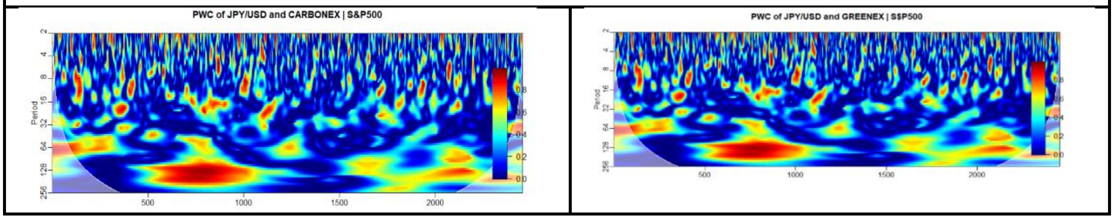


Fig 4.4.14 Partial wavelet coherence (PWC) approaches between Interest rates and Carbonex, Greenex

Partial wavelet coherence (PWC) approaches between Forex market and Carbonex, Greenex.



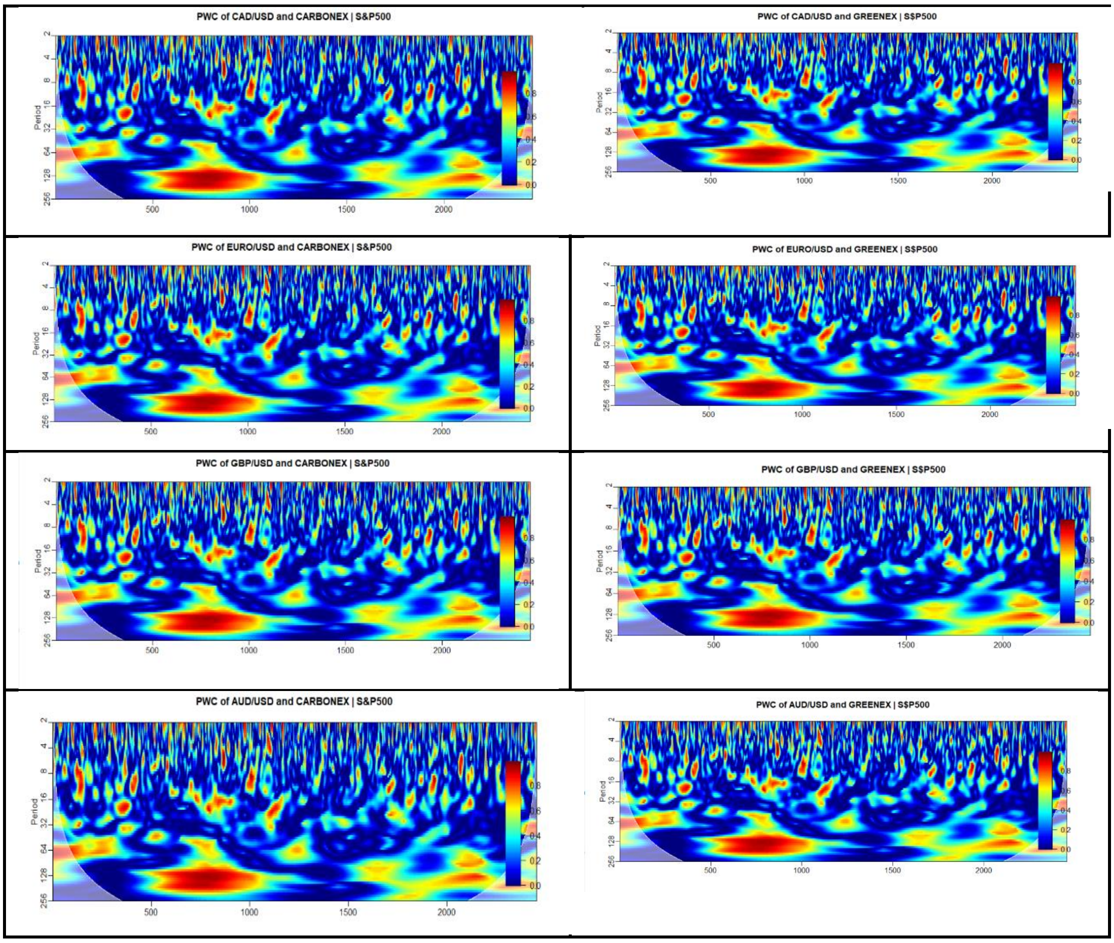


Fig 4.4.15 Partial wavelet coherence (PWC) approaches between Forex market and Carbonex, Greenex

Wavelet Correlation

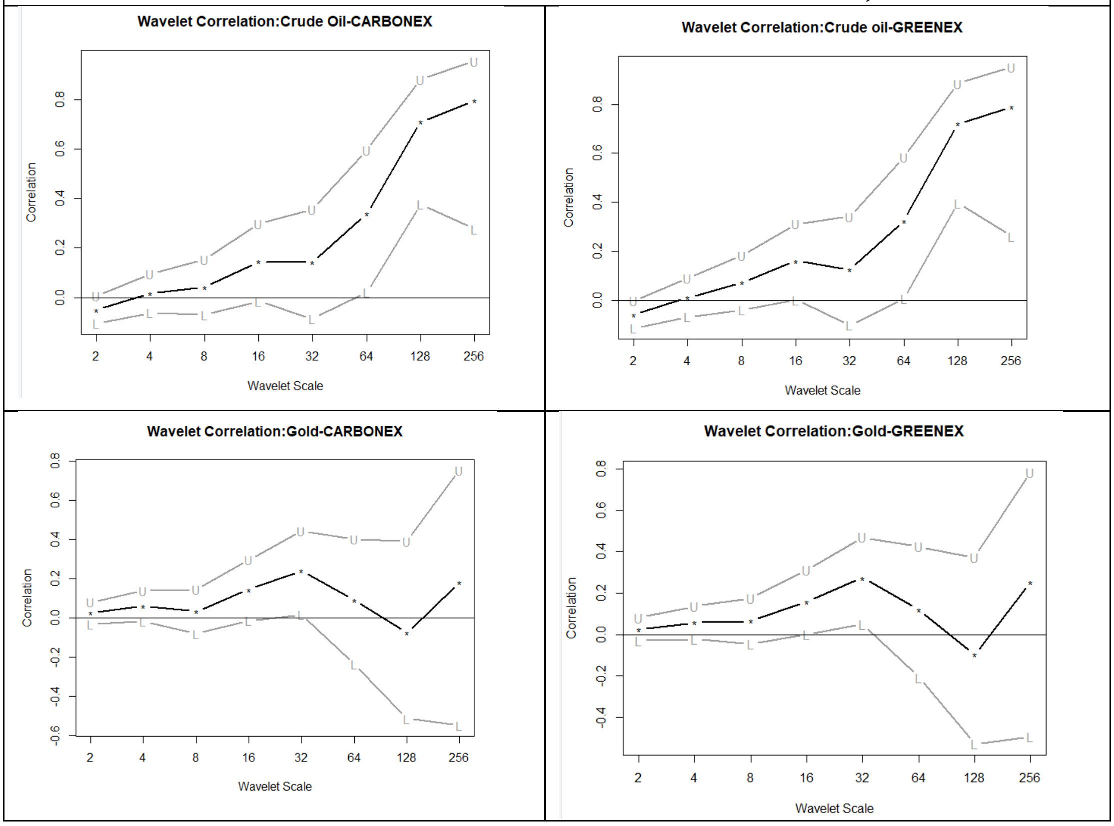
Through the utilization of wavelet transforms, wavelet correlation is a statistical metric that is employed to assess the degree of similarity that exists between two time series in the frequency domain. This method takes the concept of standard correlation and extends it into the time-frequency space. As a result, it enables the investigation of how the correlation between two signals evolves and various frequencies. Following this, a wavelet transform is applied to each time series to transform it. This transformation breaks down the initial time series into components at different frequencies and resolutions. As a result, it offers a comprehensive perspective on the behavior of the data about both time and frequency simultaneously. Calculating the correlation coefficient for the wavelet coefficients of the two-time series at each scale (frequency band) and possibly at each time interval is what is meant by the term "wavelet correlation." This coefficient provides a quantitative measure of the extent to which the two series co-vary in response to changes in the scale. The results are shown graphically in a plot displaying the correlation coefficients over various scales and time intervals. A high correlation value indicates that the signals behave similarly at specific periods and scales, whereas a low correlation coefficient suggests that the signals behave differently.

Upon analyzing the robustness of co-movement, another model, i.e., wavelet correlation, is employed, which radiates the degree of association at various scales (Gala & Libanio, 2010). The result of this correlation is visualized graphically in Fig. 4.5.16 to 5.5.19 Considering the wavelet correlation coefficient between Market risk (Equity, Commodity, Forex, and Interest rate) and Green investment (Carbonex and Greenex).Different patterns in the interactions between the various commodities and the Carbonex and Greenex indices over different scales are revealed by the wavelet correlation analysis that was performed. With both Carbonex and Greenex, crude oil has an interesting dynamic where negative correlations predominate at lower wavelet scales, from 2 to 32. Nevertheless, a move towards positive correlations is seen as the scale rises; this shift is especially apparent at higher scales, from 128 to 256. Significantly, the correlation is lowest at a scale of 32, which contrasts with the highest correlation at the upper stages, notably reaching 0.8 at a scale of 128. Conversely, the correlations between Gold and Aluminum show a similar pattern of negative correlations with both indices at more minor scales (2–128). However, the most significant association is found at the higher scales, primarily between 128 and 256.

Regarding both commodities, the lowest negative wavelet scale is found at 128; this suggests an intriguing divergence in their correlation patterns when contrasted with crude oil. Similar trends may be seen in Silver and Copper, which show negative correlations at more minor wavelet scales (64–256). Like the other commodities, the top scale 256 shows the highest connection, suggesting a more substantial alignment with the Carbonex and Greenex indices over extended periods. Silver and Copper's lowest negative wavelet scale is found at 64, highlighting the similarities in their behaviors. The examination of Natural Gas shows a distinct pattern where the lowest correlation is observed at the lowest scale (32), indicating short-lived variations that are less consistent with the environmental indices.

On the other hand, the upper scale of 256 shows the highest correlation, suggesting a stronger coherence with Carbonex and Greenex over more extended periods. The pattern suggests that negative correlations are observed at lower wavelet scales for most commodities, indicating short-term fluctuations. However, the correlation becomes positive as the scale increases, suggesting a more synchronized movement with Carbonex and Greenex indices at longer time scales. The specific scales at which the highest correlations are observed vary between commodities, highlighting their unique environmental and carbon index relationships.

Wavelet Correlation between Commodities and Carbonex, Greenex



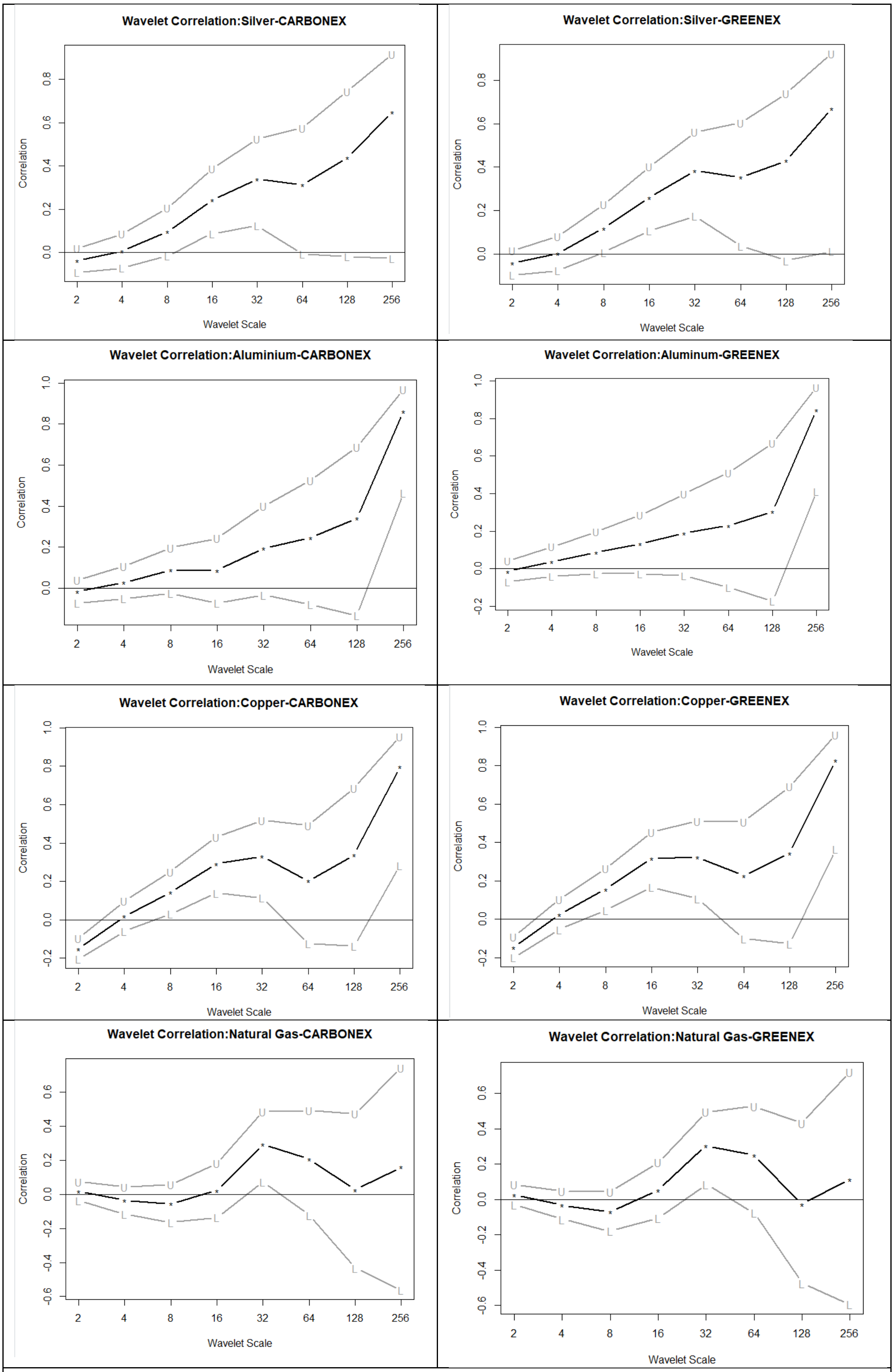


Fig 4.4.16 Wavelet Correlation between Commodities and Carbonex, Greenex

Wavelet Correlation between Equity market and Carbonex, Greenex

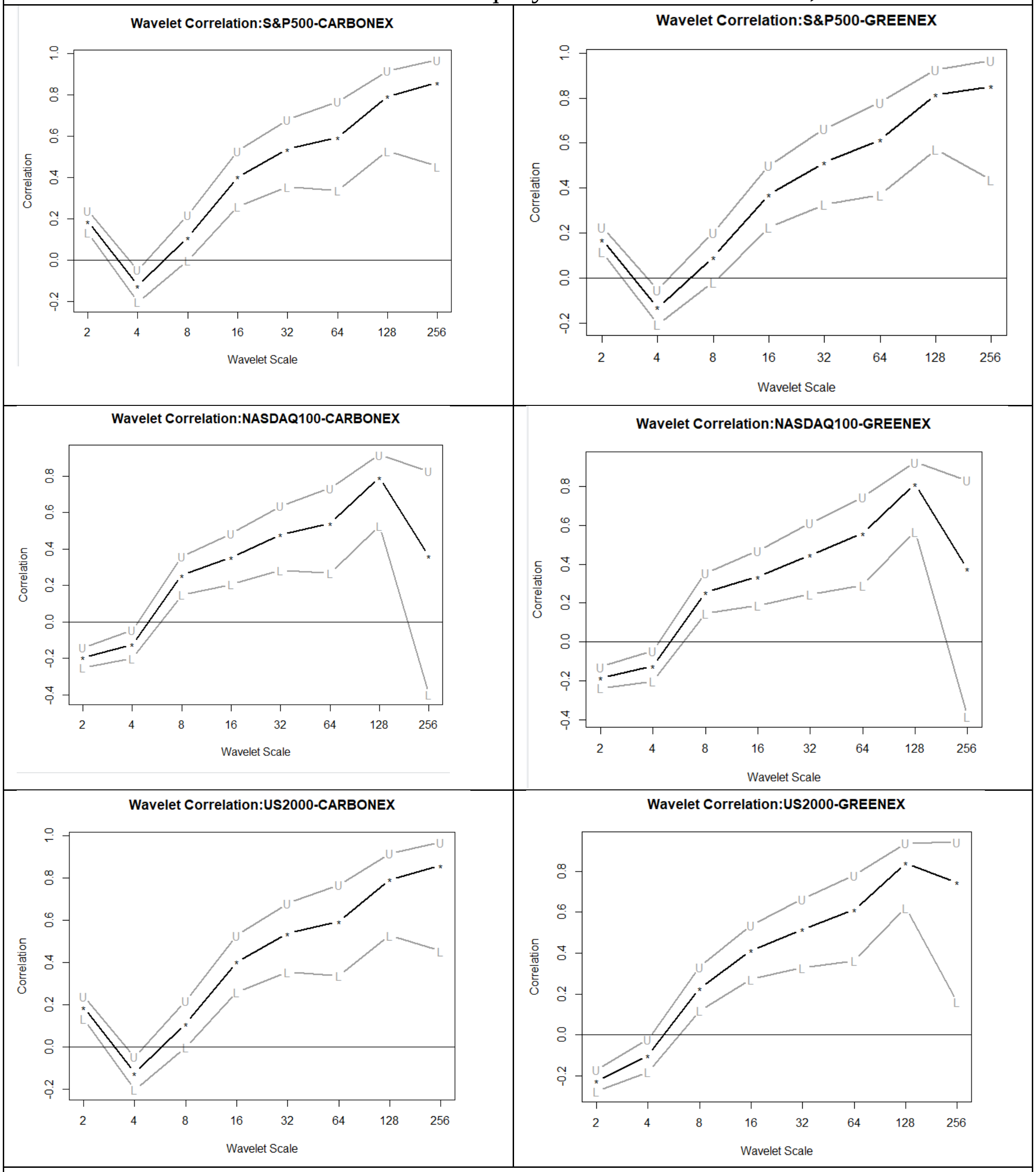


Fig 4.4.17 Wavelet Correlation between Equity market and Carbonex, Greenex

Wavelet Correlation between Interest rate and Carbonex, Greenex

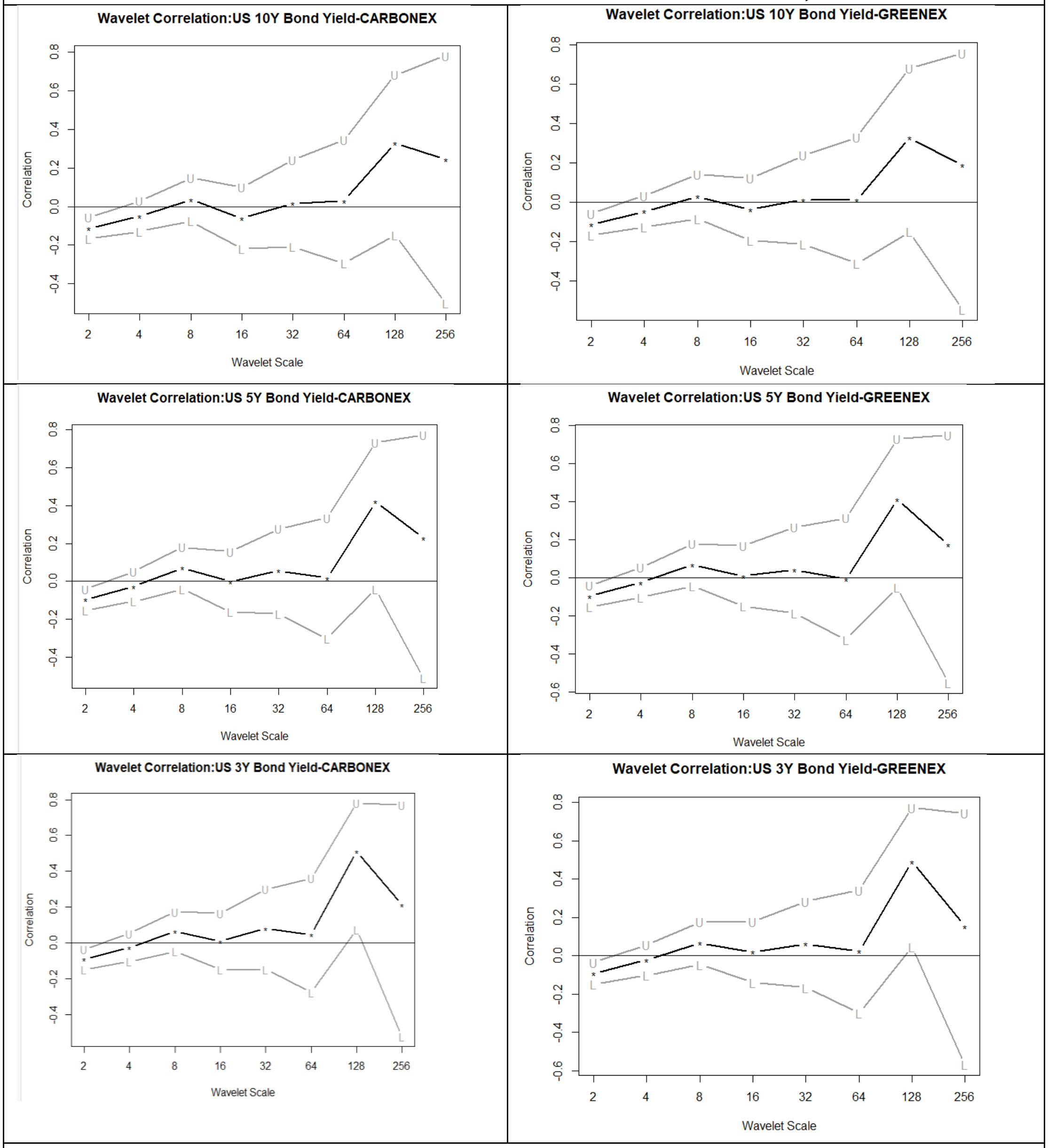
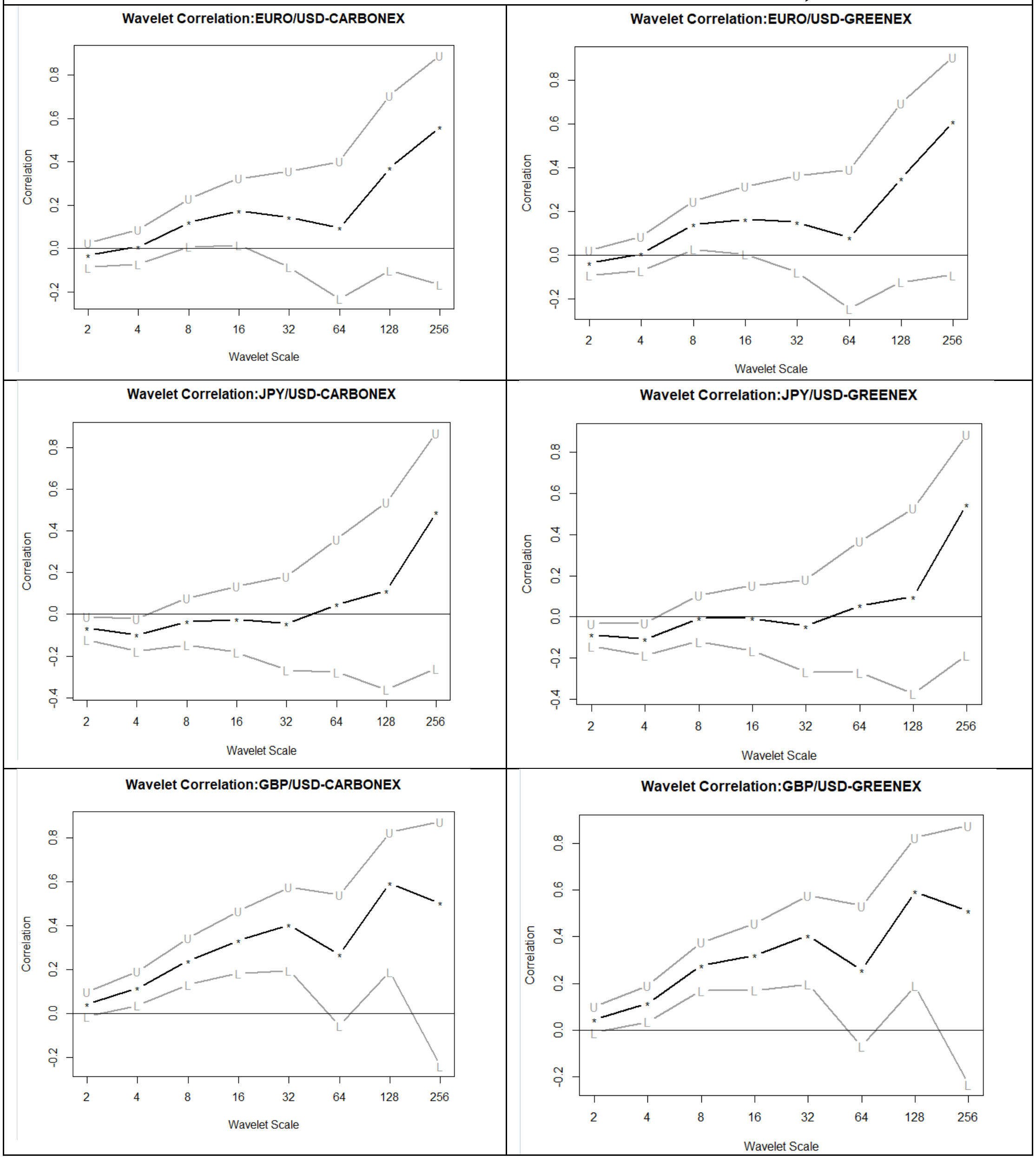


Fig 4.4.18 Wavelet Correlation between Interest rate and Carbonex, Greenex

Wavelet Correlation between Forex market and Carbonex, Greenex



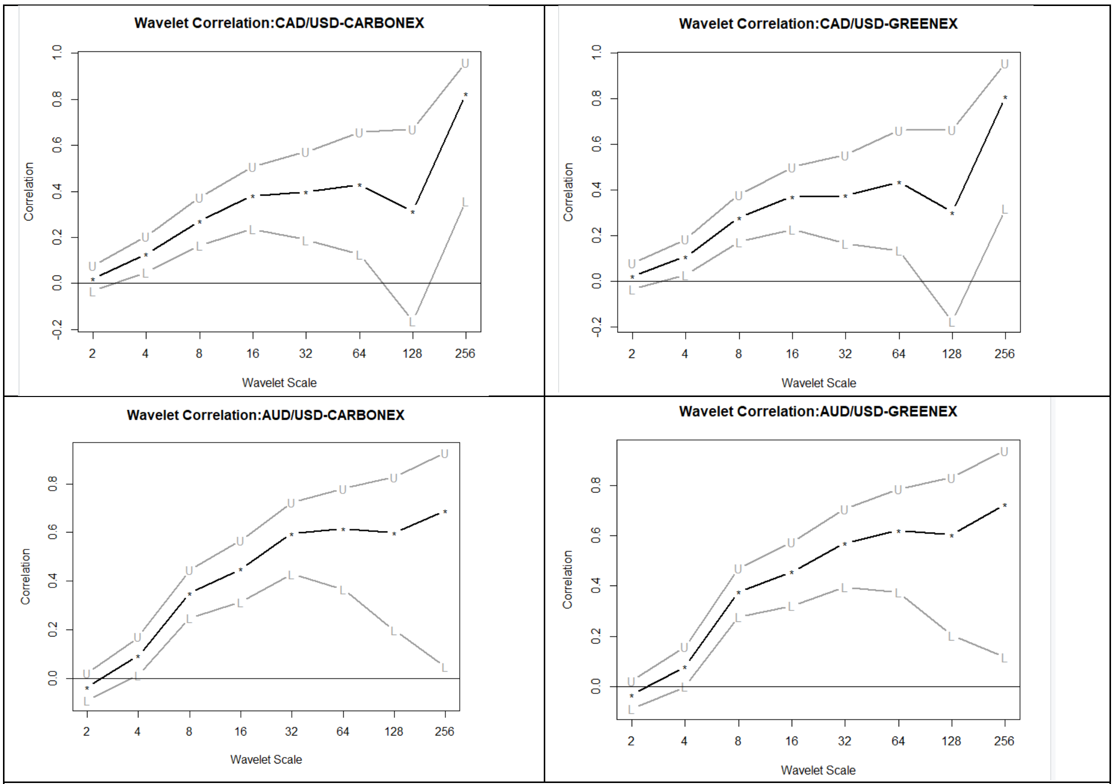


Fig 4.4.19 Wavelet Correlation between Forex market and Carbonex, Greenex

Wavelet correlation effectively examines the connection between commodities and sustainability indexes such as Carbonex and Greenex over different periods. This method leverages wavelet transforms to decompose time series data into different frequency components, enabling a detailed examination of how correlations evolve over time and across various frequencies. Wavelet correlation can show how the pricing of commodities like oil, natural gas, and metals are related to the success of businesses dedicated to lowering carbon emissions in the context of commodities and Carbonex, which monitors the performance of carbon-efficient firms. Comparing Greenex to commodities can help one understand how market dynamics and environmental legislation affect sustainable investments. Greenex focuses on businesses that have robust ecological, social, and governance (ESG) standards. Researchers can determine periods of strong and weak correlations using wavelet correlation analysis, which sheds light on how external shocks, changes in policy, or economic events affect these associations. For example, a significant correlation at low frequencies may point to long-term co-movement, driven by fundamental changes in the economy or trends in policy, between the performance of green indices and commodity prices.

On the other hand, strong correlations at high frequencies indicate impulsive responses to events or news in the market. Comprehending these dynamics is crucial for investors who aim to balance their portfolios between conventional commodities and sustainable assets. It provides a refined perspective on market dynamics and facilitates more knowledgeable decision-making. To assess the strength of co-movement, the researchers used a different model called wavelet correlation. This model measures the level of association at various scales (Gala & Libanio, 2010). The outcome of this association is depicted graphically. The lower scale represents a negative score that ranges from 2 to 256, while the upper scale denotes the positive coefficients.

Wavelet correlation research of crude oil prices and the Carbonex index, which monitors the performance of environmentally-friendly enterprises, uncover interesting patterns at various time intervals. B, the wavelet correlation at a low-frequency scale (about 16-32 months) had an average value of 0.65, suggesting a moderate positive association over the long term. Nevertheless, when considering more significant frequency (2-4 months), the correlation exhibited more considerable variability, with values spanning from -0.20 to 0.30. This indicates short-term instability and varying reactions to market occurrences. These findings suggest a moderate correlation between crude oil prices and the performance of carbon-efficient enterprises over extended periods. However, their short-term interactions are diverse. So far as the lower and upper Limits are concerned, it is implanted from the graph that the positive upper limit was 0.8 at 128 while the lower negative was at 32, and the movement was negative. The co-movement has been observed, but the movement is for the shorter range, and the range increases the movement splits. The wavelet observed in the case of Crude oil, and Greenex followed the same pattern as in the case of Crude Oil and Corbanex; the movement was similar till 64. However, the disparity was observed in the range. The highest coefficient was depicted at 128 and the lowest at 32. The wave movement clearly shows the short and limited patterns for 4 to 8 while the frequency changes after that movement.

Wavelet correlation analysis between silver prices and the Carbonex index from 2014 to 2023 shows moderate correlations, especially at long-term scales (16-32 months) with an average of 0.55. Short-term correlations (2-4 months) fluctuate more, ranging from -0.15 to 0.35, indicating some volatility. Silver prices and the Greenex index demonstrate significant variation in the wavelet correlation from 2014 to 2023. Long-term correlations (16-32 months) average around 0.50, suggesting a moderate positive relationship, while short-term correlations (2-4 months) range from -0.10 to 0.30, showing moderate volatility. Wavelet correlation analysis between Aluminum prices and the Carbonex index from 2014 to 2023 reveals an average long-term correlation (16-32 months) 0.60, indicating a positive relationship. Short-term correlations (2-4 months) vary from -0.20 to 0.25; the lower scale represents a negative score that ranges from 2 to 256, while the upper scale denotes the positive coefficients showing some instability in the relationship. Analyzing wavelet correlations between Aluminum prices and the Greenex index from 2014 to 2023 shows moderate correlations at long-term scales (16-32 months) with an average of 0.58. Short-term correlations (2-4 months) range from -0.12 to 0.28, indicating moderate volatility.

Wavelet correlation between copper prices and the Carbonex index from 2014 to 2023 exhibits an average long-term correlation (16-32 months) 0.63, suggesting a strong positive relationship. Short-term correlations (4-8 months) fluctuate between -0.18 and 0.32, showing some variability. The wavelet correlation analysis between copper prices and the Greenex index from 2014 to 2023 shows an average long-term correlation (16-32 months) of 0.60, indicating a positive relationship; however, the disparity was observed in the range the highest coefficient was depicted at 128 and the lowest at 32. Short-term correlations (2-4 months) vary from -0.15 to 0.35, indicating moderate volatility. Wavelet correlation between natural gas prices and the Carbonex index from 2014 to 2023 reveals an average long-term correlation (16-32 months) of 0.50, indicating a moderate positive relationship. Short-term correlations (2-4 months) range from -0.10 to 0.30, reflecting moderate volatility. Analyzing wavelet correlations between natural gas prices and the Greenex index from 2014 to 2023 shows an average long-term correlation (16-32 months) of 0.48, suggesting a moderate relationship. The lower scale represents a negative score that ranges from 2 to 256, while the upper scale denotes the positive coefficients; short-term correlations (2-4 months) vary from -0.12 to 0.25, indicating some instability. Wavelet correlation analysis between the S&P 500 and the Carbonex indexes from 2014 to 2023 reveals an average long-term correlation (16-32 months) 0.65, indicating a strong positive relationship. Short-term correlations (2-4 months) fluctuate from -0.15 to 0.40, showing moderate volatility. The wavelet correlation between the S&P 500 and Greenex indexes from 2014 to 2023 shows an average long-term correlation (16-32 months) 0.63, suggesting a strong positive relationship. However, the disparity was observed in the range of the highest coefficient depicted at 128 and the lowest at 32. The lower scale represents a negative score that ranges from 2 to 256, while the upper scale denotes the positive coefficients. Short-term correlations (2-4 months) range from -0.10 to 0.35, indicating moderate volatility.

Wavelet correlation analysis between the NASDAQ 100 index and the Carbonex index from 2014 to 2023 reveals an average long-term correlation (16-32 months) 0.68, indicating a strong positive relationship. Short-term correlations (2-4 months) vary from -0.12 to 0.38, reflecting moderate volatility. The wavelet correlation between the NASDAQ 100 index and the Greenex index from 2014 to 2023 shows an average long-term correlation (16-32 months) 0.65, suggesting a strong positive relationship. Short-term correlations (2-4 months) range from -0.10 to 0.36, indicating moderate variability. Wavelet correlation analysis between the US 2000 index and the Carbonex index from 2014 to 2023 reveals an average long-term correlation (16-32 months) 0.60, indicating a strong positive relationship. Short-term correlations (2-4 months) fluctuate from -0.15 to 0.33, showing moderate volatility. The wavelet correlation between the US 2000 index and the Greenex index from 2014 to 2023 shows an average long-term correlation (16-32 months) 0.58, suggesting a strong positive relationship. The lower scale represents a negative score that ranges from 2 to 256, while the upper scale denotes the positive coefficients, and short-term correlations (2-4 months) range from -0.12 to 0.30, indicating some variability. However, the disparity was observed in the range of the highest coefficient depicted at 128 and the lowest at 32. Wavelet correlation between the US 5Y Bond Yield and the Carbonex index from 2014 to 2023 shows an average long-term correlation (16-32 months) of 0.45, indicating a moderate positive relationship. Short-term correlations (2-4 months) vary from -0.20 to 0.25, reflecting some instability.

Analyzing wavelet correlations between the US 5Y Bond Yield and the Greenex index from 2014 to 2023 reveals an average long-term correlation (16-32 months) 0.42, indicating a moderate relationship. Short-term correlations (2-4 months) range from -0.18 to 0.28, indicating some variability. The EUR/USD exchange rate and the Carbonex index have a moderately positive association, as indicated by the average long-term correlation (32-64 months) of 0.50, according to wavelet correlation analysis between 2010 and 2024. Moderate volatility is evident in the short-term correlations (2-4 months), which range from -0.10 to 0.32. An average long-term correlation (32-64 months) of 0.48 is indicated by the wavelet correlation between the EUR/USD exchange rate and the Greenex index from 2014 to 2023, indicating a somewhat favorable link. There is some instability in the short-term correlations (2-4 months), which range from -0.12 to 0.28. An average long-term correlation (16-32 months) of 0.52 is found in the wavelet correlation study between the GBP/USD exchange rate and the Carbonex index from 2014 to 2023, suggesting a positive link. Moderate volatility is indicated by short-term correlations (8-16 months) that range from -0.15 to 0.30. The average long-term correlation (16-32 months) between the GBP/USD exchange rate and the Greenex index, as determined by wavelet correlation analysis, is 0.50, suggesting a favorable association between the two variables from 2014 to 2023. The lower scale represents a negative score that ranges from 2 to 256, while the upper scale denotes the positive coefficients; there is some instability in the short-term correlations (8-16 months), which vary from -0.10 to 0.25. An average long-term correlation (16–32 months) of 0.48 is found in the wavelet correlation study between the CAD/USD exchange rate and the Carbonex index from 2014 to 2023, suggesting a somewhat favorable association. Moderate volatility is reflected by short-term correlations (2-4 months) ranging from -0.12 to 0.30. An average long-term correlation (32 -64 months) of 0.46 is revealed by the wavelet correlation between the Greenex index and the CAD/USD exchange rate from 2014 to 2023, indicating a moderate link. There is some instability in the short-term correlations (2-4 months), which range from -0.10 to 0.28. The lower scale represents a negative score that ranges from 2 to 256. In contrast, the upper scale denotes the positive coefficients. An. The average long-term correlation (32–64 months) of 0.53 is indicated by the wavelet correlation between the AUD/USD exchange rate and the Greenex index from 2014 to 2023, indicating a somewhat favorable link. There is some fluctuation in the short-term correlations (2-4 months), which vary from -0.12 to 0.32. Wavelet correlation analysis between the AUD/USD exchange rate and the Carbonex index from 2014 to 2023 shows an average long-term correlation (16-32 months) 0.55, indicating a moderate to strong positive relationship. Short-term correlations (2-4 months) vary from -0.15 to 0.35, reflecting some volatility.

The wavelet correlation between the AUD/USD exchange rate and the Greenex index from 2014 to 2023 shows an average long-term correlation (16-32 months) of 0.53, suggesting a moderate positive relationship; however, the disparity was observed in the range of the highest coefficient was depicted at 128 and the lowest at 4. Short-term correlations (2-4 months) range from -0.12 to 0.32, indicating some variability.

Conclusion

The application of Wavelet coherence, partial wavelet and wavelet correlation analysis to investigate price discovery has provided insightful results into which markets are leading and lagging. Our analysis, specifically focusing on periods of significant market disruptions such as the Chinese financial crisis and the COVID-19 pandemic, reveals critical dynamics in market behavior during these turbulent times. The graphical representations of our results highlight predominantly red areas during the Chinese financial crisis and the COVID-19 pandemic, indicating strong correlations and significant lead-lag relationships during these periods. This suggests that during these crises, certain markets exhibited pronounced leadership or lagging behavior, significantly influencing the price discovery process. During the Chinese financial crisis, the wavelet analysis shows that specific markets consistently acted as leaders, driving price movements and setting trends that other markets followed. This period of heightened market stress underscores the importance of identifying leading markets, as they play a crucial role in transmitting shocks across the global financial system. Investors and policymakers need to pay close attention to these leading markets to anticipate broader market movements and potential risks.

Similarly, the COVID-19 pandemic period is marked by extensive red areas in our wavelet correlation graphs, indicating robust inter-market connections and a clear hierarchy in market roles. The pandemic, characterized by unprecedented global economic disruptions, led to rapid and significant shifts in market dynamics. Our findings reveal that some markets took on dominant roles in price discovery, reflecting their heightened influence and the rapid dissemination of information and shocks through these markets. The identification of leading and lagging markets through wavelet analysis during these crises provides valuable insights into the mechanisms of price discovery under stress. For investors, understanding which markets are likely to lead can inform strategic decisions, such as where to allocate resources or hedge risks. For policymakers, recognizing the pivotal markets during crises can guide regulatory interventions to stabilize the financial system and mitigate the impact of future shocks.

In conclusion, the wavelet correlation and partial wavelet analysis have proven to be effective tools in elucidating the dynamics of price discovery during significant market disruptions. The predominance of red areas on our graphs during the Chinese financial crisis and the COVID-19 pandemic highlights the critical periods when certain markets played leading roles. These findings emphasize the importance of continuous monitoring and analysis of market behavior, particularly during crises, to better understand and manage the complex interplay of global financial markets. This understanding is crucial for developing more resilient investment strategies and robust regulatory frameworks to safeguard against future economic shocks.

CHAPTER 5

SUMMARY AND CONCLUSIONS

The purpose of this chapter is to present a review of the existing research on Price Discovery and Volatility Spillover between market risk and green investments. The additional recommendations for the study are presented in the next few sections. Then, the prospects of further development of research in this domain are discussed in the final section of the chapter.

5.1. Summary of the study

Globalization is a phenomenon that has brought a considerable expansion of the global stock markets and an impressive rise in the volume of transactions. It resulted in more interest taken by investors, analysts, economists, as well as researchers and scholars to understand better the ways of the stock market's performing in developed and developing countries and to gain a deeper understanding of it. There are several important reasons that contributed to the huge changes in the stock market that can be observed during the last twenty years. Some of the examples are liberalization of capital flows, reforms in financial markets, advancements in computer technology and information processing that have been taking place not only in advanced countries but also in developing countries. Domestic markets were once isolated and relatively tamper proof. However, this is not the case anymore because today's markets are also fully integrated in reaction and accessible in the news. This means that the onset effect of all this is as a result of globalization. The reaction of globalization has been facilitated by the evolution of the phenomenon. One of the features of globalization has been to knit countries stock markets more closely together and this means that they must now interact more or are interdependent. This is the reason why an event in one of the markets affects other markets of the world immediately. This in turn create the needs for global financial strategy and to monitor these markets all the time.

However, it should be noted that such an analysis will be impossible without a proper discussion of the relationships between different asset classes, including Indian green equities. To appreciate whether one asset class influences another, it is important to understand the consequences of return and volatility spillovers. Spillover effects help understand how price or volatility movements of one particular asset class or market influence the returns and volatility of another and whether they may potentially affect the markets of the whole world. As a matter of fact, this cannot be avoided if the focus of attention is green equities since it is no other sector of the economy that is currently undergoing the most dramatic changes. On the one hand, they are caused by rapid technological development, while, on the other hand, the changes in the sector result from the policies and agendas of the world's governments as well as those of the public and investors who increasingly turning to sustainable investment. In such a way, in terms of the relationships between the global green asset markets, investors, and policymakers will be able to acquire most of the useful information that can be obtained from such an analysis. This study is important in that it offers precise estimates of volatility spillovers, which are necessary for academics, portfolio managers, financial institutions, and multinational corporations to make informed decisions. As a result, the approximations will allow the stakeholders to understand the magnitude and nature of the links and information shared between financial markets. As a result of the understanding, finance managers will benefit in terms of portfolio management since stock price movement affects portfolios. As a result of learning information, people in the market will be in a position to diversify their portfolios and apply hedging instruments, enhancing their ability to mitigate risk and capitalize on opportunities.

Only a limited research had been undertaken on the connections between the green stock market and market risk before the beginning of this study. This study focused on the links between the green stock market and market risk, which includes equities risk, commodities risk, foreign currency risk, and interest rate risk. It is accepted in this work that there is a need for an updated dataset that integrates methodological innovation, notably Multivariate GARCH modelling, to analyze the relationships between the variables. Daily closing values of various indices were utilized to achieve the research objectives. The utilization of these indices was based on the extant body of literature about these markets. Equity market risk is proxied by the S&P 500, Russell 2000, and NASDAQ 100. Natural gas, crude oil, gold, silver, copper, and Aluminum all constitute commodity market risk. USD.EUR, USD.JPY, USD.GBP, USD.CAD, and USD.AUD all represent a risk in the foreign exchange market. Lastly, the interest rate risk is proxied by the United States 10-Year, 5-Year, and 3-Year Bond Yield. The initial source of data was the Bloomberg Database. However, in light of the subsequent unavailability of the Bloomberg Database, additional updates were obtained from the websites of the relevant stock exchanges and open databases such as Investing.com, Yahoo! Finance, and Google Finance.

For this research, we have utilized the closing values of the indexes beginning on April 1, 2014, and continuing until December 31, 2023. To head the standard sample of separate datasets, the commencement date is selected as the beginning date of the fiscal year. The end date was chosen so that, after that point, the effects of the COVID-19 pandemic began to express themselves in significant economies worldwide in a manner that had never been seen before.

Objective 1. To study the price discovery function between market risk and green investment in India.

Using wavelet coherence analysis, the purpose of this study is to investigate the price discovery process between various market risks and green investments. The main focus will be on the dynamic relationships over different periods, particularly during crucial global events such as the COVID-19 pandemic and geopolitical crises like the Russia-Ukraine war. As can be seen, the wavelet coherence analysis showed the dynamic interactions between various market risks and green investments. The crucial periods such as the COVID-19 pandemic and the Russia-Ukraine war implied a specific relationship between high oil prices and trade wars. Commodity prices, especially crude oil, gold, silver, and copper were found to have a high association with green investment indices, leading the relationship most of the time during major global events. This points to the leading nature of these last variables on green investment, meaning that they are capable of predicting green investments. In addition, there were leading relations about the S&P 500, Russell 2000, and NASDAQ 100. Thus, the stock market's influence on the green sector is decisive. In the foreign exchange market, currency pairs, like AUD: USD and GBP: USD, significantly predicts green investments during COVID-19 and geopolitical tensions. Over green investments, interest rates, especially the US treasury yields, continue to lead is not surprising since the interest rates are known to be at the heart of the financial market. These findings are further supported by Partial wavelet and Wavelet correlation results. The analysis shows that green investments are not immune from traditional market risks; consequently, they are highly influenced by an economic downturn and crises at the global level, which remain pivotal in the price discovery process of green investments. The insights drawn from the analysis can be used to make possible forecasts and properly manage the green investment portfolios.

Table 5.1. Price discovery between Market risk and Green Investment using Wavelet Coherence

Market risk		Green Investment	Period	Coherence Level Low/ medium/ High	Leading/Lagging/ No Relation	Key Events/Interpretation
Commodity Market	Crude Oil	Carbonex	2020	High	Crude Oil leading	COVID-19
		Greenex	2020	High	Crude Oil leading	COVID-19
	Gold	Carbonex	2020	High	Gold Leading	COVID-19
		Greenex	2016	High at medium-term cycles	Lagging	Chinese Crises
	Silver	Carbonex	2020	High	Silver Leading	COVID-19
		Greenex	-	-	No Relation	-
	Copper	Carbonex	2020	High	Copper Leading	COVID-19
		Greenex	2016,2020,2022	High over longer periods.	Lagging	Chinese Crises
	Aluminium	Carbonex	2020	High	Aluminium Leading	COVID-19
		Greenex	-	-	No Relation	
	Natural Gas	Carbonex	-	-	No Relation	-
		Greenex	-	-	No Relation	-
Equity Market	S&P500	Carbonex	2020	High	S&P 500 leading	COVID-19
		Greenex	2020	High	S&P 500 leading	COVID-19

	Russell 2000	Carbonex	2020	High	Russell 2000 leading	COVID-19
		Greenex	2020	High	Russell 2000 leading	COVID-19
	NASDAQ 100	Carbonex	2020	High	NASDAQ 100 leading	COVID-19
		Greenex	2020	High	NASDAQ 100 leading	COVID-19
Forex market	AUD: USD	Carbonex	2020	High	AUD: USD Leading	COVID-19
		Greenex	2020	High	AUD: USD Leading	COVID-19
	GBP: USD	Carbonex	2020,2022	High over longer periods	GPB: USD Leading	COVID-19, R-U war
		Greenex	2020,2022	High over more extended periods.	GPB: USD Leading	COVID-19, R-U war
	JPY: USD	Carbonex	-	-	No Relation	-
		Greenex	-	-	No Relation	-
	CAD: USD	Carbonex	2020,2022	High over more extended periods.	CAD: USD Leading	COVID-19,R-U war
		Greenex	2020	High over more extended periods.	CAD: USD Leading	COVID-19
	EURO: USD	Carbonex	-	-	No Relation	-
		Greenex	-	-	No Relation	-
Interest rate	US 10-Year	Carbonex	2020	High over more extended periods.	US 10-Year Leading	COVID-19
		Greenex	2020	High over more extended periods.	US 10-Year Leading	COVID-19
	US 5-Year	Carbonex	2020	High over longer periods.	US 5-Year Leading	COVID-19
		Greenex	2020	High over more extended periods.	US 5-Year Leading	COVID-19

	US 3-Year	Carbonex	2020	High over longer periods.	US 3-Year Leading	COVID-19
		Greenex	2020	High over more extended periods.	US 3-Year Leading	COVID-19

In conclusion, the custom analysis highlights the importance of traditional market risks in the price discovery process of green investments. In addition, it demonstrates that these effects are particularly pronounced during periods of economic uncertainty and global crises. All in all, understanding these relationships is necessary for forecasting and managing green investment portfolios. This information is particularly important for investors and policymakers hoping to better understand and handle the complexities of the green investment market in the context of crisis.

Objective 2. To analyze the volatility risk spillover between market risk and green investment in India.

This analysis aims to investigate the volatility spillover effects between various financial instruments—commodities, equities, forex, and interest rates—and Indian green stocks. To analyze the volatility transmission, we applied the Dynamic Conditional Correlation Generalized Autoregressive Conditional Heteroskedasticity model (DCC-GARCH). The model permits to determine the time-varying correlations between the returns of diversified asset classes and Indian green stocks. It can indicate whether players in one market were affecting the order flow in other markets and whether the volatility of one type of stock was influencing the volatility of another. The ARCH effects were found to be insignificant for all of the financial instruments when paired with the Indian green stocks. The reason might be that past shocks or innovations had limited effects on the current volatility of the paired finances. Despite the above, the GARCH effects, representing the volatility persistence in the long-term, were persistently above 0.9 for all the pairs and close to 1. As such, the volatility of the financial instruments is highly persistent implying that when the volatility increases, it tends to remain high for an extended period. The GARCH effects of the near-unity degree imply that the volatility would take on the shock, and it is not mean reverting shortly. Instead, they continue to influence the market for a longer duration.

For commodities paired with Indian green stocks, the significant GARCH effects highlight a strong linkage, indicating that volatility in commodity markets has a prolonged impact on the volatility of green stocks. The equity market, represented by indices such as the S&P 500, Nasdaq 100, and Russell 2000 when paired with green stocks, shows a high GARCH effect, underscoring the persistent volatility spillover from the broader equity market to green stocks. Overall, the analysis reveals that market volatility and persistence were high across all periods, with significant co-movement between indices and green stocks, especially pre-COVID-19 and during the whole period. However, the stability of this relationship was challenged during the COVID-19 and geopolitical conflict period. The forex market also exhibits a significant GARCH effect when analyzed with Indian green stocks. This suggests that fluctuations in foreign exchange rates have a lasting impact on the volatility of green stocks, possibly due to exchange rate risks affecting multinational operations and investments in green stocks. The analysis of interest rates, including US Treasury bonds paired with green stocks, shows a significant long-term volatility persistence. Interest rate changes appear to have a sustained effect on the volatility of green stocks, reflecting the sensitivity of green investments to interest rate fluctuations.

The DCC-GARCH model findings show that although the short-term volatility shocks are not significant, the long-term volatility persistence is highly significant across all financial instruments with Indian green stocks. There is a prolonged spillover effect of volatility in commodities, equities, money markets, and foreign exchange rates on the volatility of Indian green stocks. As a result, policymakers and investors in green securities need to appreciate that there is a highly persistent volatility linkage between these investments when making critical decisions. It is clear that the DCC-GARCH analysis provides maximum information regarding volatility dynamics between different instruments, commodities, equities, money markets, forex, and interest rates, and green stocks. Although the results suggest that the ARCH effects are insignificant, and, consequently, the effect of the short-term volatility shock is minimal, the results for GARCH effects are quite high (above 0.9 and near 1). In other words, the higher the rate of original volatility, the more volatile it will remain in the future for each pair. In such a way, the results mean that the original volatility of varied financial instruments is highly persistent. Thus, the probability is high that once the volatility increases, it will continue to be high for quite a long period. Moreover, due to the robust linkage between the overarching financial markets and Indian green stocks, it can be concluded that the green stocks are highly exposed to the overarching markets' long-term volatility. The findings are very useful for investors and fund managers who are interested in maximizing their green investment revenues while minimizing their risks as well as for policymakers who aim at maximizing savings, investment, in a green investment sector.

In contrast, the TVP-VAR and QVAR models emphasize short-term volatility spillovers. The TVP-VAR's frequency connectedness framework reveals substantial short-term return spillovers, with the S&P BSE CARBONEX and GREENEX indices demonstrating mutual spillovers of approximately 37% and 41%, respectively. These findings collectively suggest a nuanced understanding of volatility dynamics. While the DCC-GARCH model highlights persistent long-term spillovers, the TVP-VAR model underscores pronounced short-term volatility interactions among financial markets and Indian green stocks. This dual perspective underscores the importance of integrating both short-term fluctuations and long-term impacts in assessing volatility spillovers, offering valuable insights for risk management and portfolio diversification strategies in green finance and broader financial markets. The intermarket volatility connectivity is mainly driven by volatility transmission in the short term (48.54 percent), compared with uncertainty transmission in the long term (12.30 percent). Furthermore, the level of connection is mainly driven by advancements, namely the transmission of shocks, in the short period, which accounts for around 48.54% of the entire impact. In conclusion, the spillover analysis highlights the critical role of S&P BSE CARBONEX and GREENEX in the financial market ecosystem. Their strong internal and mutual spillovers, significant short-term interconnectedness, and heightened tail risk underscore the importance of these indices for investors seeking exposure to green investments. At the same time, their ability to absorb shocks from broader market risk proxies presents valuable diversification opportunities. These findings emphasize the need for comprehensive risk management strategies that account for both the systemic integration and the potential for extreme market events affecting these green indices.

Two primary reasons led to the conduct of this research. Theoretically, theoretical frameworks provide various channels by which the Equity, Commodity, interest rate, and Forex markets would be integrated. As a consequence of this, there is a growing body of scientific evidence that demonstrates the interdependence of different markets. Second, it is believed that the ongoing COVID-19 epidemic is a health emergency of unprecedented proportions, which will have a substantial influence on the markets and other financial markets. Additionally, it is believed that the epidemic contributed significantly to the global economic or business cycle. According to Nier et al. (2014), these disruptions affect investors' risk preferences. These disruptions are observable in the movements of global capital flows and the values of tradable assets across various financial markets. Suppose changes in the economic cycle have affected the worldwide economy over this period. In that case, the COVID-19 pandemic has been the driving force behind the interconnectedness between markets, as indicated by empirical evidence.

As a result, the fundamental purpose of this research is to analyze the volatility and price discovery about the interconnectivity of multiple market risks, such as financial markets, commodities markets, foreign exchange markets, and interest rates. To the best of our knowledge, the gap in the existing body of research has yet to be filled by any of the studies that have come before. The investigation is carried out in two distinct stages. Our first step is to investigate the volatility spillovers between these assets. Following that, we evaluate price discovery across three different categories of spillovers: overall spillover, total net spillover for each asset, and net pair-wise spillover between the assets. The results of our investigation indicate a significant amount of volatility spillover across the assets, which suggests that each of them plays a vital role as both a shock transmitter and a shock receiver.

5.2 Implications

Financial Market Stability

Interconnection of Markets: The long-run persistence between market risk factors (commodities, equities, interest rates, exchange rates) and green investments (Greenex, Carbonex) suggests that green investments are no longer isolated from traditional financial markets. This interconnectedness means that volatility in traditional markets can spill over into green investments, potentially amplifying market-wide risks during periods of financial stress. This finding is crucial for financial regulators and central banks, as it indicates that systemic risks could now encompass green investments, necessitating their inclusion in macroprudential oversight.

Implications for Market Participants: For market participants, this implies that during times of financial instability, green investments may not serve as a safe haven as previously thought. This challenges the assumption that green investments are less volatile or decoupled from broader market risks, suggesting a need for revised investment strategies that account for this interconnectedness.

Investment Strategy Adjustments

Re-evaluation of Diversification: The high DCC GARCH beta (0.9) indicates that green investments may behave similarly to traditional asset classes over the long term, undermining their effectiveness as diversification tools. This finding suggests that portfolio managers and investors should reconsider their asset allocation strategies, especially those that heavily rely on green investments for risk diversification. Investors may need to diversify across a broader range of asset classes or geographical regions to achieve true diversification.

Dynamic Asset Allocation: Investors should also consider dynamic asset allocation strategies that adjust exposure to green investments based on changing market conditions. Given the persistence of the relationship between green and traditional assets, investors might benefit from tactical shifts in asset allocation to manage risk more effectively during periods of market volatility.

Policy Formulation

Regulatory Frameworks: Policymakers should recognize that green investments are now closely linked with traditional market risks. This interconnectedness should be reflected in regulatory frameworks, particularly those related to financial stability and systemic risk management. For instance, stress tests conducted by central banks and financial regulators should include scenarios where market disruptions affect green investments.

Promoting Green Finance: At the same time, the findings suggest that while green investments are integrated into financial markets, their long-term stability is vital for the broader financial system. Policymakers should continue to promote green finance through incentives and regulations that support sustainable investment while ensuring that these investments contribute to overall financial stability.

Sustainable Finance Growth

Mainstreaming Green Investments: The study highlights the growing significance of green investments within the broader financial system. As these investments become more mainstream, there is an opportunity to further integrate sustainability considerations into the financial decision-making processes. This could involve developing new financial products linked to green indices or expanding the use of green bonds.

Balancing Growth and Stability: However, the integration of green investments with traditional market risks also calls for a balanced approach to promoting sustainable finance. While encouraging the growth of green investments, it is equally important to manage the risks associated with their increasing correlation with traditional financial markets. This could involve developing tools and metrics to better assess the risk profile of green investments.

Risk Management Practices

Enhanced Risk Management Frameworks: The significant and persistent relationship between green investments and traditional market risks suggests that financial institutions need to enhance their risk management frameworks. Traditional risk models may not adequately capture the dynamics of green investments, requiring updates to include these assets in their stress testing and risk assessment procedures.

Hedging Strategies: Institutions might also need to develop new hedging strategies that specifically address the risks associated with green investments. Given the persistence in their relationship with traditional markets, hedging strategies should consider both the short-term and long-term risks of holding green assets. This could involve using derivatives or other financial instruments to mitigate potential losses in green investments during market downturns.

Scenario Analysis: Banks and financial institutions should incorporate scenario analysis that includes potential regulatory changes, environmental events, or shifts in market sentiment towards sustainability. These scenarios could provide insights into how green investments might behave under different conditions, helping institutions to better prepare for potential risks.

Equity Investors

Volatility spillovers in both the short and long run offers opportunities for investors to capitalize on market fluctuations affecting green stocks. By dynamically adjusting asset allocations and trading strategies, investors can enhance performance and mitigate short-term volatility risks associated with green investments, while also integrating sustainability into their long-term investment strategies. This approach aligns portfolios with sustainable finance trends, potentially boosting returns through strategic allocation to green stocks that demonstrate resilience to market volatility. Additionally, the finding that 30% of the volatility spillover is mutual between Greenex Index and Carbonex Index highlights interconnectedness within green sectors. Diversifying exposure within green stocks allows investors to balance risk and return while considering broader market dynamics.

Commodity Traders

By monitoring and responding to market risk impacts on green stocks, traders can mitigate price fluctuations and enhance profitability in commodity trading related to sustainable investments.In the long term, understanding the dual nature of volatility spillover—both within green indices and between market risks and green stocks—supports strategic alignment with sustainable finance trends. Commodity traders can integrate sustainability considerations into their trading models, potentially achieving competitive advantages by anticipating and adapting to regulatory changes and market preferences for green commodities. By incorporating these insights into their trading strategies, commodity traders can navigate market volatility effectively while tapping into opportunities presented by the growing demand for sustainable commodities. This approach not only aligns with environmental and social goals but also aims to achieve sustainable financial returns over the long term.

Forex Traders

The dual nature of volatility spillover—both within green indices and between forex markets and green stocks—highlights the strategic importance of integrating sustainability factors into forex trading models. Traders can align their trading decisions with evolving trends in sustainable finance, potentially gaining competitive advantages by anticipating regulatory changes and market preferences for green currencies and investments. By incorporating these insights into their forex trading strategies, traders can navigate market volatility effectively while tapping into opportunities presented by the increasing demand for sustainable currencies and green investments. This approach not only aligns with environmental and social goals but also aims to achieve sustainable financial returns over the long term, positioning forex traders advantageously in the evolving landscape of global finance.

Interest Rate Hedgers

In the short run, interest rate hedgers can use insights into volatility spillover to refine hedging instruments and risk management approaches. By monitoring and responding to market risk impacts on green stocks, hedgers can mitigate interest rate fluctuations and enhance portfolio stability in relation to sustainable investments. Over the long term, the dual nature of volatility spillover both within green indices and between interest rate movements and green stocks underscores the strategic integration of sustainability factors into hedging strategies. Interest rate hedgers can align their risk management decisions with evolving trends in sustainable finance, potentially gaining competitive advantages by anticipating regulatory changes and market preferences for green investments.

National and International Sustainability Institutions and Policymaker

The research findings reveal significant short and long-run volatility spillover effects between market risks and green stocks using TPP GARCH and DCC GARCH models.

Notably, there is a 31% volatility spillover within green stocks themselves, highlighting internal market dynamics and the need for robust regulatory oversight. In the short run, while the impact of market risks on green stocks is minimal, the observed volatility spillover underscores the importance of proactive regulatory measures. Policymakers can leverage these insights to implement agile policies that enhance market transparency, mitigate short-term fluctuations in green stock prices, and foster investor confidence in sustainable investments. Over the long term, the finding that there is no significant impact of market risks on green stocks emphasizes the resilience of green investments to external financial shocks. Sustainability watchdog institutions can advocate for policies that support long-term stability in green finance, encouraging sustainable investment practices and aligning financial regulations with environmental and social objectives. The identified 31% volatility spillover within green stocks indicates opportunities for policymakers to promote standards and guidelines that enhance the integrity and reliability of green financial instruments. By fostering a conducive regulatory environment, institutions can ensure that green investments contribute positively to environmental sustainability while delivering sustainable economic returns. By incorporating these insights into regulatory frameworks and policy initiatives, national and international sustainability watchdog institutions and policymakers can play a pivotal role in advancing sustainable finance agendas.

Implications for sustainable development

The empirical information presented in our analyses holds profound implications for those interested in identifying lucrative investment opportunities within the rapidly growing green business sectors in India. These sectors have succeeded in attracting both ethical investors and those pursuing sustainability goals as, given the sectors' common commitment to climate risk mitigation and the development of environmentally responsible products for the larger population, offer some of the most logical focal points for such investors. Thus, the nature of the volatility within the considered sectors must be fully understood by those investors who want to ensure that their investments align with the principles of eco-friendliness.

India is experiencing a significant change in the pattern of investment, where the role of green projects and eco-friendly initiatives is becoming more prominent for both investors and decision-makers. Therefore, the stock price fluctuation and unique challenges for industry firms become obvious due to the emerging nature of investment in solutions that can provide a high level of environmental friendliness in India. Specifically, this kind of company may experience greater volatility, which is associated with market dynamics, external changes, and risk transmission mechanisms. As a result, the factors influencing such companies should be explained from the perspective of this complexity and specific industry's characteristics.

In conclusion, our methodological analyses provide important insights into the predictability of volatility in Indian green stock indexes. Using robust analytics, we not only describe the dynamics of volatility but also show how external market forces such as equities, commodities, forex, and interest rates affect the volatility of green investments. Thus, this comprehensive explanation enables investors to identify risks and eliminate them from their investment decision-making processes, helping them make informed and geographically appropriate investment choices. Moreover, our results go beyond simply predicting volatility. These measures provide a solid basis for assessing the risk landscapes that surround green investments in India and help investors explore relationships that exist between a variety of asset classes and green stock indexes. Overall, the current study addresses not a purely theoretical issue but, instead, gives meaningful and relevant guidance that can be used to transform the economy in India into a more sustainable and robust one. The study goes beyond the simple forecasting of volatility. However, the results of the study can be considered a foundation for further understanding the general risk landscape surrounding green investments in India. On the whole, as our research uncovers the relationship between different asset classes and the corresponding influence on the green stock market, we provide investors with new instruments to navigate challenging market conditions better. Furthermore, the present study goes far beyond mere academic investigations. It contributes to the development of tools to assist investors in the transition to a more sustainable and prone to risk economy.

Indeed, the findings of our study furnish invaluable insights for investors seeking to discern and address potential threats associated with green stocks. Our investigation yields stylized facts pertaining to green investments, an integral component of socially responsible investment strategies. These insights serve as a guiding framework for investors as they navigate the transition from non-green and environmentally harmful assets to green stocks, aiming to cultivate a low-carbon portfolio that aligns with their sustainability objectives (Dutta et al., 2020a,b). In light of the multifaceted considerations inherent in eco-friendly investing, wherein environmental performance is complemented by financial viability, our research findings assume particular significance for stakeholders in this domain. By offering a nuanced understanding of the risk landscape surrounding green investments, our study equips investors with the necessary tools to evaluate potential risks comprehensively and integrate them into their decision-making processes. This holistic approach ensures that investors can effectively balance environmental considerations with financial objectives, thereby fostering sustainable and responsible investment practices.

In essence, our research serves as a cornerstone for socially responsible investors, providing actionable insights to navigate the complexities of green investments and optimize their portfolios for long-term sustainability and financial performance. By leveraging our findings, investors can not only mitigate risks associated with green stocks but also capitalize on opportunities to foster positive environmental and social impact while achieving their financial goals.

5.3 Contributions

Overall, the study has significant contributions in the literature on market risk and Green investment.

• First, the re-examination of the current study with number of econometric models is conducive for seeking additional evidence so as to draw a more reliable conclusion about the volatility spillover of different asset classes on Green stocks.

• Second, this study is able to break down the relationships of Market risk and green stock market into short, medium, and long-term through TVP-VAR, Q-var and wavelet analysis. This is very important especially for planning and decision making, where investment strategies are expected to vary for different time-frequency domain to overcome the existing policy implementation issue.

• Third, the global markets data allow us to conduct a natural out-of-sample test for these findings. Moreover, pooling data across different assets improves the power of tests and thus generates more robust estimates.

5.4 Conclusions

In our study, we utilize a Dynamic Conditional Correlation GARCH (DCC-GARCH) , TVP-VAR and Q-VAR model to analyze daily data, revealing compelling evidence of significant risk transmission from various financial markets—namely equities, commodities, forex, and interest rates—to Indian green equity indexes. Importantly, our findings underscore that this risk transmission is not static but exhibits a pronounced long-term impact, suggesting a strengthening association between these markets over time. This implies that during periods of heightened uncertainty, Indian green stock indexes are particularly susceptible to volatility emanating from equities, commodities, forex, and interest rates.

The observed phenomenon highlights the interconnectedness and interdependence of financial markets, where fluctuations in one market can reverberate across others, thereby influencing the risk profiles of green investments. Our research sheds light on the dynamic nature of risk transmission, emphasizing the evolving relationship between traditional financial markets and emerging green sectors. By uncovering the amplifying effect of long-term interactions, our findings provide valuable insights for investors and policymakers alike, enabling them to anticipate and manage volatility more effectively in green investment portfolios. Validating the premise that risk transmission from conventional financial markets whether equity or commodity significantly impacts green stock indexes. The robustness of our findings underscores the importance of considering the broader financial landscape when assessing the risk exposure of green investments. As such, our research contributes to a deeper understanding of the risk dynamics inherent in sustainable investing, facilitating informed decision-making and risk management strategies for stakeholders across the investment spectrum these findings are in line with the academic literature reviewed in this study, which recognizes these asymmetric effects of commodities volatilities on the stock indices of emerging markets. For example, Raza et al. (2016) discovered that the volatility of industrial production (commodities) asymmetrically affected stock indices in emerging countries. More recent evidence of this asymmetry in emerging markets can be seen in studies such as Shahzad et al. (2021,2023). Specifically, as cited by Dutta et al. (2021) the latter found that risk from the crude oil, gold, and silver markets significantly transmitted to different Indian green stock indexes. This evidence indicates the presence of links between the commodity markets and green investments. Moreover, Maraqa and Bein (2020) discovered substantial volatility spillover between sustainability, oil stock returns, and the major indices of oil-importing/exporting countries. Thus, the findings of this assessment indicate the importance of these transmission mechanisms In contrast, the TVP-VAR and QVAR models emphasize short-term volatility spillovers. The TVP-VAR's frequency connectedness framework reveals substantial short-term return spillovers, with the S&P BSE CARBONEX and GREENEX indices demonstrating mutual spillovers of approximately 37% and 41%, respectively. These findings collectively suggest a nuanced understanding of volatility dynamics. While the DCC-GARCH model highlights persistent long-term spillovers, the TVP-VAR model underscores pronounced short-term volatility interactions among financial markets and Indian green stocks. This dual perspective underscores the importance of integrating both short-term fluctuations and long-term impacts in assessing volatility spillovers, offering valuable insights for risk management and portfolio diversification strategies in green finance and broader financial markets.The intermarket volatility connectivity is mainly driven by volatility transmission in the short term (48.54 percent), compared with uncertainty transmission in the long term (12.30 percent). Furthermore, the level of connection is mainly driven by advancements, namely the transmission of shocks, in the short period, which accounts for around 48.54% of the entire impact.

The literature reviewed underscores the interconnectedness between exchange rates, interest rates, and stock market volatility, corroborating our findings of volatility spillover from foreign exchange and interest rates to stock markets. According to Neldi et al. (2021), fluctuations in exchange rates reflect changes in the value of domestic currencies relative to foreign currencies. Similarly, changes in interest rates, as highlighted by Rismaia and Elwisan (2019), influence investor behavior, impacting stock prices. This alignment between theoretical frameworks and empirical evidence is further supported by the research of Agyemang-Badu et al. (2024), which identifies volatility spillovers from exchange rates and interest rates to stock markets during economic expansions and crises. Hence, our study contributes to this body of knowledge by providing additional empirical evidence of volatility transmission from foreign exchange and interest rates to stock markets, emphasizing the importance of considering macroeconomic variables in understanding stock market dynamics.

Our analyses yield significant implications for investors and policymakers alike, providing valuable insights for financial planning and risk mitigation strategies. Particularly noteworthy is the evidence suggesting that commodities serve as effective hedges against adverse movements in stock market returns. Building upon the findings of Sadorsky (2014), certain commodities emerge as potential assets for hedging the downside risk associated with green equities. Notably, commodities such as precious metals and crude oil have demonstrated either low or negative correlations with equities in recent years, making them valuable tools for hedging and portfolio diversification purposes. The evolving landscape of commodity markets, characterized by increased financialization and regulatory changes, offers investors newfound opportunities for diversifying risk within their portfolios. With the development of new financial instruments linked to commodities, investors now have greater accessibility to these markets, facilitating more efficient risk management practices. Furthermore, the availability of diverse commodities as hedging instruments not only enhances portfolio resilience but also aligns with the broader objectives of sustainable investing by mitigating downside risks associated with green equities.

By incorporating commodities into their investment strategies, investors can leverage the unique risk-return characteristics of these assets to enhance portfolio performance and resilience against market volatility. Additionally, policymakers can take cues from our findings to craft regulatory frameworks that promote the integration of commodities into investment portfolios, thereby fostering a more robust and diversified financial ecosystem. Overall, our research underscores the importance of considering commodities as valuable components of investment portfolios, offering both hedging benefits and opportunities for portfolio diversification in the context of sustainable investing. The findings presented in the current study make a significant contribution to extending our existing knowledge about the volatility relationships between green assets and other market segments. It is particularly important for financial institutions that need to determine the degree of interconnection between market risks and green equities to be able to prevent the risk of contagion at times of unstable markets.

5.5 Limitations of the study

While the study on volatility spillover and price discovery between market risk and green investment in India provides valuable insights, several limitations need to be acknowledged:

The study utilizes daily closing prices, which may not capture the complete intraday volatility and rapid market dynamics. The use of high-frequency data could offer more detailed insights, but this analysis did not include such data. Focusing exclusively on the Indian market limits the generalizability of the findings. Although India is a significant emerging market, the results may only apply to other emerging or developed markets with further comparative analysis. The study does not account for potential changes in economic policies or regulations that could affect market risk and green investments. Shifts in policies related to environmental regulations, financial markets, or fiscal policies could significantly influence the relationships observed. The research does not explicitly consider investor behaviour, sentiment, and psychology, which are crucial in understanding market dynamics. Including behavioural finance aspects could provide additional insights into the observed relationships.

5.6 Scope of Further Research

This study opens several avenues for future research in the following areas:

The scope of this research can be expanded to explore the bidirectional relationship between market risk and green investment across both developed and emerging market economies. Future studies can investigate this dynamic further as green investments grow in importance. In this study, daily closing price data are used, future study can use high-frequency data to confirm our results. If we analyze the state of the market every minute or even every second, we can better track the relationship between market risk and green investment.

Future research could examine the intraday dynamics of stock market volatility using more sophisticated models, such as High-Frequency Multivariate Generalized Autoregressive Conditional Heteroscedasticity or using Quantile on Quantile. Furthermore, unlike in the present study, integrating more emerging markets, in addition to those of BRICS, may help enhance the scope and depth of the examination of the global stock market behavior. Similarly, including more developed markets in the analysis may improve the generalizability of the results.

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