Are green bonds more resilient than conventional bonds in times of high market volatility?

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ABSTRACT

In recent years, the investment landscape has been reshaped by environmental crises and unprecedented events such as the COVID-19 pandemic. This thesis explores the dynamics between green bonds and treasury bonds in this altered scenario, aiming to guide investors in crafting strategies that align with their risk and return objectives during turbulent times. Utilizing a substantial dataset from the Refinitiv Eikon database, which includes detailed information on 432 green bonds from 2007 to May 2023, the study analyses the volatility dynamics of these bonds using the GARCH model. The findings indicate that green bonds tend to be a more stable investment option, although with lower returns compared to the potentially higher, yet riskier, returns of treasury bonds. The research highlights a notable negative correlation between the two bond types, suggesting that a mixed portfolio could offer a hedge against losses, providing stability in unstable markets. The study advocates for a balanced portfolio tailored to individual investor profiles to navigate the complex risk-return landscape effectively. Grounded in meticulous research, the thesis aims to be a valuable resource for investors, contributing to discussions on sustainable finance and environmental policy, and guiding stakeholders in fostering financial resilience in the face of environmental challenges.

Key words: Green bonds; Treasury bonds; Environmental Social and Governance (ESG); Corporate Social Responsibility (CSR); GARCH

Os títulos verdes são mais resilientes do que os títulos convencionais em períodos de alta volatilidade do mercado?

Kevin Loyo Díaz

RESUMO

Nos últimos anos, a paisagem de investimentos foi reformulada devido a crises ambientais e eventos sem precedentes, como a pandemia da COVID-19. Esta tese explora as dinâmicas entre os títulos verdes e os títulos do tesouro neste cenário alterado, com o objetivo de orientar os investidores na criação de estratégias que se alinhem com os seus objetivos de risco e retorno em tempos turbulentos. Utilizando um conjunto de dados substancial da base de dados Refinitiv Eikon, que inclui informações detalhadas sobre 432 títulos verdes de 2007 a maio de 2023, o estudo analisa a dinâmica da volatilidade destes títulos usando o modelo GARCH. As descobertas indicam que os títulos verdes tendem a ser uma opção de investimento mais estável, embora com retornos mais baixos comparados aos retornos potencialmente mais altos, mas mais arriscados, dos títulos do tesouro. A pesquisa destaca uma correlação negativa notável entre os dois tipos de títulos, sugerindo que um portfólio misto poderia oferecer uma proteção contra perdas, proporcionando estabilidade em mercados instáveis. O estudo defende um portfólio equilibrado, adaptado aos perfis individuais dos investidores, para navegar eficazmente na complexa paisagem de risco-retorno. Baseada em uma pesquisa meticulosa, a tese aspira ser um recurso valioso para os investidores, contribuindo para discussões sobre finanças sustentáveis e política ambiental, e orientando as partes interessadas na promoção da resiliência financeira face aos desafios ambientais.

Palavras clave: Green bonds; Treasury bonds; Environmental Social and Governance (ESG); Corporate Social Responsibility (CSR); GARCH

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List of Abbreviations.

ESG - Environmental, Social, and Governance

WB - World Bank

USD - United States Dollar

EIB - European Investment Bank

CEO - Chief Executive Officer

ICMA - International Capital Market Association

ESG - Environmental, Social, and Governance

EU - European Union

KPI - Key Performance Indicator

LCA - Life Cycle Assessment

ISO - International Organization for Standardization

GBP - Green Bond Principles

CBS - Climate Bonds Standard

OECD - Organisation for Economic Co-operation and Development

CSR - Corporate Social Responsibility

ESG - Environmental, Social, and Governance

SDGs - Sustainable Development Goals

ICMA - International Capital Market Association

CBI - Climate Bonds Initiative ISIN - International Securities Identification Number

€ - Euro (currency symbol)

U.S. - United States

UK - United Kingdom

TBill - Treasury Bill

GARCH - Generalized Autoregressive Conditional Heteroskedasticity

WTI - West Texas Intermediate

COVID-19 - Coronavirus Disease 2019

INTRODUCTION.

Investment attitudes have evolved recently (World Bank, 2020) as a result of growing understanding of the dangers and difficulties posed by climate change and global disasters that cause a great fear to investors (Stocker et al., 2013).

The year 2020 was an unprecedented one for investors, with geopolitical tensions such as the fear of a war between North Korea and the U.S., a trade war between the U.S. and China, and a possible hard Brexit. However, the COVID-19 pandemic changed everything (Venturini, 2022). Governments closed borders, economies, and societies, leading to a drop in the stock markets in March and the fall of oil prices below zero for the first time in history (World Bank, 2020). In response, governments and central banks launched fiscal stimulus packages and quantitative easing programs, which helped markets return to normal patterns and maintain investor confidence during the second wave of COVID-19 in the fall. However, greater resilience to losses was observed in funds that followed an ESG-related investment strategy (Ozili, 2022).

In the ongoing global battle against climate change, the financial sector has unveiled a powerful weapon: the green finance initiative. This rapidly evolving field has garnered substantial attention and critical acclaim, thanks in part to its innovative financial instruments designed to mitigate the adverse effects of climate change (Jin et al., 2021; Wang et al., 2022a). From green bonds and green stocks to carbon finance and green loans, this arsenal of tools not only represents a beacon of resilience but also an epitome of an integrated approach, standing superior to the traditional capital market structures (Ozili, 2022; Born et al., 2021). Their large market capitalization and significant issuance potential have propelled them to the forefront, gaining support among an ever-growing pool of investors. An analysis by the Climate Bonds Initiative shines a light on the explosive growth witnessed in this sphere, with the issuance volume of green bonds hitting the $1.9 trillion mark in the first half of 2022, a figure projected to swell to an impressive $2.36 trillion by 2023 (Zanon, 2022). The increasing liquidity signalled by this surge in issuance volume has unsurprisingly captured the attention and interest of investors globally.

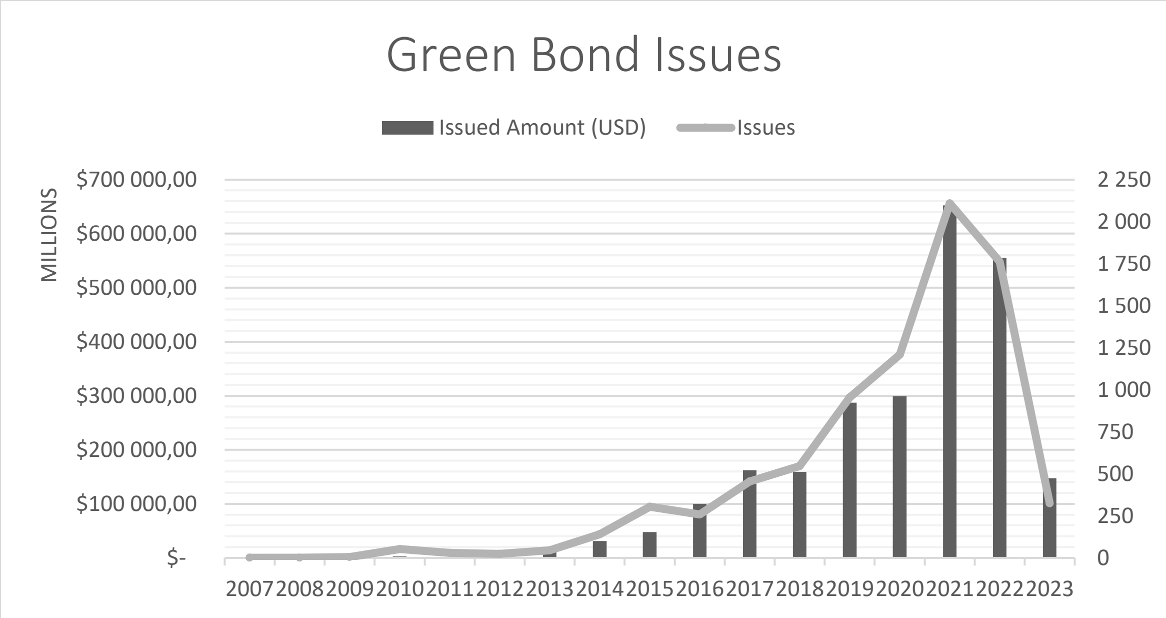

Figure 1 Green Bond Issues. Data Source: Refinitiv Eikon

In this context, a pertinent question arises: Are green bonds more resilient than conventional bonds in times of high market volatility? This thesis guides investors to address this question through a detailed exploration based on extensive studies. Leveraging the GARCH model and descriptive analysis, it offers a comprehensive understanding of using green bonds as a type of hedge during times of high volatility and investigates the promotion of their usage for sustainable development. The study contributes to the ongoing discussion about sustainable finance and environmental policy by providing evidence for financiers and policymakers who wish to strengthen financial resilience in the face of environmental concerns (Flammer, 2018).

The research shows that investing in green bonds is usually a safer bet, although they offer lower profits compared to the sometimes higher but riskier gains you can get from treasury bonds. The study points out a noticeable opposite trend between these two types of bonds, hinting that having a mix of both in your investment portfolio could protect you from big losses, offering a stable option in unpredictable markets. It emphasizes that green bonds have demonstrated a tendency to be more resilient during times of high market volatility, offering a semblance of stability in a turbulent market landscape. However, the optimal investment strategy would invariably hinge on individual investor preferences, risk tolerance, and return objectives. Thus, a judicious mix of green and treasury bonds, tailored to the investor's profile, could potentially offer a pathway to navigate the complex risk-return landscape effectively.

1. LITERATURE REVIEW.

In the face of escalating concerns surrounding climate change and the urgent need for sustainable development, the financial markets have witnessed a surge in green financial instruments, one of which is green bonds (Jin et al., 2021; Wang et al., 2022a). Amidst the volatile market conditions, understanding the resilience and hedging capabilities of green bonds as compared to conventional bonds becomes crucial. This literature review aims to delve into existing research and perspectives to foster a deeper understanding of the topic at hand.

Understanding the regulatory landscape governing green bonds can shed light on their reliability as investment options. Several international bodies and frameworks guide the issuance and transparency requirements of green bonds, aiming to curb issues such as "greenwashing" (European Commission, 2018). A deeper analysis into how regulatory standards influence the market perception and performance of green bonds can be pivotal in understanding their hedging potential.

The EU Technical Expert Group on Sustainable Finance highlighted the role of active and specialized green bond managers in ensuring investments have the desired impact. They pointed to avenues like Article 9 ESG fund as a means to enhance investor confidence in green bonds. (EU Technical Expert Group on Sustainable Finance, 2020) Therefore, it is important to understand this regulations and requirements at the moment we are making an investment decision.

1.1 How Green are Green Bonds?

Although the market for green bonds is expanding quickly, critics contend that there have been many instances of "greenwashing," or making false or exaggerated claims about how a country or company's products, processes, or corporate strategies are environmentally friendly in order to raise money in the most active area of the fixed income markets (Schroder, 2017). Due to the market's voracious need for green bonds, new, possibly dubious participants can now easily access the market to finance normal operations (Flammer, 2018). But experts also point out that one of the main issues facing the market is the absence of universal guidelines or norms (Karpf & Mandis, 2017). However, EU policymakers are trying to regulate this problem (European Commission, 2018).

How can investors ensure that their green bond investments are having the desired impact in the face of this continued uncertainty? Instead of using an index that can have exposure to dishonest issuers, the first step is to invest with an active and specialized green bond manager

(Kidney, 2016). One method to have more confidence that the manager's underlying assets are linked to the EU's green taxonomy is to invest with an Article 9 ESG fund as opposed to an Article 8 ESG fund (EU Technical Expert Group on Sustainable Finance, 2020). Article 8 funds could be considered as 'light green' and article 9 as 'dark green' since the requirements are higher to be labelled as an article 9 fund.

Calculating the "greenness" of the green bonds could be a difficult task to do, as there is not an only way to do it to properly quantify the environmental impact (Lebègue, 2015). However, some recommendations that one can follow are:

- Examine how the money was used: Examine the green bond-funded projects to see if they support well-known environmental goals like climate change adaptation, mitigation, or renewable energy or sustainable water management (OECD, 2017).
- Evaluate the factors for project selection: Examine the issuer's selection and evaluation procedures for green projects that qualify. Make that the initiatives adhere to accepted sustainability standards and support the issuer's overall environmental policy (ICMA, 2018).
- Analyse the environmental effect of the financed projects by computing key performance indicators (KPIs), such as decreased carbon emissions, energy, water, or waste production savings. To measure these effects, you can utilize tried-and-true approaches like life cycle assessment (LCA) (ISO, 2006).
- Compare to other criteria or the Green Bond Principles (GBP): Verify if the green bonds adhere to the GBP or other accepted standards for green bonds, such as the Climate Bonds Standard (CBS) or the European Union (EU) Green Bond Standard (Climate Bonds Initiative, 2017).

This text digs deep into the critical aspect of the authenticity and the genuine impact of green bonds, which is a hot topic given the rise in "greenwashing" activities. By dissecting the means through which an investor can ensure the true "greenness" of a bond, it provides a gateway to understand the stability and potential resilience these bonds could offer in tumultuous market conditions (Schroder, 2017; Flammer, 2018).

Moreover, exploring the EU's regulatory attempts and differentiating between 'light green' and 'dark green' funds according to the EU's green taxonomy offers a nuanced understanding of the protective measures in place for investors, potentially speaking to the resilience of green bonds (EU Technical Expert Group on Sustainable Finance, 2020; European Commission, 2018).

1.2 Green Bonds Principles.

The International Capital Market Association (ICMA) developed the four fundamental Green Bond Principles (GBP) as a set of rules to encourage openness, candour, and integrity in the green bond market. These guidelines guarantee that projects with an environmental impact are funded with the proceeds from green bonds. The GBP provide guidelines and recommendations for issuing bonds serving social and/or environmental purposes to promote transparency and disclosure, and they aim to attract more capital to support sustainable development. The GBP provide high-level categories for eligible Green Projects, while encouraging all market participants to develop their own robust practices. Green Bonds are any type of bond instrument where the proceeds or an equivalent amount will be exclusively applied to finance or re-finance eligible Green Projects that are aligned with the four core components of the GBP. Bonds issued under earlier Green Bond Guidance released prior to this version are deemed consistent with the GBP. (Green Bond Principles, 2021) These four core components for alignment with the GBP are:

a. Use of Proceeds: Only suitable green projects, including those involving renewable energy, energy efficiency, preventing pollution, sustainable water management, or climate change adaptation, shall get funding from the revenues of green bonds. The project's environmental goals should be made clear in the material given. (Green Bond Principles, 2021)
b. Process for Project Evaluation and Selection: Green bond issuers must distinctly describe the procedure for assessing and choosing qualified green projects. This may entail outlining the eligibility requirements, the goals for environmental sustainability, and how the projects fit within the issuer's environmental strategy. (Green Bond Principles, 2021)
c. Management of Proceeds: Issuers should set up a clear and traceable framework for handling the proceeds from their green bonds. This can entail utilizing a different account or subaccount where the money is only allotted to approved green projects. Investors should be informed about the management process, and it should be documented. (Green Bond Principles, 2021)

d. Reporting: Issuers shall regularly report on how proceeds are being used, including updates on how much money has been allocated to green projects that qualify, how much has been distributed, and what the estimated environmental impact will be. These reports ought to be made available to the public, ideally once a year, and might be subject to external evaluation or verification by unaffiliated third parties. (Green Bond Principles, 2021)

The importance of standards and certifications in the market for green bonds is another crucial factor. Issuers frequently seek accreditation from independent groups like the International Capital Market Association or the Climate Bonds Initiative to ensure that green bonds are really funding initiatives that are good for the environment. It's pivotal to underline how adherence to recognized standards and guidelines, like the Green Bond Principles (GBP), might be a contributing factor to their resilience, creating a trust factor that can possibly steer them towards stability even in volatile markets. (Climate Bonds Initiative, 2017) This detailed exploration of the mechanisms that govern green bonds lays a robust groundwork for arguing their resilience compared to conventional bonds. It sets a premise that they are backed by tangible, environmentally beneficial projects, which might be seen as more sustainable and reliable during unstable times in the market (OECD, 2017; ICMA, 2018; ISO, 2006).

There are still issues to be resolved despite the green bond market's expansion. One of the most significant is the market's lack of standardization, which can make it challenging for investors to compare various bonds and evaluate their environmental impact. According to SEB's Anna Zubets-Anderson, head of sustainable finance, "For the green bond market to flourish, standardization is essential. So that investors may make wise selections, we need to provide standardized definitions and measures."

1.3 Crisis Identification

Over the past 20 years, there have been multiple financial crises around the world, each of which has had a huge and lasting effect on global economies and financial markets (World Bank, 2020). It is crucial to evaluate and comprehend the mechanics of these crises in order to create efficient risk management plans. This section explores the crisis identification process and evaluates the potential of green bonds as a superior hedge compared to conventional bonds during times of high market volatility. The crises selected for examination in this study include:

1. **Global Financial Crisis (2007-2008):** The crisis began with the depreciation of the subprime mortgage market in the United States, and it peaked with the bankruptcy of Lehman Brothers (Sorkin, 2009).

2. **European Sovereign Debt Crisis (2010-2012):** The crisis occurred when Greece accepted a bailout, and again from 2011-2012. Sovereign bond yields for several European countries, particularly Greece, Ireland, Portugal, Spain, and Italy, skyrocketed as investors feared default (Mody, 2018).

3. **U.S. Debt Ceiling Crisis (2011):** Political deadlock over the U.S. debt ceiling led to fears of a potential U.S. default, causing Treasury yields to fluctuate (Klein, 2013).

4. **Taper Tantrum (2013):** The U.S. Federal Reserve suggested it might start tapering its quantitative easing program, leading to a sharp rise in Treasury yields (Stein, 2014).

5. **Chinese Stock Market Crash (2015-2016):** Concerns about high debt levels among Chinese corporations led to increased yields and volatility in the Chinese bond market (Lardy, 2019).

6. **UK Brexit Vote (June 23, 2016):** The referendum took place on June 23, 2016, and markets reacted immediately to the decision (Hobolt, 2016).

7. **U.S. Stock Market Crash (February 2018):** The Dow Jones Industrial Average fell 1,175 points on February 5, 2018, its largest one-day point drop in history at the time (Cox, 2018).

8. **U.S. Stock Market Fall (December 2018):** The stock market downturn happened throughout December 2018, with a significant drop occurring on December 24 (Imbert & Huang, 2018).

9. **Oil Price Crash (2020):** The price of oil dropped significantly, with West Texas Intermediate (WTI) going negative for the first time in history. The crash in oil prices put significant pressure on oil-producing nations and oil companies, leading to rising yields on their debt due to fears of default. (DiChristopher, 2020)

10. **COVID-19 Market Crash (2020):** The rapid global spread of the virus triggered a sharp sell-off in global stock markets (Goodman, Swanson, & Platt, 2020).n

Throughout this thesis, we will analyse the distinctive characteristics and consequences of each crisis, highlighting their impact on conventional bonds. Additionally, we will explore the potential of green bonds as a more robust hedge during times of high market volatility, considering their unique features and alignment with sustainability objectives. By investigating these crises and the performance of green bonds within them, this study seeks to provide valuable insights for investors, policymakers, and financial institutions aiming to enhance their risk management practices in the face of market turmoil.

1.4 GARCH Model.

In the final chapter of this analytical journey, the GARCH model took centre stage, unveiling the volatility dynamics that played out in the bond market. The GARCH model is an extension of the simpler ARCH (Autoregressive Conditional Heteroskedasticity) model introduced by Robert Engle in 1982 (Engle, 1982). The GARCH model, introduced by Tim Bollerslev in 1986, incorporates lagged values of both the conditional variance and the squared return into the model, allowing for a more flexible representation of the volatility dynamics (Bollerslev, 1986). Using the GARCH model to calculate the volatility of green bond and treasury bond returns during specific periods is beneficial for several reasons:

Capturing Volatility Dynamics: The GARCH model is adept at capturing the time-varying volatility that is often observed in financial time series data. It can effectively model changing volatility patterns over time, which is essential in understanding the risk dynamics of both green and treasury bonds during different periods. (Bollerslev, 1986)

Incorporating Past Information: The model considers both past returns and past volatilities in its formulation. This feature allows it to incorporate more information in the volatility estimation, providing a richer analysis compared to using just simple descriptive statistics. (Bollerslev, 1986)

Risk Management and Investment Strategy: Understanding volatility dynamics through GARCH can aid investors in risk management and in devising investment strategies that are aligned with their risk tolerance levels. It helps in understanding the risk-return trade-off associated with green and treasury bonds, facilitating more informed investment decisions. (Bollerslev, 1986)

Comparative Analysis: Using the GARCH model facilitates a comparative analysis of the volatility of green and treasury bonds. It helps in identifying periods where one type of bond offers a lower risk compared to the other, aiding in portfolio optimization and risk diversification. (Bollerslev, 1986)

Insights into Market Reactions to Economic Events: By analysing different periods separately, it is possible to understand how the volatilities of green and treasury bonds respond to different economic events and crises. This can provide valuable insights into the resilience and stability of these bonds in various market conditions. (Bollerslev, 1986)

Enhanced Forecasting: The GARCH model can be used to forecast future volatility based on past data, which can be a valuable tool for investors looking to anticipate future market conditions and adjust their strategies accordingly. (Bollerslev, 1986)

In summary, using the GARCH model for analysing the volatility of green and treasury bond returns during different periods can provide a deep and nuanced understanding of the risk characteristics of these bonds, aiding investors in making informed decisions and crafting strategies that align with their risk and return objectives. It complements descriptive analysis by providing a dynamic view of volatility, which is grounded in historical data and considers the changing nature of financial markets.

2. METHODOLOGY.

2.1 Data

In the early stages of my research, I embarked on a meticulous journey of data extraction using the reliable Refinitiv Eikon database. The first step was to manually gather detailed information on green bonds annually, from 2007 all the way to May 31, 2023. This treasure trove of data included specifics such as ISIN, issuing country, and the yield, among other details.

As I delved deeper, I organized the data, focusing on the issuance amounts which spanned a substantial €2,461,315,348,400.41 for 432 bonds. Despite the early years showcasing smaller amounts, they held their ground in the analysis, contributing to a rich historical perspective. My sample carved out a significant portion, encapsulating around 34% of the total, amounting to €844,780,842,164.65.

The journey then led to a meticulous extraction of daily bid and ask prices for each bond. While this was feasible for 163 bonds, the remaining required a manual approach, a testament to the hands-on nature of this research.

Recognizing the substantial disparity in the bond issuances over the studied period, I resolved to create two indices where I averaged the daily returns of all green and traditional bonds, ensuring a consistent number of observations over the same timeframe. This strategy, although with limitations such as varying issuing countries and their respective unemployment and risk-free rates, proved to be aligned with the general conclusions drawn from the study. The findings illustrated that over time, green bonds exhibited significantly lower volatility compared to their traditional counterparts, albeit with slightly reduced yields.

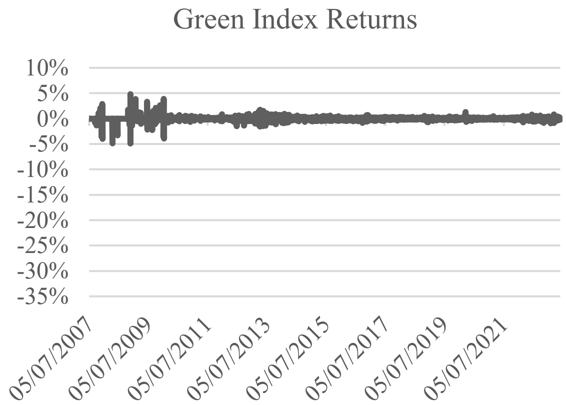

Figure 3. Green Index Returns. Data Source: Refinitiv Eikon

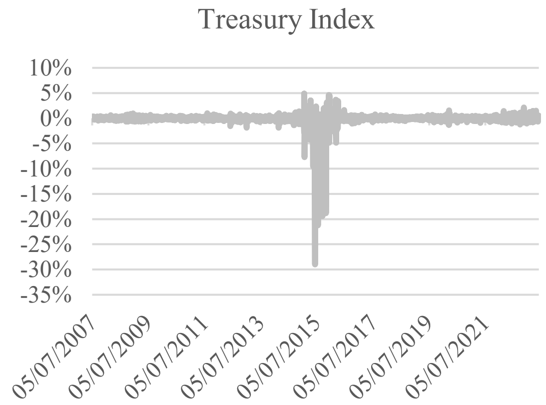

Figure 2. Treasury Bonds Returns. Data Source: Refinitiv Eikon

The narrative then expanded its horizons to encompass a global perspective, spotlighting four major countries - the United States, China, Germany, and the United Kingdom. These nations, pivotal in the bond market, became the focus as I extracted bond returns for maturities ranging from one to ten years, a range that represented the majority of the issued amount in my sample.

With a rich dataset at my disposal, I ventured into descriptive analytics, a stage where the data began to tell its story through a spectrum of statistical measures. From mean and median to skewness and excess kurtosis, each metric wove a part of the larger narrative, offering a detailed statistical portrait of the bond landscape. It is important to point out that for the correlation and beta between both assets, I used the indices created before to have the same number of data per date.

Once I had this, GARCH model was crucial in this thesis to calculate volatility of green and conventional bonds, since it can effectively model changing volatility patterns over time, which is essential in understanding the risk dynamics of both bonds during different periods.

The GARCH (p, q) model can be represented mathematically as follows(Bollerslev, 1986):

$rt=\mu+\varepsilon t$

$\varepsilon_t=\sigma_t z_t$

$\sigma_t^2=\alpha_0+\sum_{i=1}^{p}\alpha_i\varepsilon_{t-i}^2+\sum_{j=1}^{q}\beta_j\sigma_{t-j}^2$

Where:

- r_t: Return at time t
- μ: Mean of the return series
- ε_t: Error term at time t
- σ_t: Conditional volatility at time t
- z_t: A white noise error term with zero mean and unit variance
- α_0: Constant term
- α_i: ARCH parameters (relating to past squared returns)
- β_j: GARCH parameters (relating to past conditional variances)
- p: The number of lags of the squared return to include (ARCH terms)
- q: The number of lags of the conditional variance to include (GARCH terms)

Estimation

The parameters of the GARCH model (α's and β's) are typically estimated using maximum likelihood estimation (MLE), which involves finding the parameter values that maximize the likelihood function of the observed data. (Bollerslev, 1986)

By comparing this model between the two assets, and joined to the descriptive analysis, the image became clear, showing which type of bond had better returns during certain periods, as well as showing how much volatility they had. In addition to this, having a bigger image with the indices and the biggest issuer countries, helped me to give more validation to the studies, showing similar result over the years in the majority of the scenarios.

3. RESULTS

A major constraint in this study was the disparate number of observations for the green and treasury bonds during the specified period. To mitigate this, we devised two indices to average out the returns from each category of bonds, hoping to enable a more equitable analysis. Nonetheless, this solution is not without its flaws, as it might overlook the subtle differences and complexities inherent to the various bonds encompassed in the study, including influences from the economic condition of the country of issuance and other geopolitical aspects. Therefore, while the formulated indices serve to create a somewhat even playing field for analysing the data, they are not exempt from limitations. It beckons a circumspect appraisal of the results, recognizing the possible impact of variables not accounted for in the study. It remains an avenue for future studies to enhance the methodology by considering these factors for a more nuanced examination.

3.1 Green and Treasury Index

As I delve into the data, I notice that the mean returns of the green bonds are -0.0079%, which is higher compared to the treasury bonds which stand at -0.0887%. This indicates a slightly better average performance of green bonds over the treasury bonds during the whole period studied, from January 2007 until May 2023.

Moving forward, I observe the median values, where the green bonds have a median return of 0.0000%, slightly outperforming the treasury bonds which have a median return of 0.0009%. This suggests that the central tendency of green bonds is to remain stable, offering a slight edge over the treasury bonds.

As I analyze the extreme values, it is evident that green bonds have experienced less fluctuation, with a minimum and maximum return of -4.8655% and 4.8225% respectively, compared to the treasury bonds which have a wider range, with returns varying from -28.9772% to 4.8802%. This data points towards a more stable performance of green bonds in turbulent market conditions, indicating their potential as a safer investment avenue during the period analyzed.

Examining the standard deviation, which stands at 0.3277% for green bonds and 1.1228% for treasury bonds, it is clear that green bonds have exhibited less volatility compared to treasury bonds. This lower standard deviation suggests that green bonds might offer a more stable investment option, demonstrating less susceptibility to market fluctuations.

Looking at the skewness of the distribution, the green bonds have a value of -0.9635, compared to -13.0397 for the treasury bonds, indicating a less negative skew for the green bonds. This suggests that green bonds have experienced fewer extreme negative returns compared to treasury bonds, which is a favorable indicator of their resilience in volatile markets.

Further, the Jarque-Bera test results, being 880,383.07 for green bonds and 9,960,145.57 for treasury bonds, and the corresponding p-values of 0.00% for both, reject the hypothesis of a normal distribution for the returns of both indices. This implies that the returns have experienced significant deviations from the normal distribution, indicating the presence of outliers and the need for a cautious approach while interpreting the data.

Lastly, the beta value of the green index is -0.0168, illustrating that it has a tendency to move in the opposite direction to the market. This negative beta suggests that green bonds can potentially serve as a protective hedge during market downturns, offering a level of safety against market volatility.

In conclusion, the data suggests that green bonds have demonstrated a tendency towards more stability and resilience compared to treasury bonds during periods of high market volatility. The lower standard deviation, higher mean and median returns, and a negative but closer to zero skewness value indicate a potentially safer investment avenue in green bonds. However, the high kurtosis values and the results of the Jarque-Bera test signal the necessity for a careful and detailed analysis to fully understand the risk and return dynamics of investing in green bonds.

	Green Index	**Treasury Index**
Date	**Jan 2007 - May 2023**	
Mean	-0,0079%	-0,0887%
Median	0,0000%	0,0009%
Minimum	-4,8655%	-28,9772%
Maximum	4,8225%	4,8802%
Standar. Dev	0,3277%	1,1228%
Skew	-0,9635	-13,0397
Excess Kurtosis	71,3278	238,5806
Observations	4150	4150
Jarque-Bera	880 383,07	9 960 145,57
P value	0,00%	0,00%
Correlation	-0,057557606	
Beta	-0,016799167	

Table 1. Green and Treasury Index

3.2 United States, Germany, China and United Kingdom

When we look at the US market, it is quite fascinating to note that both the green and TBill bonds are neck and neck with a mean and median hovering around a negligible 0.00%. However, as a budding analyst, I couldn't help but notice a slightly higher volatility in green bonds, a detail that might pique the interest of risk-tolerant investors. The skewness paints a vivid picture of the contrasting landscapes of these bonds; the green bonds leaning towards negative returns and the TBill bonds showcasing a propensity for positive spikes. The high kurtosis in both bonds, especially green bonds, whispers tales of extreme values lying in the tails of their distribution.

Shifting our gaze to Germany, the green bonds slightly edge out with a 0.01% mean, a hint at the potential for marginally higher average daily returns. The story of volatility continues with green bonds portraying a character of lesser volatility, a trait that might find favor with risk-averse investors. The plot thickens with the TBill bonds exhibiting a dramatic skewness and kurtosis, narrating a saga of a more leptokurtic distribution with potential for extreme events.

As we traverse to the Chinese market, the narrative remains consistent with the US and Germany, with both types of bonds narrating a tale of negligible mean and median returns. However, the green bonds take a conservative stance, showcasing a lower volatility, a narrative that might resonate with investors seeking stability. The skewness and kurtosis values weave a story of a relatively balanced distribution for green bonds, albeit with a slight negative skew, hinting at a cautious approach to investment.

Finally, in the UK market, the green bonds seem to be undergoing a turbulent phase with a negative mean return, albeit marginally, narrating a tale of slight losses. The TBill bonds, on the other hand, narrate a tale of extremes, with a skewness and kurtosis that are off the charts, indicating a landscape of high volatility and potential for extreme values.

	3-10 Green US	**3-10 TBill US**	**3-10 Green DE**	**3-10 TBill DE**	**3-10 Green CN**	**3-10 TBill CN**	**3-10 Green UK**	**3-10 TBill UK**
Mean	0,00%	0,00%	0,01%	0,00%	0,00%	0,00%	-0,01%	0,00%
Median	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Minimum	-21,96%	-10,51%	-3,09%	-9,80%	-1,06%	-4,44%	-4,72%	-35,91%
Maximum	11,37%	14,09%	2,95%	14,83%	0,82%	4,00%	4,21%	35,13%
Std. Dev	0,59%	0,53%	0,38%	0,49%	0,07%	0,29%	0,41%	0,84%
Skew	-1,1872	0,8685	-0,05043	2,7647	-0,2700	0,4679	0,06302	7,8083
Excess Kurtosis	109,7453	137,07536	5,4550	248,2005	21,9208	40,7876	27,8500	1104,1851
Observations	26183	8566	22589	12849	6328	8767	7149	12849

Table 2. US, DE, CN, UK

3.3 Global Financial Crisis (2007-2008)

During this period, green bonds exhibited a mean return of 0.0017%, a median of 0.0011%, and a standard deviation, a measure of volatility, of 0.0135%. On the other hand, treasury bonds had a higher mean return of 0.0107% but with a much higher standard deviation of 0.5424%, indicating a more volatile nature. The green bonds had a negative skewness and a high kurtosis, suggesting a tendency for extreme negative returns, although less frequent. Conversely, treasury bonds had a positive skewness, indicating a propensity for higher returns, coupled with a very high kurtosis, pointing to more frequent extreme returns.

The GARCH model, employed to further understand the volatility dynamics, revealed that green bonds had a slightly negative mean return with a significant alpha and beta coefficients, indicating a substantial influence of past volatilities and returns on the current volatility. The treasury bonds, however, showcased a small positive mean return with a higher alpha coefficient, suggesting a higher responsiveness to past shocks compared to green bonds.

Drawing from the correlation coefficient of 0.0191 and a beta of 0.0512, it is evident that green bonds and treasury bonds have a very low linear relationship, and the green bonds exhibit a low sensitivity to the movements in the treasury bonds.

In conclusion, if an investor is seeking less volatility, green bonds would be the preferable choice given their lower standard deviation compared to treasury bonds. However, if the investor is chasing higher returns, treasury bonds would stand as the better option, admitting a higher risk due to increased volatility. Moreover, considering the low correlation and beta between the two, incorporating a mix of green and treasury bonds in a portfolio could potentially offer a diversification benefit, helping to balance the pursuit of higher returns while mitigating risks. Thus, a mixed approach would be a strategic choice for investors aiming for a balanced portfolio with a nuanced understanding of the risk-return landscape during crisis periods.

	Global Financial Crisis	
	Green Bonds	**Treasury Bonds**
Date	**Jan 2007-Dec 2008**	
Mean	0,0017%	0,0107%
Median	0,0011%	0,0000%
Minimum	-0,1209%	-14,3811%
Maximum	0,0317%	34,1545%
Standard Dev	0,0135%	0,5424%
Skew	-6,7705	8,1139
Excess Kurtosis	60,7199	654,3094
Observations	107	26816
Correlation	0,019156186	
Beta	0,05119174	

Table 3. Global Financial Crisis

3.4 European Sovereign Debt Crisis (2010-2012)

In this period, green bonds experienced a negative mean return of -0.0075% and a median return of -0.0003%, with a standard deviation of 0.3378%, indicating a moderate level of volatility. The treasury bonds, however, showcased a positive mean return of 0.0055%, given a higher standard deviation of 0.9421%, pointing to a more volatile nature. The green bonds had a negative skewness, suggesting a tendency for lower returns, and a high kurtosis, indicating a presence of extreme values in the returns data. Conversely, treasury bonds exhibited a positive skewness, hinting at a propensity for higher returns, but with a significantly higher kurtosis, showcasing more frequent extreme returns.

The GARCH model, a tool to understand volatility dynamics, revealed that green bonds had a slightly negative mean return with significant alpha and beta coefficients, pointing to a considerable influence of past volatilities and returns on the current volatility. The treasury bonds, on the other hand, had a small positive mean return with a higher beta coefficient, indicating a higher persistence of volatility over time.

The correlation coefficient of -0.0301 and a beta of -0.0428 between the green and treasury bonds suggest a very weak inverse relationship, with green bonds showing a slight tendency to move in the opposite direction to the treasury bonds, although a very small degree.

In conclusion, green bonds would be the more stable choice for investors seeking to avoid volatility, given their lower standard deviation compared to treasury bonds. However, they come with negative mean returns during this period, indicating a loss on average. Treasury bonds, despite their higher volatility, offer positive mean returns, presenting an opportunity for higher gains. Given the very weak inverse relationship between the two, a mixed portfolio of green and treasury bonds might not offer substantial diversification benefits in mitigating risks or enhancing returns. Therefore, the choice between green and treasury bonds would hinge on individual investor preferences, where a risk-averse investor might prefer green bonds for stability, while a risk-tolerant investor might opt for treasury bonds for higher returns. This analysis, grounded in a rich dataset and meticulous research, aims to steer investors in crafting a strategy that aligns with their risk and return objectives during crisis periods.

	European Sovereign Debt Crisis	
	Green Bonds	**Treasury Bonds**
Date	Jan 2010- Dec 2012	
Mean	-0,0075%	0,0055%
Median	-0,0003%	0,0000%
Minimum	-4,1174%	-59,7837%
Maximum	3,3125%	81,6973%
Standard Dev	0,3378%	0,9421%
Skew	-0,6125	6,5711
Excess Kurtosis	33,9625	1822,4470
Observations	1117	44629
Correlation	-0,030165346	
Beta	-0,042806653	

Table 4. European Sovereign Debt Crisis

3.5 U.S. Debt Ceiling Crisis (2011)

The green bonds during this period exhibited a minimal mean return of 0.0003% and a slightly negative median return of -0.0006%. The standard deviation stood at 0.1408%, indicating a relatively low level of volatility. The skewness was negative, suggesting a tendency for the returns to be less than the mean, and the kurtosis was positive, indicating a leptokurtic distribution with heavier tails, which means more frequent extreme values in the returns data.

On the other hand, treasury bonds had a substantial mean return of 0.0410% and a positive median return of 0.0038%. However, they exhibited a higher standard deviation of 0.7778%, pointing to a more volatile nature. The skewness was slightly negative, and the kurtosis was significantly higher, indicating a very leptokurtic distribution with a high frequency of extreme values.

The GARCH model, utilized to understand the volatility dynamics, revealed that green bonds had a positive mean return with significant alpha and beta coefficients, indicating a considerable influence of past volatilities and returns on the current volatility. The treasury bonds also exhibited a positive mean return with significant alpha and beta coefficients, suggesting a high persistence of volatility over time.

The correlation coefficient between the green and treasury bonds was 0.1168, indicating a weak positive relationship. The beta value was 0.0366, suggesting that green bonds were less sensitive to the movements in the treasury bonds.

In conclusion, during the U.S. Debt Ceiling Crisis, green bonds offered a more stable investment avenue with lower volatility compared to treasury bonds, although with much lower mean returns. Treasury bonds, despite their higher volatility, presented a substantial opportunity for gains with a higher mean return. Given the weak positive correlation between the two, a mixed portfolio might offer some level of diversification benefits, helping to balance the risk and return profile. Therefore, an investor aiming for stability might lean towards green bonds, while one seeking higher returns might favor treasury bonds. However, considering the substantial mean return offered by treasury bonds during this period, they appear to be the more favorable option for investors seeking to maximize returns, despite the higher volatility. This analysis, grounded in meticulous research, aims to guide investors in navigating the turbulent waters of a financial crisis with informed investment choices.

	U.S. Debt Ceiling Crisis	
	Green Bonds	**Treasury Bonds**
Date	Jul 2011 - Sep 2011	
Mean	0,0003%	0,0410%
Median	-0,0006%	0,0038%
Minimum	-0,6416%	-10,5130%
Maximum	0,2202%	9,8149%
Standard Dev	0,1408%	0,7778%
Skew	-1,3093	-0,1813
Excess Kurtosis	2,6894	31,8662
Observations	66	3771
Correlation	0,116814962	
Beta	0,036583993	

Table 5. US Debt Ceiling Crisis

3.6 Taper Tantrum (2013)

Green bonds during this period exhibited a positive mean return of 0.0063% but a slightly negative median return of -0.0003%. The standard deviation was relatively high at 1.6793%, indicating a higher level of volatility. The skewness was near zero, suggesting a fairly symmetrical distribution of returns, while the kurtosis was positive, indicating a leptokurtic distribution with a higher probability of extreme values. The GARCH model revealed a positive mean with significant alpha and beta coefficients, indicating a considerable influence of past volatilities and returns on the current volatility.

In contrast, treasury bonds had a negative mean return of -0.0441% and a median return of 0.0000%. The standard deviation was 1.0143%, pointing to a high volatility, although lower than that of green bonds. The skewness was significantly negative, indicating a tendency for the returns to be less than the mean, and the kurtosis was extremely high, pointing to a very leptokurtic distribution with a high frequency of extreme values. The GARCH model for treasury bonds showed a negative mean return with significant alpha and beta coefficients, indicating a high persistence of volatility over time.

The correlation between the green and treasury bonds was -0.0709, suggesting a weak negative relationship, while the beta was -0.3247, indicating that green bonds were less sensitive to the movements in the treasury bonds and might even move in the opposite direction.

In conclusion, during the Taper Tantrum period, green bonds demonstrated a positive mean return, but with high volatility, making them a potentially profitable but risky investment. On the other hand, treasury bonds exhibited negative mean returns with high volatility, representing a less favorable investment option during this period. Given the negative correlation between the two, a mixed portfolio could potentially offer diversification benefits, helping to hedge against losses.

Therefore, for investors seeking to maintain a positive return during this period, green bonds appear to be the better option, despite their high volatility. However, a cautious approach would be to hold a mix of green and treasury bonds to leverage the diversification benefits arising from their negative correlation, thereby creating a portfolio that is somewhat shielded from extreme market fluctuations while still retaining the potential for positive returns. This strategy aligns with the principle of not putting all eggs in one basket, promoting a balanced risk-return profile during turbulent market phases.

	Taper Tantrum	
	Green Bonds	**Treasury Bonds**
Date	Apr 2013 - Jun 2013	
Mean	0,0063%	-0,0441%
Median	-0,0003%	0,0000%
Minimum	-7,0130%	-23,0123%
Maximum	6,6758%	11,0001%
Standard Dev	1,6793%	1,0143%
Skew	-0,0498	-3,4685
Excess Kurtosis	4,4730	119,0151
Observations	286	3660
Correlation	-0,070887151	
Beta	-0,324690494	

Table 6. Taper Tantrum

3.7 Chinese Stock Market Crash (2015-2016)

Firstly, it is noteworthy to mention that green bonds exhibited a positive mean return of 0.0310%, even with a small magnitude, while treasury bonds faced a substantial negative mean return of -1.2725%. The extreme values in the distribution of the treasury bonds returns, indicated by the minimum and maximum values, point towards a highly volatile period for these bonds, with fluctuations reaching as low as -1550.0000% and as high as 256.4949%. In contrast, green bonds maintained a more stable profile with a maximum and minimum return of 4.4382% and -3.2745% respectively.

The standard deviation, a measure of volatility, was significantly higher for treasury bonds (29.8979%) compared to green bonds (0.5061%), highlighting a period of greater uncertainty and risk associated with treasury bonds. The skewness and excess kurtosis values further corroborate the presence of heavy tails and extreme values in the distribution of the treasury bonds returns, indicating a period of tumultuous fluctuations.

The GARCH model results, utilized to understand the volatility dynamics, reveal that both sets of bonds maintained a constant mean model with negligible R-squared values, implying that the returns were not influenced significantly by the past values. However, the volatility dynamics, represented by the alpha and beta parameters, were more stable for green bonds, with a higher beta value (0.8800) compared to treasury bonds (0.7800), suggesting a more persistent volatility.

In conclusion, for an investor with a risk-averse profile seeking to maintain a portfolio with lower volatility during the Chinese Stock Market Crash period, green bonds would be the preferable choice, offering positive returns with much lower volatility compared to treasury bonds. However, for an investor willing to embrace a higher risk for potentially higher (yet highly volatile) returns, a strategy involving a mix of treasury bonds could be considered, with a cautious approach given the extreme fluctuations witnessed in this period.

Therefore, a prudent strategy would be to hold a more substantial portion of green bonds to leverage the positive mean returns and lower volatility, complemented by a smaller allocation to treasury bonds to potentially capitalize on high-return opportunities, although with a readiness to bear higher risk. This strategy would essentially aim to strike a balance between risk and return, steering towards a more stable and positive return landscape.

	Chinese Stock Market Crash	
	Green Bonds	**Treasury Bonds**
Date	May 2015 - Mar 2016	
Mean	0,0310%	-1,2725%
Median	0,0000%	0,0000%
Minimum	-3,2745%	-1550,0000%
Maximum	4,4382%	256,4949%
Standard Dev	0,5061%	29,8979%
Skew	1,9624	-29,6433
Excess Kurtosis	11,2037	1098,9786
Observations	4447	14801
Correlation	-0,13724316	
Beta	-0,007065797	

Table 7.Chinese Stock Market Crash

3.8 UK Brexit Vote (2016)

Looking at the mean returns, it is observed that both green and treasury bonds experienced positive returns, with treasury bonds slightly outperforming green bonds with a mean return of 0.0756% compared to 0.0416%. However, when we delve deeper into the data, it is evident that the treasury bonds exhibited a higher level of volatility, as indicated by a standard deviation of 1.4705%, compared to green bonds which had a standard deviation of 0.6166%.

The skewness and excess kurtosis values for both bond types were significantly high, indicating a presence of extreme values in the returns distribution, with treasury bonds showing a higher propensity for extreme values, as evidenced by a higher skewness of 6.6401 and a remarkably high excess kurtosis of 325.3114.

The GARCH model results further substantiate the observations made from the descriptive statistics. The green bonds exhibited a negative mean in the model, which contrasts with the positive mean observed in the descriptive statistics, suggesting a potential anomaly or a period of negative shocks influencing the returns. The volatility parameters for green bonds indicate a less stable volatility process compared to treasury bonds, as seen in the lower beta value and a not statistically significant alpha value. In contrast, the treasury bonds maintained a more stable volatility process, with significant alpha and beta parameters, indicating a well-fitted model to the returns series.

Drawing conclusions from the analysis, it is evident that during the Brexit vote period, holding treasury bonds would have yielded higher returns compared to green bonds. However, this comes with a caveat of higher volatility and a greater propensity for extreme values, indicating a higher risk associated with treasury bonds during this period.

Therefore, for investors seeking higher returns and willing to absorb a higher level of risk, treasury bonds would be the more suitable option. Conversely, for those looking for a less volatile asset, green bonds would be the preferable choice, although with lower returns. Given the negative correlation of -0.2665 between the two assets, a mixed portfolio holding both green and treasury bonds could potentially offer benefits of diversification, allowing for a reduction in risk while still achieving reasonable returns.

In conclusion, a balanced approach involving a mix of both green and treasury bonds would be the most prudent strategy during the UK Brexit vote period, leveraging the diversification benefits to navigate a period characterized by high uncertainty and market fluctuations. This strategy would aim to strike a harmonious balance between risk and return, providing a shield against extreme market movements while capitalizing on the opportunities presented during this historic event.

	UK Brexit Vote	
	Green Bonds	**Treasury Bonds**
Date	May 2016 - Jul 2016	
Mean	0,0416%	0,0756%
Median	-0,0024%	0,0030%
Minimum	-4,2031%	-22,3144%
Maximum	7,0472%	43,9367%
Standard Dev	0,6166%	1,4705%
Skew	5,2544	6,6401
Excess Kurtosis	49,5388	325,3114
Observations	1827	3442
Correlation	-0,266550249	
Beta	-0,12434645	

Table 8. UK Brexit Vote

3.9 U.S. Stock Market Crash (2018)

Looking at the mean returns, it is observed that both green and treasury bonds experienced positive returns, with treasury bonds slightly outperforming green bonds with a mean return of 0.0756% compared to 0.0416%. However, when we delve deeper into the data, it is evident that the treasury bonds exhibited a higher level of volatility, as indicated by a standard deviation of 1.4705%, compared to green bonds which had a standard deviation of 0.6166%.

The skewness and excess kurtosis values for both bond types were significantly high, indicating a presence of extreme values in the returns distribution, with treasury bonds showing a higher propensity for extreme values, as evidenced by a higher skewness of 6.6401 and a remarkably high excess kurtosis of 325.3114.

The GARCH model results further substantiate the observations made from the descriptive statistics. The green bonds exhibited a negative mean in the model, which contrasts with the positive mean observed in the descriptive statistics, suggesting a potential anomaly or a period of negative shocks influencing the returns. The volatility parameters for green bonds indicate a less stable volatility process compared to treasury bonds, as seen in the lower beta value and a not statistically significant alpha value. In contrast, the treasury bonds maintained a more stable volatility process, with significant alpha and beta parameters, indicating a well-fitted model to the returns series.

Drawing conclusions from the analysis, it is evident that during the Brexit vote period, holding treasury bonds would have yielded higher returns compared to green bonds. However, this comes with a caveat of higher volatility and a greater propensity for extreme values, indicating a higher risk associated with treasury bonds during this period.

Therefore, for investors seeking higher returns and willing to absorb a higher level of risk, treasury bonds would be the more suitable option. Conversely, for those looking for a less volatile asset, green bonds would be the preferable choice, although with lower returns. Given the negative correlation of -0.2665 between the two assets, a mixed portfolio holding both green and treasury bonds could potentially offer benefits of diversification, allowing for a reduction in risk while still achieving reasonable returns.

In conclusion, a balanced approach involving a mix of both green and treasury bonds would be the most prudent strategy during the UK Brexit vote period, leveraging the diversification benefits to navigate a period characterized by high uncertainty and market fluctuations. This strategy would aim to strike a harmonious balance between risk and return, providing a shield against extreme market movements while capitalizing on the opportunities presented during this historic event.

	U.S. Stock Market Crash	
	Green Bonds	**Treasury Bonds**
Date	Jan 2018 - Mar 2018	
Mean	0,0098%	0,0165%
Median	0,0000%	0,0000%
Minimum	-2,1338%	-11,4365%
Maximum	3,4005%	6,5945%
Standar. Dev	0,3910%	0,4641%
Skew	0,5559	-2,1081
Excess Kurtosis	6,3580	162,5570
Observations	3807	3384
Correlation	-0,508285453	
Beta	-0,430531853	

Table 9. U.S. Stock Market Crash

3.10 U.S. Stock Market Fall (2018 – 2019)

Looking at the descriptive statistics, green bonds had a negative mean return of -0.0522%, while treasury bonds managed to secure a positive mean return of 0.0335%. The standard deviation, a measure of volatility, was higher for green bonds at 0.6492% compared to 0.3754% for treasury bonds, indicating a higher volatility in green bonds during this period.

The skewness and kurtosis values reveal a significant departure from the normal distribution for both assets, with green bonds having a highly negative skew and treasury bonds having a positive skew. This suggests that green bonds had a tendency for more negative returns, while treasury bonds had a tendency for more positive returns. The kurtosis values were extremely high for both, indicating a presence of extreme values in the returns distribution.

The GARCH model results for both bond types indicate a well-defined volatility process with significant alpha and beta parameters, suggesting that the model captures the volatility dynamics effectively. The green bonds had a slightly higher alpha, indicating a higher responsiveness to recent shocks compared to treasury bonds.

The correlation coefficient of -0.4068 suggests a moderate negative correlation between the two assets, implying that they tend to move in opposite directions. The beta value of -0.6301 further supports this, indicating that green bonds tend to move inversely relative to the treasury bonds, offering a potential diversification benefit.

Drawing from the above analysis, it is evident that during the period of the U.S. stock market fall, treasury bonds would have served as a safer haven for investors, providing positive returns with lower volatility compared to green bonds. However, the green bonds, despite their negative returns, offer a diversification benefit due to their negative correlation with treasury bonds.

In conclusion, for investors navigating the U.S. stock market fall period, holding a mix of green and treasury bonds would be the optimal strategy to both mitigate risk and seek potential returns. Given the negative returns of green bonds, a conservative approach would be to allocate a larger proportion to treasury bonds to leverage their positive returns and lower volatility, while maintaining a smaller proportion of green bonds to capitalize on the diversification benefits arising from their negative correlation with treasury bonds. This strategy aims to strike a balance between risk and reward, offering a pathway to navigate turbulent market conditions with a degree of safety and potential for positive returns.

	U.S. Stock Market Fall	
	Green Bonds	**Treasury Bonds**
Date	Nov 2018 - Jan 2019	
Mean	-0,0522%	0,0335%
Median	0,0000%	0,0010%
Minimum	-12,0711%	-4,5786%
Maximum	4,3993%	7,3519%
Standar. Dev	0,6492%	0,3754%
Skew	-8,4671	1,5769
Excess Kurtosis	124,3743	59,4353
Observations	5181	3568
Correlation	-0,406784095	
Beta	-0,630093562	

Table 10. U.S. Stock Market Fail

3.11 Oil Price Crash (2020)

The mean return for green bonds was slightly positive, standing at 0.0259%, while treasury bonds registered a negative mean return of -0.0375%. This initial data suggests that green bonds offered a refuge of positive yield amidst the economic turmoil instigated by the oil price crash.

A deeper analysis into the volatility of both assets, as represented by the standard deviation, reveals that treasury bonds were more volatile with a standard deviation of 1.3789% compared to green bonds which had a standard deviation of 1.1221%. This higher volatility in treasury bonds is further corroborated by a significantly higher excess kurtosis value, indicating a larger presence of extreme values in its returns distribution, thereby portraying a riskier profile.

The skewness of the returns distribution for green bonds was positive, suggesting a tendency for higher returns, while treasury bonds exhibited a highly negative skew, indicating a propensity for lower returns.

The GARCH model, employed to analyze the volatility dynamics of both assets, presented a positive mean coefficient (mu) for green bonds, further affirming their resilience during this period. Conversely, treasury bonds had a negative mean coefficient, aligning with their negative mean return observed in the descriptive statistics.

Given the analysis, it is evident that green bonds demonstrated a more stable performance during the oil price crash period, offering positive returns with relatively lower volatility compared to treasury bonds. The negative correlation of -0.6557 between the two assets suggests that they generally moved in opposite directions during this period, which opens up an opportunity for diversification benefits in a mixed portfolio.

Therefore, for investors aiming to maintain a positive yield with lower volatility, green bonds emerge as the more favorable option. However, a strategic mix of green and treasury bonds could potentially offer a hedge against adverse market movements, leveraging the negative correlation to achieve a more balanced risk-return profile.

	Oil Price Crash	
	Green Bonds	**Treasury Bonds**
Date	**Mar 2020 - May 2020**	
Mean	0,0259%	-0,0375%
Median	0,0000%	0,0000%
Minimum	-14,6170%	-43,3808%
Maximum	12,5494%	16,1104%
Standar. Dev	1,1221%	1,3789%
Skew	1,0073	-11,4316
Excess Kurtosis	29,1623	337,0059
Observations	8613	3325
Correlation	-0,655726864	
Beta	-0,409937566	

Table 11. Oil Price Crash

3.12 COVID-19 Market Crash (2020)

The green bonds exhibited a slightly positive mean return of 0.0271%, a beacon of hope in a market overshadowed by uncertainty. This positive mean return, although small, stands in contrast to the treasury bonds which faced a slight dip, recording a mean return of -0.0027%. The median values for both assets were near zero, with the treasury bonds slightly edging out with a median return of 0.0035% compared to the zero median return of green bonds.

A deeper dive into the data reveals a stark contrast in the maximum and minimum returns of both assets. While green bonds had a maximum return of 12.5494%, the treasury bonds soared higher, reaching a peak return of 33.7101%. However, this high return came with a caveat of a significantly lower minimum return of -43.3808%, compared to the -14.6170% of green bonds, showcasing a higher risk associated with treasury bonds.

The standard deviation, a measure of volatility, was higher for treasury bonds, indicating a more turbulent journey for investors. This narrative of higher risk in treasury bonds is further reinforced by the skewness and excess kurtosis values, which depict a distribution more prone to negative returns and extreme values, respectively.

The GARCH model, a tool to understand volatility dynamics, echoes the story told by the descriptive statistics. The green bonds had a positive mean coefficient, suggesting a tendency for positive returns. The treasury bonds, however, hovered around a near-zero mean, indicating a period of stagnation.

In a period characterized by a pandemic-induced market crash, green bonds emerged as a relatively stable asset, offering slight positive returns with a lower volatility profile compared to treasury bonds. The negative correlation of -0.6534 between the two assets suggests a diversification opportunity, where the inclusion of both assets in a portfolio could potentially mitigate risk and enhance stability.

For investors with a conservative approach, focusing on green bonds could be a prudent strategy, leveraging their positive mean return and lower volatility to navigate the stormy waters of the market crash. However, for those willing to embrace a higher risk for a chance at greater returns, a mixed portfolio leaning towards treasury bonds could be a viable option, given their higher maximum return potential.

	COVID-19 Market Crash	
	Green Bonds	**Treasury Bonds**
Date	Feb 2020 - Apr 2020	
Mean	0,0271%	-0,0027%
Median	0,0000%	0,0035%
Minimum	-14,6170%	-43,3808%
Maximum	12,5494%	33,7101%
Standar. Dev	1,1135%	1,4565%
Skew	0,9654	-5,0136
Excess Kurtosis	30,3014	340,7211
Observations	8329	3305
Correlation	-0,653441749	
Beta	-0,383094793	

Table 12. COVID-19 Market Crash

4. CONCLUSION

By understanding the risk-return landscape during this period, investors can craft a strategy that aligns with their risk tolerance and return objectives. The negative correlation between green and treasury bonds suggests that a mixed portfolio could potentially offer a hedge against losses, helping to stabilize the portfolio in a turbulent market environment.

Moreover, the analysis across different crisis periods consistently shows that green bonds tend to offer a more stable investment avenue, although often with lower returns compared to treasury bonds. The lower standard deviation of green bonds in most of the periods analysed indicates their lesser volatility, making them a preferable choice for risk-averse investors. However, it is also noted that in certain periods, green bonds have exhibited high volatility, emphasizing the necessity for a cautious approach while including them in the portfolio.

On the other hand, treasury bonds have shown the potential for higher returns in several instances, although accompanied by higher volatility, indicating a riskier investment compared to green bonds. Therefore, for risk-tolerant investors seeking higher returns, treasury bonds could be a viable option, provided they are willing to absorb the associated higher level of risk.

Furthermore, the GARCH model analysis across different periods has revealed the significant influence of past volatilities and returns on the current volatility of both green and treasury bonds, highlighting the importance of considering historical data while making investment decisions.

In light of the above, it can be concluded that during times of high market volatility, green bonds generally act as a more resilient investment compared to conventional bonds, offering a safer haven with lower volatility. However, they often come with the trade-off of lower returns. Therefore, a strategic approach involving a well-balanced mix of green and treasury bonds could potentially offer a solution that navigates the fine line between risk and return, providing a diversified portfolio that can withstand market shocks while pursuing potential gains.

Moreover, the varying degrees of correlation between green and treasury bonds across different crisis periods underscore the potential for diversification benefits, allowing investors to hedge risks effectively. Hence, a nuanced understanding of the market dynamics, grounded in meticulous research and analysis, would be pivotal in steering investment strategies during times of high market volatility.

In conclusion, green bonds have demonstrated a tendency to be more resilient during times of high market volatility, offering a semblance of stability in a turbulent market landscape. However, the optimal investment strategy would invariably hinge on individual investor preferences, risk tolerance, and return objectives. Thus, a judicious mix of green and treasury bonds, tailored to the investor's profile, could potentially offer a pathway to navigate the complex risk-return landscape effectively, leveraging the unique characteristics of each bond type to foster a portfolio that is both resilient and poised for growth. It is hoped that this analysis, grounded in a rich dataset and meticulous research, will serve as a valuable guide for investors in crafting strategies that align with their risk and return objectives during crisis periods.

5. LIMITATIONS

During the development of my thesis, I faced several limitations that should be noted as they have a considerable impact on the comprehensiveness and depth of the conclusions drawn in this study.

Firstly, while I have endeavoured to provide a broad analysis comparing green bonds and traditional treasury bonds, I recognize that a more detailed, bond-by-bond analysis would have allowed for a finer understanding of the risk-return landscape. This individualized approach could potentially uncover specific patterns and correlations that remain hidden in a more generalized analysis. Going forward, I believe that focusing on a detailed study of each bond could offer more precise insights into market dynamics.

Furthermore, my research primarily focused on a global perspective, which, in retrospect, might have missed the nuances of country-specific impacts during various crisis periods. Analysing the repercussions of each crisis on a national scale and correlating them with the bond returns of the respective country, would have facilitated a more grounded understanding of market responses. I see now that a deeper exploration of the unique economic landscapes of individual countries would have added a valuable dimension to my research.

In addition to the above, I acknowledge that incorporating a broader range of variables into the analysis could have enriched the study significantly. Considering factors , such as the unemployment rates during the crises, the risk-free rate at the time, and the performance of other assets like stocks, utilities, and cryptocurrencies would have provided a more comprehensive view of the financial landscape. I am aware that evaluating the volatility and returns against these assets could offer a fuller picture of the investment environment, aiding investors in crafting more resilient and robust strategies.

Moreover to the aforementioned limitations, it is pertinent to note the relatively short time frame available for analysis, given that the issuance of the first green bond only dates back to

2007. This limited period, spanning just over a decade and a half, may not be sufficiently extensive to draw hard and fast conclusions regarding the long-term performance and volatility of green bonds in comparison to traditional bonds. The relatively nascent stage of the green bond market implies that it has not yet undergone the test of time through various economic cycles to the same extent as traditional bonds. Consequently, while the study endeavours to provide a comprehensive analysis within this timeframe, it acknowledges the potential for a broader spectrum of insights that could be garnered from a more extended period analysis, allowing for a more nuanced understanding of the evolving dynamics and the true potential of green bonds in the financial landscape. It is hoped that as the green bond market matures, future research will be able to delve deeper, drawing from a richer and more varied historical data set to offer more conclusive insights.

Lastly, a significant limitation was the unequal number of observations for green and treasury bonds within the designated time frame. To counteract this, we established two indices to average the returns of each bond type, striving to facilitate a more balanced comparison. However, this approach may not fully encapsulate the nuances associated with the diverse bonds included, as various external variables such as the issuing country's economic status and geopolitical factors can significantly affect the results. Consequently, while the indices created aid in offering a more levelled ground for analysis, it is not devoid of shortcomings, inviting a cautious interpretation of the findings and acknowledging the potential influences of uncontrolled variables. Future research should aim to address these issues for a more refined analysis.

In conclusion, while I have strived to offer a detailed analysis of the green and treasury bonds landscape, I am cognizant of the limitations present in my study. I aspire that future research will address these gaps, adopting a more detailed and multifaceted approach to offer insights that are even more precise and grounded in the complex realities of the financial markets. I remain committed to enhancing the research methodology, driven by a desire to furnish investors with the most accurate and insightful guidance possible.

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7. APPENDIX

7.1 Correlation:

- **Definition:** Measures the strength and direction of the linear relationship between two variables.
- **Range:** Varies between -1 and +1, where -1 indicates a perfect negative linear relationship, +1 indicates a perfect positive linear relationship, and 0 indicates no linear relationship.
- **Formula:**

Correlation (ρ)=$\sigma X \cdot \sigma Y$Cov(X, Y)

where Cov(X, Y) is the covariance between X and Y, and σ_X and σ_Y are the standard deviations of X and Y, respectively.

7.2 Beta (β):

- **Definition:** In the context of finance, beta is a measure of the sensitivity of an asset's returns to the returns of a market or benchmark index.
- **Interpretation:**
    - $\beta > 1$: The asset is more volatile than the market.
    - $\beta = 1$: The asset has volatility equal to the market.
    - $\beta < 1$: The asset is less volatile than the market.
    - $\beta < 0$: The asset and the market move in opposite directions.
- **Formula:**

Beta (β)=Var(Rm)Cov(Ra, Rm)

where Cov(R_a, R_m) is the covariance between the asset returns (R_a) and the market returns (R_m), and Var(R_m) is the variance of the market returns.

7.3 GARCH Model Results

```
                     Constant Mean - GARCH Model Results
==============================================================================
Dep. Variable:                Returns   R-squared:                       0.000
Mean Model:             Constant Mean   Adj. R-squared:                  0.000
Vol Model:                      GARCH   Log-Likelihood:                1880.97
Distribution:                  Normal   AIC:                          -3753.93
Method:            Maximum Likelihood   BIC:                          -3737.10
                                        No. Observations:                  497
Date:                Sun, Sep 10 2023   Df Residuals:                      496
Time:                        15:18:46   Df Model:                            1
                                  Mean Model
===============================================================================
                 coef    std err          t      P>|t|       95.0% Conf. Int.
-------------------------------------------------------------------------------
mu        -2.5652e-04  1.884e-08 -1.361e+04      0.000 [-2.566e-04,-2.565e-04]
                            Volatility Model
============================================================================
                 coef    std err          t      P>|t|     95.0% Conf. Int.
----------------------------------------------------------------------------
omega      1.2468e-06  1.484e-12  8.403e+05      0.000 [1.247e-06,1.247e-06]
alpha[1]       0.0500  3.376e-02      1.481      0.139 [-1.616e-02,  0.116]
beta[1]        0.9300  3.520e-02     26.418 8.482e-154     [  0.861,  0.999]
============================================================================
```

Table 13. Global Financial Crisis - Green Bonds

```
                     Constant Mean - GARCH Model Results
==============================================================================
Dep. Variable:                Returns   R-squared:                       0.000
Mean Model:             Constant Mean   Adj. R-squared:                  0.000
Vol Model:                      GARCH   Log-Likelihood:                105661.
Distribution:                  Normal   AIC:                          -211315.
Method:            Maximum Likelihood   BIC:                          -211282.
                                        No. Observations:                26816
Date:                Sun, Sep 10 2023   Df Residuals:                    26815
Time:                        02:38:31   Df Model:                            1
                                 Mean Model
=============================================================================
                 coef    std err          t      P>|t|       95.0% Conf. Int.
-----------------------------------------------------------------------------
mu         7.1329e-05  4.593e-05      1.553      0.120 [-1.870e-05,1.614e-04]
                            Volatility Model
============================================================================
                 coef    std err          t      P>|t|     95.0% Conf. Int.
----------------------------------------------------------------------------
omega      2.9418e-06  4.121e-12  7.139e+05      0.000 [2.942e-06,2.942e-06]
alpha[1]       0.1000  4.762e-04    209.995      0.000  [9.907e-02,  0.101]
beta[1]        0.8000  5.358e-02     14.931  2.073e-50     [  0.695,  0.905]
============================================================================
```

Table 14. Global Financial Crisis - Treasury Bonds

```
                     Constant Mean - GARCH Model Results
==============================================================================
Dep. Variable:                Returns   R-squared:                       0.000
Mean Model:             Constant Mean   Adj. R-squared:                  0.000
Vol Model:                      GARCH   Log-Likelihood:                8118.09
Distribution:                  Normal   AIC:                          -16228.2
Method:            Maximum Likelihood   BIC:                          -16206.3
                                        No. Observations:                 1767
Date:                Sun, Sep 10 2023   Df Residuals:                     1766
Time:                        17:06:22   Df Model:                            1
                                 Mean Model
===============================================================================
                  coef    std err          t      P>|t|        95.0% Conf. Int.
-------------------------------------------------------------------------------
mu         -4.1115e-05  5.341e-07    -76.977      0.000 [-4.216e-05,-4.007e-05]
                              Volatility Model
============================================================================
                 coef    std err          t       P>|t|      95.0% Conf. Int.
----------------------------------------------------------------------------
omega      4.4982e-07  8.644e-11   5203.853       0.000 [4.496e-07,4.500e-07]
alpha[1]       0.2000  6.184e-02      3.234   1.220e-03  [7.880e-02,  0.321]
beta[1]        0.7800  3.478e-02     22.425  2.245e-111     [  0.712,  0.848]
============================================================================
```

Table 15. European Sovereign Debt Crisis - Green Bonds

```
                     Constant Mean - GARCH Model Results
==============================================================================
Dep. Variable:                Returns   R-squared:                       0.000
Mean Model:             Constant Mean   Adj. R-squared:                  0.000
Vol Model:                      GARCH   Log-Likelihood:                162885.
Distribution:                  Normal   AIC:                          -325763.
Method:            Maximum Likelihood   BIC:                          -325728.
                                        No. Observations:                44629
Date:                Sun, Sep 10 2023   Df Residuals:                    44628
Time:                        17:09:58   Df Model:                            1
                                 Mean Model
=============================================================================
                 coef    std err          t      P>|t|       95.0% Conf. Int.
-----------------------------------------------------------------------------
mu         5.4937e-05  1.861e-04      0.295      0.768 [-3.098e-04,4.197e-04]
                              Volatility Model
============================================================================
                 coef    std err          t      P>|t|       95.0% Conf. Int.
----------------------------------------------------------------------------
omega      1.7749e-06  6.234e-12  2.847e+05      0.000 [1.775e-06,1.775e-06]
alpha[1]       0.0500  4.787e-03     10.445  1.544e-25 [4.062e-02,5.938e-02]
beta[1]        0.9300  2.087e-02     44.556      0.000     [  0.889,  0.971]
============================================================================
```

Table 16. European Sovereign Debt Crisis - Treasury Bonds

Constant Mean - GARCH Model Results

Dep. Variable:	Returns	R-squared:	0.000
Mean Model:	Constant Mean	Adj. R-squared:	0.000
Vol Model:	GARCH	Log-Likelihood:	-14.1141
Distribution:	Normal	AIC:	36.2282
Method:	Maximum Likelihood	BIC:	47.7594
		No. Observations:	132
Date:	Sun, Sep 10 2023	Df Residuals:	131
Time:	18:59:58	Df Model:	1

Mean Model

	coef	std err	t	P>|t|	95.0% Conf. Int.
mu	0.0361	1.134e-07	3.184e+05	0.000	[3.612e-02,3.612e-02]

Volatility Model

	coef	std err	t	P>|t|	95.0% Conf. Int.
omega	1.5754e-07	2.980e-11	5286.536	0.000	[1.575e-07,1.576e-07]
alpha[1]	0.0500	3.279e-02	1.525	0.127	[-1.427e-02, 0.114]
beta[1]	0.8500	0.187	4.540	5.626e-06	[0.483, 1.217]

Table 17. U.S. Debt Ceiling Crisis - Green Bonds

Constant Mean - GARCH Model Results

Dep. Variable:	Returns	R-squared:	0.000
Mean Model:	Constant Mean	Adj. R-squared:	0.000
Vol Model:	GARCH	Log-Likelihood:	14253.1
Distribution:	Normal	AIC:	-28498.2
Method:	Maximum Likelihood	BIC:	-28473.3
		No. Observations:	3771
Date:	Sun, Sep 10 2023	Df Residuals:	3770
Time:	19:05:35	Df Model:	1

Mean Model

	coef	std err	t	P>|t|	95.0% Conf. Int.
mu	7.3123e-04	5.633e-04	1.298	0.194	[-3.727e-04,1.835e-03]

Volatility Model

	coef	std err	t	P>|t|	95.0% Conf. Int.
omega	1.2100e-06	5.454e-12	2.219e+05	0.000	[1.210e-06,1.210e-06]
alpha[1]	0.2000	3.576e-02	5.593	2.231e-08	[0.130, 0.270]
beta[1]	0.7800	4.070e-02	19.164	7.338e-82	[0.700, 0.860]

Table 18. U.S. Debt Ceiling Crisis - Treasury Bonds

```
                 Constant Mean - GARCH Model Results
==============================================================================
Dep. Variable:                Returns   R-squared:                       0.000
Mean Model:             Constant Mean   Adj. R-squared:                  0.000
Vol Model:                      GARCH   Log-Likelihood:                991.938
Distribution:                  Normal   AIC:                          -1975.88
Method:            Maximum Likelihood   BIC:                          -1961.25
                                        No. Observations:                  286
Date:                Sun, Sep 10 2023   Df Residuals:                      285
Time:                        19:25:33   Df Model:                            1
                               Mean Model
============================================================================
                 coef    std err          t      P>|t|      95.0% Conf. Int.
----------------------------------------------------------------------------
mu         3.1747e-04  3.274e-06     96.961      0.000 [3.111e-04,3.239e-04]
                            Volatility Model
============================================================================
                 coef    std err          t      P>|t|      95.0% Conf. Int.
----------------------------------------------------------------------------
omega      5.6402e-06  5.830e-11  9.675e+04      0.000 [5.640e-06,5.640e-06]
alpha[1]       0.2000  6.347e-02      3.151  1.626e-03   [7.560e-02,  0.324]
beta[1]        0.7800  1.986e-02     39.278      0.000     [  0.741,  0.819]
============================================================================
```

Table 19. Taper Tantrum - Green Bonds

```
                 Constant Mean - GARCH Model Results
==============================================================================
Dep. Variable:                Returns   R-squared:                       0.000
Mean Model:             Constant Mean   Adj. R-squared:                  0.000
Vol Model:                      GARCH   Log-Likelihood:                13642.1
Distribution:                  Normal   AIC:                          -27276.3
Method:            Maximum Likelihood   BIC:                          -27251.5
                                        No. Observations:                 3660
Date:                Sun, Sep 10 2023   Df Residuals:                     3659
Time:                        19:46:24   Df Model:                            1
                                 Mean Model
================================================================================
                  coef    std err          t      P>|t|        95.0% Conf. Int.
--------------------------------------------------------------------------------
mu         -4.4084e-04  1.473e-06   -299.299      0.000 [-4.437e-04,-4.380e-04]
                            Volatility Model
============================================================================
                 coef    std err          t      P>|t|      95.0% Conf. Int.
----------------------------------------------------------------------------
omega      2.0574e-06  4.775e-12  4.309e+05      0.000 [2.057e-06,2.057e-06]
alpha[1]       0.2000  4.591e-02      4.356  1.324e-05     [  0.110,  0.290]
beta[1]        0.7800  5.160e-02     15.116  1.266e-51     [  0.679,  0.881]
============================================================================
```

Table 20. Taper Tantrum - Treasury Bonds

```
                   Constant Mean - GARCH Model Results
==============================================================================
Dep. Variable:                Returns   R-squared:                       0.000
Mean Model:             Constant Mean   Adj. R-squared:                  0.000
Vol Model:                      GARCH   Log-Likelihood:                18114.3
Distribution:                  Normal   AIC:                          -36220.7
Method:            Maximum Likelihood   BIC:                          -36195.1
                                        No. Observations:                 4447
Date:                Sun, Sep 10 2023   Df Residuals:                     4446
Time:                        20:10:49   Df Model:                            1
                                Mean Model
============================================================================
                 coef    std err          t      P>|t|      95.0% Conf. Int.
----------------------------------------------------------------------------
mu         3.0959e-04  1.940e-05     15.955  2.651e-57 [2.716e-04,3.476e-04]
                              Volatility Model
============================================================================
                 coef    std err          t      P>|t|      95.0% Conf. Int.
----------------------------------------------------------------------------
omega      5.1217e-07  3.127e-12  1.638e+05      0.000 [5.122e-07,5.122e-07]
alpha[1]       0.1000  2.062e-02      4.851  1.229e-06   [5.960e-02,  0.140]
beta[1]        0.8800  1.837e-02     47.894      0.000     [  0.844,  0.916]
============================================================================
```

Table 21. Chinese Stock Market Crash - Green Bonds

```
                   Constant Mean - GARCH Model Results
==============================================================================
Dep. Variable:                Returns   R-squared:                       0.000
Mean Model:             Constant Mean   Adj. R-squared:                  0.000
Vol Model:                      GARCH   Log-Likelihood:                20819.5
Distribution:                  Normal   AIC:                          -41630.9
Method:            Maximum Likelihood   BIC:                          -41600.5
                                        No. Observations:                14801
Date:                Sun, Sep 10 2023   Df Residuals:                    14800
Time:                        20:16:49   Df Model:                            1
                                  Mean Model
=============================================================================
                 coef    std err          t      P>|t|       95.0% Conf. Int.
-----------------------------------------------------------------------------
mu         1.0363e-04  1.057e-04      0.981      0.327 [-1.035e-04,3.108e-04]
                              Volatility Model
============================================================================
                 coef    std err          t      P>|t|      95.0% Conf. Int.
----------------------------------------------------------------------------
omega      1.7878e-03  2.058e-05     86.873      0.000 [1.747e-03,1.828e-03]
alpha[1]       0.2000  4.097e-02      4.882  1.049e-06     [  0.120,  0.280]
beta[1]        0.7800  5.316e-03    146.728      0.000     [  0.770,  0.790]
============================================================================
```

Table 22. Chinese Stock Market Crash - Treasury Bonds

```
                     Constant Mean - GARCH Model Results
==============================================================================
Dep. Variable:                Returns   R-squared:                       0.000
Mean Model:             Constant Mean   Adj. R-squared:                  0.000
Vol Model:                      GARCH   Log-Likelihood:               -7530.23
Distribution:                  Normal   AIC:                           15068.5
Method:            Maximum Likelihood   BIC:                           15090.5
                                        No. Observations:                 1827
Date:                Sun, Sep 10 2023   Df Residuals:                     1826
Time:                        20:54:13   Df Model:                            1
                               Mean Model
========================================================================
                 coef    std err          t      P>|t|  95.0% Conf. Int.
------------------------------------------------------------------------
mu            -0.4345  6.897e-02     -6.299  2.994e-10 [ -0.570, -0.299]
                              Volatility Model
============================================================================
                 coef    std err          t      P>|t|      95.0% Conf. Int.
----------------------------------------------------------------------------
omega      3.8016e-06  5.185e-10   7331.658      0.000 [3.801e-06,3.803e-06]
alpha[1]       0.2000      1.272      0.157      0.875    [ -2.292,  2.692]
beta[1]        0.7000      2.316      0.302      0.762    [ -3.839,  5.239]
============================================================================
```

Table 23. UK Brexit Vote - Green Bonds

```
                     Constant Mean - GARCH Model Results
==============================================================================
Dep. Variable:                Returns   R-squared:                       0.000
Mean Model:             Constant Mean   Adj. R-squared:                  0.000
Vol Model:                      GARCH   Log-Likelihood:                12457.8
Distribution:                  Normal   AIC:                          -24907.6
Method:            Maximum Likelihood   BIC:                          -24883.0
                                        No. Observations:                 3442
Date:                Sun, Sep 10 2023   Df Residuals:                     3441
Time:                        20:58:43   Df Model:                            1
                                 Mean Model
===============================================================================
                  coef    std err          t      P>|t|        95.0% Conf. Int.
-------------------------------------------------------------------------------
mu         -1.8536e-05  6.021e-06     -3.078  2.081e-03 [-3.034e-05,-6.735e-06]
                              Volatility Model
============================================================================
                 coef    std err          t      P>|t|      95.0% Conf. Int.
----------------------------------------------------------------------------
omega      4.3249e-06  9.844e-12  4.394e+05      0.000 [4.325e-06,4.325e-06]
alpha[1]       0.2000  9.643e-02      2.074  3.807e-02  [1.100e-02,  0.389]
beta[1]        0.7800  7.228e-02     10.792  3.754e-27     [  0.638,  0.922]
============================================================================
```

Table 24. UK Brexit Vote - Treasury Bonds

```
                 Constant Mean - GARCH Model Results
==============================================================================
Dep. Variable:                Returns   R-squared:                       0.000
Mean Model:             Constant Mean   Adj. R-squared:                  0.000
Vol Model:                      GARCH   Log-Likelihood:                16613.9
Distribution:                  Normal   AIC:                          -33219.7
Method:            Maximum Likelihood   BIC:                          -33194.7
                                        No. Observations:                 3807
Date:                Sun, Sep 10 2023   Df Residuals:                     3806
Time:                        21:30:00   Df Model:                            1
                               Mean Model
============================================================================
                 coef    std err          t      P>|t|      95.0% Conf. Int.
----------------------------------------------------------------------------
mu         9.7508e-05  2.908e-07    335.358      0.000 [9.694e-05,9.808e-05]
                            Volatility Model
============================================================================
                 coef    std err          t      P>|t|      95.0% Conf. Int.
----------------------------------------------------------------------------
omega      3.0574e-07  6.708e-12  4.558e+04      0.000 [3.057e-07,3.057e-07]
alpha[1]       0.1000  1.016e-02      9.842  7.420e-23   [8.009e-02,  0.120]
beta[1]        0.8800  8.806e-03     99.928      0.000     [  0.863,  0.897]
============================================================================
```

Table 25. U.S. Stock Market Crash - Green Bonds

```
                 Constant Mean - GARCH Model Results
============================================================================
Dep. Variable:              Returns   R-squared:                       0.000
Mean Model:           Constant Mean   Adj. R-squared:                  0.000
Vol Model:                    GARCH   Log-Likelihood:                13049.7
Distribution:                Normal   AIC:                          -26091.4
Method:          Maximum Likelihood   BIC:                          -26066.9
                                      No. Observations:                 3384
Date:              Sun, Sep 10 2023   Df Residuals:                     3383
Time:                      21:35:05   Df Model:                            1
                               Mean Model
==============================================================================
                 coef    std err          t      P>|t|        95.0% Conf. Int.
------------------------------------------------------------------------------
mu        -2.4081e-03  1.486e-08 -1.621e+05      0.000 [-2.408e-03,-2.408e-03]
                            Volatility Model
===========================================================================
                coef    std err          t      P>|t|      95.0% Conf. Int.
---------------------------------------------------------------------------
omega     2.1542e-06  7.498e-13  2.873e+06      0.000 [2.154e-06,2.154e-06]
alpha[1]      0.0500  5.039e-02      0.992      0.321  [-4.875e-02,  0.149]
beta[1]       0.8500  7.996e-02     10.630  2.163e-26    [  0.693,  1.007]
===========================================================================
```

Table 26. U.S. Stock Market Crash - Treasury Bonds

```
                     Constant Mean - GARCH Model Results
==============================================================================
Dep. Variable:                Returns   R-squared:                       0.000
Mean Model:             Constant Mean   Adj. R-squared:                  0.000
Vol Model:                      GARCH   Log-Likelihood:                22221.1
Distribution:                  Normal   AIC:                          -44434.1
Method:            Maximum Likelihood   BIC:                          -44407.9
                                        No. Observations:                 5181
Date:                Sun, Sep 10 2023   Df Residuals:                     5180
Time:                        21:40:02   Df Model:                            1
                                   Mean Model
===============================================================================
                  coef    std err          t      P>|t|       95.0% Conf. Int.
-------------------------------------------------------------------------------
mu         -4.0808e-04  7.990e-09 -5.108e+04      0.000 [-4.081e-04,-4.081e-04]
                              Volatility Model
============================================================================
                 coef    std err          t      P>|t|      95.0% Conf. Int.
----------------------------------------------------------------------------
omega      8.4285e-07  1.065e-12  7.916e+05      0.000 [8.428e-07,8.429e-07]
alpha[1]       0.2000  2.203e-02      9.079  1.093e-19     [  0.157,  0.243]
beta[1]        0.7800  1.232e-02     63.286      0.000     [  0.756,  0.804]
============================================================================
```

Table 27. U.S. Stock Market Fall - Green Bonds

```
                     Constant Mean - GARCH Model Results
==============================================================================
Dep. Variable:                Returns   R-squared:                       0.000
Mean Model:             Constant Mean   Adj. R-squared:                  0.000
Vol Model:                      GARCH   Log-Likelihood:                15877.3
Distribution:                  Normal   AIC:                          -31746.6
Method:            Maximum Likelihood   BIC:                          -31721.9
                                        No. Observations:                 3568
Date:                Sun, Sep 10 2023   Df Residuals:                     3567
Time:                        21:43:11   Df Model:                            1
                                 Mean Model
============================================================================
                 coef    std err          t      P>|t|      95.0% Conf. Int.
----------------------------------------------------------------------------
mu         3.5121e-04  3.708e-07    947.182      0.000 [3.505e-04,3.519e-04]
                              Volatility Model
============================================================================
                 coef    std err          t      P>|t|      95.0% Conf. Int.
----------------------------------------------------------------------------
omega      2.8187e-07  5.006e-12  5.630e+04      0.000 [2.819e-07,2.819e-07]
alpha[1]       0.1000  4.907e-02      2.038  4.154e-02   [3.832e-03,  0.196]
beta[1]        0.8800  4.462e-02     19.723  1.362e-86     [  0.793,  0.967]
============================================================================
```

Table 28. U.S. Stock Market Fall - Treasury Bonds

```
                     Constant Mean - GARCH Model Results
==============================================================================
Dep. Variable:                Returns   R-squared:                       0.000
Mean Model:             Constant Mean   Adj. R-squared:                  0.000
Vol Model:                      GARCH   Log-Likelihood:                31606.6
Distribution:                  Normal   AIC:                          -63205.2
Method:            Maximum Likelihood   BIC:                          -63176.9
                                        No. Observations:                 8613
Date:                Sun, Sep 10 2023   Df Residuals:                     8612
Time:                        22:17:52   Df Model:                            1
                                 Mean Model
============================================================================
                 coef    std err          t      P>|t|      95.0% Conf. Int.
----------------------------------------------------------------------------
mu         2.5914e-04  4.446e-05      5.828  5.605e-09 [1.720e-04,3.463e-04]
                              Volatility Model
============================================================================
                 coef    std err          t      P>|t|      95.0% Conf. Int.
----------------------------------------------------------------------------
omega      2.5182e-06  4.218e-13  5.970e+06      0.000 [2.518e-06,2.518e-06]
alpha[1]       0.2000  2.964e-03     67.486      0.000     [  0.194,  0.206]
beta[1]        0.7800  1.229e-02     63.486      0.000     [  0.756,  0.804]
============================================================================
```

Table 29. Oil Price Crash - Green Bonds

```
                     Constant Mean - GARCH Model Results
==============================================================================
Dep. Variable:                Returns   R-squared:                       0.000
Mean Model:             Constant Mean   Adj. R-squared:                  0.000
Vol Model:                      GARCH   Log-Likelihood:                11966.4
Distribution:                  Normal   AIC:                          -23924.9
Method:            Maximum Likelihood   BIC:                          -23900.4
                                        No. Observations:                 3325
Date:                Sun, Sep 10 2023   Df Residuals:                     3324
Time:                        22:07:40   Df Model:                            1
                                 Mean Model
==============================================================================
                 coef    std err          t      P>|t|        95.0% Conf. Int.
------------------------------------------------------------------------------
mu        -3.7497e-04  1.053e-06   -356.061      0.000 [-3.770e-04,-3.729e-04]
                              Volatility Model
============================================================================
                 coef    std err          t      P>|t|      95.0% Conf. Int.
----------------------------------------------------------------------------
omega      3.8027e-06  1.921e-12  1.980e+06      0.000 [3.803e-06,3.803e-06]
alpha[1]       0.2000  3.610e-02      5.541  3.015e-08     [  0.129,  0.271]
beta[1]        0.7800  2.519e-02     30.969 1.421e-210     [  0.731,  0.829]
============================================================================
```

Table 30. Oil Price Crash - Treasury Bonds

```
                     Constant Mean - GARCH Model Results
==============================================================================
Dep. Variable:                Returns   R-squared:                       0.000
Mean Model:             Constant Mean   Adj. R-squared:                  0.000
Vol Model:                      GARCH   Log-Likelihood:                30588.6
Distribution:                  Normal   AIC:                          -61169.3
Method:            Maximum Likelihood   BIC:                          -61141.2
                                        No. Observations:                 8329
Date:                Sun, Sep 10 2023   Df Residuals:                     8328
Time:                        22:32:41   Df Model:                            1
                                 Mean Model
============================================================================
                 coef    std err          t      P>|t|      95.0% Conf. Int.
----------------------------------------------------------------------------
mu         2.7071e-04  5.461e-05      4.957  7.155e-07 [1.637e-04,3.777e-04]
                              Volatility Model
============================================================================
                 coef    std err          t      P>|t|      95.0% Conf. Int.
----------------------------------------------------------------------------
omega      2.4799e-06  2.012e-12  1.233e+06      0.000 [2.480e-06,2.480e-06]
alpha[1]       0.2000  3.440e-03     58.132      0.000     [  0.193,  0.207]
beta[1]        0.7800  1.412e-02     55.235      0.000     [  0.752,  0.808]
============================================================================
```

Table 31. COVID-19 Market Crash - Green Bonds

```
                     Constant Mean - GARCH Model Results
==============================================================================
Dep. Variable:                Returns   R-squared:                       0.000
Mean Model:             Constant Mean   Adj. R-squared:                  0.000
Vol Model:                      GARCH   Log-Likelihood:                10109.8
Distribution:                  Normal   AIC:                          -20211.7
Method:            Maximum Likelihood   BIC:                          -20187.2
                                        No. Observations:                 3305
Date:                Sun, Sep 10 2023   Df Residuals:                     3304
Time:                        22:37:30   Df Model:                            1
                                 Mean Model
==============================================================================
                  coef    std err          t      P>|t|       95.0% Conf. Int.
------------------------------------------------------------------------------
mu         -2.5990e-05  2.534e-04     -0.103      0.918 [-5.226e-04,4.706e-04]
                              Volatility Model
============================================================================
                 coef    std err          t      P>|t|      95.0% Conf. Int.
----------------------------------------------------------------------------
omega      2.1214e-05  3.105e-13  6.833e+07      0.000 [2.121e-05,2.121e-05]
alpha[1]       0.2000      0.133      1.508      0.132 [-5.999e-02,  0.460]
beta[1]        0.7000      0.165      4.248  2.158e-05     [  0.377,  1.023]
============================================================================
```

Table 32. COVID-19 Market Crash - Treasury Bonds