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Correlation between green bonds and financial markets

The benefit of replacing conventional bonds with green bonds in the stock-bond portfolio

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ABSTRACT:
Several decades of research have investigated ways to effectively diversify the investment portfolio. In particular, stocks and bonds and their interconnection are examined in several studies, as the same macroeconomic and uncertainty factors drive their price fluctuations. Previous results have presented the long-term stock-bond correlation to be slightly negative in developed markets. Market uncertainty, on the other hand, is generally found to have a strong negative effect on correlation in the short term. In the past, these results have served as good guidelines for diversifying the investment portfolio over time. However, in the 21st century, concerns related to environmental and social issues have made investment decisions increasingly dependent on non-financial aspects. With this trend, new asset classes were developed on the market, where "green" bonds and stocks focus specifically on preventing and reducing social and sustainable development issues. Thus, traditional allocation recommendations are no longer accurate enough when an increasing number of investment decisions are made according to ethical principles in addition to financial assessment.

Green bonds, which were introduced to investors for the first time in 2007, have become one of the most effective tools for financing projects that support sustainable development. Green bonds have experienced explosive growth in recent years, which has inspired the literature to increasingly explore the correlation of green bonds with other asset classes. According to research results, in the long term, green bonds behave like conventional bonds and thus diversify the stock portfolio. On the other hand, during market turbulence, green bonds prove to positively correlate with equity markets. This way, the diversification benefits from green bonds are expected to be achieved in the long term. However, the recent literature has yet to actually examine whether the replacement of conventional bonds with green bonds would give the investor a better diversification benefit in the stock-bond portfolio.

The aim of this master's thesis is to extend existing stock-bond correlation literature by examining, whether investors can achieve more efficient diversification benefits when replacing conventional bonds with green bonds. Long-term examination period results from the European and US markets show that green bonds bring a more stable, but also on average, more effective diversification benefits for equity markets. Moreover, as stated in the previous literature, in market turbulence, conventional bonds provide a better diversification benefit. Thus, the results of this thesis bring a new perspective to the traditional stock-bond literature, and also expand the current green bond literature. The results can furthermore be utilized in a purely green stock-bond portfolio and this way they bring new perspective to sustainable investing.

KEYWORDS: Green bonds, conventional assets, stock markets, market turbulence, bond markets, correlation, VIX, VSTOXX, responsible investing, COVID-19, ESG

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TIIVISTELMÄ:
Portfolion tehokas ajallinen hajauttaminen on olennainen osa sijoitussalkun riskin pienentämistä. Tästä syystä useat tutkimukset läpi vuosikymmenten ovat keskittyneet parhaiden allokaatioratkaisujen löytämiseen. Etenkin osakkeet ja joukkovelkakirjalainat ja näiden välinen korrelaatio on ollut tutkimusten kohteena, sillä molempien omaisuuserien hinnanmuutoksia ajavat samat makrotaloudelliset- ja epävarmuustekijät. Tulokset ovat osoittaneet kehittyneiden markkinoiden pitkän aikavälin osake-bondi korrelaatioiden olevan lievästi negatiivinen. Markkinaepävarmuudella taas on yleisesti todettu olevan vahva negatiivinen vaikutus korrelaatioon lyhyellä aikavälillä. Aikaisemmin nämä tulokset ovat toimineet hyvinä ohjenuorina sijoitusportfolion ajallisessa hajauttamisessa, mutta 2000-luvulla nousseet ympäristöllisiin ja sosiaalisiin seikkoihin liittyvät huolenaiheet ovat tehneet sijoituspäätöksistä yhä enemmän ei-taloudellisiin aspekteihin nojautuvia. Tämän suuntauksen myötä markkinoille on kehitetty uusia omaisuusluokkia, jossa "vihreät" joukkovelkakirjat ja osakkeet keskittyvät etenkin sosiaalisten ja kestävän kehityksen ongelmien ehkäisemiseen ja pienentämiseen. Perinteiset allokaatiosuositukset eivät näin ollen toimi enää riittävän tarkkoina, kun tulevaisuudessa yhä kasvava määrä sijoituspäätöksistä tehdään taloudellisten mittareiden lisäksi eettisten periaatteiden mukaan.

Ensimmäistä kertaa vuonna 2007 sijoittajakunnalle esitellyistä vihreistä joukkovelkakirjoista on tullut yksi tehokkaimmista välineistä rahoittaa kestävää kehitystä tukevia hankkeita. Niin sanotut ”Green bondit” ovat kokenut viime vuosien aikana räjähdysmäisen kasvun, joka on innostanut kirjallisuuttaa tutkimaan kasvavassa määrin vihreiden bondien korrelaatiota muiden omaisuusluokkien kanssa. Tutkimustulosten mukaan pitkällä aikavälillä vihreät joukkovelkakirjalainat käyttäytyvät tavallisten joukkovelkakirjalainojen tavalla ja hajauttavat näin osakesalkkua. Toisaalta markkinaturbulenssin aikana vihreät velkakirjat osoittautuvat korreloivan positiivisesti osakkeiden kanssa. Hajautushyötyä vihreistä joukkovelkakirjalainoista on siis todennettu saatavan pääosin pitkällä aikavälillä. Uusissa virheisiin joukkovelkakirjalainoihin liittyvissä tutkimuksissa ei kuitenkaan ilmene tuloksia siitä, toisiko tavallisten joukkovelkakirjalainojen korvaaminen vihreillä joukkovelkakirjoilla sijoittajalle parempaa hajautushyötyä osake-bondi portfoliossa.

Tämän maisterin tutkielman tarkoituksena on laajentaa aiempaa osake-bondi korrelaatio kirjallisuutta vertaamalla, saako sijoittaja paremman hajautushyödyn kestävää kehitystä tukevilla vihreillä joukkovelkakirjalainoilla. Pitkän aikavälin tutkimustulos Euroopan ja Yhdysvaltojen markkinoilta osoittaa, että vihreät joukkovelkakirjalainat tuovat stabiilimpaa, mutta myös keskiarvoisesti tehokkaampaa hajautushyötyä. Lisäksi niin kuin aikaisemmassa kirjallisuudessa on todettu, markkinaturbulenssissa tavalliset joukkovelkakirjalainat tuovat paremman hajautushyödyn. Näin ollen tämän tutkielman tulokset tuovat uutta näkökulmaa perinteiselle osake-bondi kirjallisuudelle, sekä myös laajentaa nykyistä vihreiden bondien kirjallisuutta.

KEYWORDS: Green bonds, conventional assets, stock markets, market turbulence, bond markets, correlation, VIX, VSTOXX, responsible investing, COVID-19, ESG

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Abbreviations

CAPM	Capital Asset Pricing Model
CBI	Climate Bonds Initiative
CE	Clean energy
COVID-19	Corona virus disease 2019
Co2	Carbon dioxide
CSR	Corporate Social Responsibility factor
DCC-GARCH	Dynamic Conditional Correlation-Generalized Autoregressive Conditional Heteroskedasticity model
DDM	Dividend Discount Model
ESG	Environmental, Social and Governance factor
EU	European Union
EUR	Euro
FED	The Federal Reserve
GBP	Green Bonds Principles
GB	Green bond
GDP	Gross domestic product
GGM	Gordon Growth Model
GSS	Green, Social, Sustainability, Sustainability-linked and transition bonds
ICMA	International Capital Market Association
IRENA	International Renewable Energy Agency
MSCI	Morgan Stanley Capital International
PRI	Principles of Responsible Investing
S&P500	Standard & Poor's 500
UK	United Kingdom
US	United States
USD	United States Dollar
VIX	CBOE Volatility Index
VSTOXX	Euro Stoxx 50 Volatility Index

1 Introduction

One of the most crucial ways to decrease portfolio risk is through efficient portfolio allocation. Especially during turbulent times when asset prices tend to be more volatile, effective diversification is highlighted (Estrada, 2016). There are numerous suggestions for building an optimal investment portfolio ranging from investor-specific guidelines to general portfolio models with similar holdings in each asset class. Most typical asset classes where the literature has concentrated on where to diversify are fixed income and equity assets (Elsayed, Naifar, Nasreen, and Tiwari, 2022). Researchers have found common macroeconomic and uncertainty factors which drive the price movements of both stocks and bonds, which is why studies globally have investigated their connectedness (Yang, Zhou & Wang, 2009). Over time, various allocation recommendations have emerged for effective short-term and longer-term diversification.

Studies show that stock-bond correlations are time-varying, and changes greatly depend on the country, factors, and time period examined. Generally, it is found that that developed market correlations are highly positive before the 21st century, and after the turn of the century remains near zero or slightly below it (Aslanidis & Christiansen, 2012). Furthermore, the correlation between stocks and bonds in short-term shows to be strongly negative, and this phenomenon occurs in several major market areas; in Europe, the US, and Asian-Pacific region (Baur & Lucey, 2009; Skintzi, 2019, Andersson et al., 2008, Chang & Hsueh, 2013, p. 63-64). Interest rates and inflation are shown to be important factors explaining the correlation in long-term (Yang et al. 2009), where global market volatility index VIX turns out to drive short-term correlation changes (Aslanidis & Christiansen, 2012; Conolly, Stivers & Sun, 2007; Skintzi, 2019).

The typical asset division into stock and debt markets has however experienced changes during the 21st century (Elsayed, et al., 2022). The inequitable distribution of natural wealth and increased concerns on sustainability issues have emphasized the importance of non-economic aspects in the investment decision-making process. Market participants are increasingly looking for portfolio allocation strategies, where the diversification benefits are obtained by emphasizing companies valuing ethical and sustainable decisions (Elsayed, et al., 2022). Alongside with new investment trends, global long-term sustainability agreements and new governmental regulations have increased the requirements for institutions and companies to take actions to support sustainability targets. Due to these changes in the financial markets, new "green asset" classes were developed to enhance the allocation of funds towards projects supporting the economic and social well-being. The investment trend focusing on long-term sustainability goals has thus brought new perspectives to the traditional stock-bond correlation literature.

1.1 Purpose and previous literature

In recent years the literature has paid more attention on the sustainability aspects in the portfolio decisions as corporate practices have come more in central role. According to the 2018 Global Sustainable Investment Review, in 2018 31 trillion dollars were managed under socially responsible investment (SRI) strategies, of which $19.5 trillion incorporated ESG elements (Monti, Pattitoni, Petracci, & Randl, 2022). In January 2022, Bloomberg Intelligence (2022) reported: "*Global ESG assets may surpass $41 trillion by 2022 and $50 trillion by 2025, one-third of the projected total assets under management globally…"*. This enormous increase in interest towards responsible investing is not only driven by the sustainability aspects. High ESG and CSR scores have furthermore shown to negatively correlate with firm risk, but impact significantly positively on firm financial performance over the short- and long-term (Monti et al., 2022; Ilhan, Sautner & Vilkov, 2020). These results show that supporting sustainable development has not only environmental and social benefits, but also positive effects on company performance and competitiveness of firms in varying market circumstances.

Emerging role of impact investing has created new forms of financial assets. In 2007 new asset "Green bond" was introduced for the first time for investors, and after publication of "Principles of Green Bond" in 2014 the popularity of asset boomed (Tiwari, Abakah, Yaya & Appiah, 2022). Till the end of 2021, total of 16,697 Green, Social, Sustainability, and Sustainability-linked and transition (GSS+) bonds were issued with a cumulative value of $2.8trillion (Climate Bonds Initiative, 2022a, Climate Bonds Initiative, 2022b). In addition to significantly fast growth of the asset class, green bonds have become one of the most efficient methods to obtain funding for green projects (Naeem, Farid, Ferrer, and Shahzad, 2021). This is why, for example, policymakers prefer these instruments as global agreements require governments to mobilize significant amount of financial resources for sustainable development projects (Reboredo, Ugolini, and Aiube, 2020). Due to the rapid growth of green bond market, but also increasing number of regulations and contracts restrict companies, other significant market participants such as institutional investors are progressively constructing portfolios based on taking into consideration also ethical aspects (Reboredo, et al., 2020).

The expansion of the market for environmentally friendly assets has furthermore increased the literature focusing on green assets. This has also brought new research results for the traditional stock-bond correlation literature. Commonly it is noticed that green bonds correlate differently with conventional debt market instruments depending on the credit ranking of the bond (Boutabba & Rannou, 2022; Li, Tang, Wu, Zhang & Lv, 2017). Green bonds are mainly investment-grade rated bonds and thus during the long term, they are noticed to co-move with conventional investment-grade bonds (Arif, Hasan, Alawi and Naeem, 2021; Reboredo et al. 2020). However, with high-yield bonds, the correlation turns out to be negative similar to the long-term correlation with stock markets (Pham & Nguyen, 2021). Concentrating solely on green stocks, these assets turn out to behave similarly to conventional stock markets, and this way correlate also weakly with green bonds (Tiwari et al., 2022). Furthermore, the correlation between green bonds and clean energy markets is shown to be positive in the long term (Liu, Liu, Da, Zhang, & Guan, 2021). This way, using green bonds in a long-term investment portfolio turns out to provide similar diversification benefits, as when using conventional bonds with green and conventional stocks.

On the other hand, results of the short-term correlation in market turbulence differ from the previous stock-bond correlation findings. Naeem, et al. (2021) investigate the differences between global green and conventional bonds during the COVID-19 pandemic, and they notice green bonds to be less sentiment to market turbulence. They suggest that the more stable performance of green bonds may be due to their investor base, which perceives green bonds as less risky due to their long-term environmentally oriented strategy. Also, Pham and Nguyen (2021) find that during high market volatility in the EU and US markets, the diversification benefit of green bonds for stock markets decrease, as in such circumstances the directional effects between assets are more significant. Arif, Hasan, Alawi, and Naeem (2021) also noticed this increasing correlation between green bonds and other financial assets during market turbulence. This way, green bonds seem to lose their diversification benefit in short-term

This study aims to extend the previous stock-bond correlation literature and the new green bond literature by comparing the diversification opportunities of green and conventional bonds. Previous literature has shown that the long-term stock-bond correlation in developed markets is typically zero or slightly below it (Andersson et al., 2008; Aslanidis & Christiansen, 2012; Connolly et al., 2007; Skintzi, 2019). This weak correlation, however, drops below zero due to the increased market uncertainty. Recent literature focusing on the green bond market has further shown that green bonds diversify the long-term portfolio similarly to traditional bonds (Nguyen, Naeem, Balli, Balli, & Vo, 2021; Reboredo, et al., 2020). On the other hand, the correlation between green bonds and equity markets during the market turbulence is positive (Arif et al., 2021; Pham & Nguyen, 2021; Tiwari et al. 2022). The previous literature, however, has not yet answered the question of whether long-term investors could actually obtain more efficient diversification benefits by using green bonds. The aim of this thesis is to provide evidence on whether it is more profitable to invest in a stock-bond portfolio made of green bonds, or traditional bonds in the long term. These results can furthermore be utilized when building portfolios solely from green stocks and bonds, as green stocks are noticed to perform similarly to conventional stocks (Tiwari et al. 2022).

For best comparability with the previously developed market stock-bond correlation literature, similar to Pham and Nguyen (2021), this thesis uses data covering only US and European markets which are one of the leading markets in the green bond issuance (Climate Bonds Initiative, 2022a; Wass, Isjwara, Wu & Ahmad, 2022). To provide comparable results of the time-varying correlations between green bonds and stock markets, and conventional bonds and stock markets, there are two different portfolios examined. The green bond portfolio includes two green bond indexes issued in the EU and US markets. Furthermore, the conventional bond portfolio is constructed from the US and European treasury bonds, and investment-grade corporate bonds issued in the US and EU. Regarding the stock market indexes, the paper uses indexes measuring the performance of energy markets and large and mid-cap stocks markets. The data period lasts from December 2014 to December 2021 covering both the recent turbulence phase in 2021 and the long bull phase before the pandemic. The method used in this thesis is the DCC-GARCH model, which is widely used in stock-bond correlation studies. This way the paper aims to provide the best comparability for previous stock-bond correlation studies. The results are intended to give a new insight into the utilization of environmentally friendly investing techniques during the short and long periods when combining equity and bond markets in the portfolio.

1.2 Hypotheses

Previous literature shows how long-term green bond-equity market correlation tends to be similar to the correlation between conventional bonds and stock markets. The aim of this thesis is to compare the performance of two different portfolios during the long term and short term, and based on these, prove which one offers more effective diversification benefits. The paper states three different hypotheses based on the findings of previous literature. The first two hypotheses are related to the long-term performance and the third hypothesis to the short-term performance.

Hypotheses of the thesis are stated followingly:

H :1 *During long-term, stock-bond portfolio made from green bonds follows similar patterns with portfolio constructed of conventional bonds*

Previous literature has shown that the long-term stock-bond correlation in developed markets varies around zero or is slightly negative (Pericoli, 2018, p.7; Johnson et al., 2013; Baur & Lucey, 2009 & Skintzi, 2019). According to Reboredo et al. (2020) and Arif et al. (2021), long-term green bonds behave similarly compared to conventional treasury bonds and investment-grade corporate bonds. Furthermore, investigations such as of Reboredo et al. (2020), Reboredo (2018), Nguyen et al. (2021), and Pham and Nguyen (2021) find that the correlation of between green bonds with energy markets and stock markets is negative during long-term. Based on these findings, the first hypothesis suggests that the correlations between green bonds and stock markets, as well as the correlations between bond markets and energy stock markets, exhibit similar behavior to the correlations observed in the portfolio composed of conventional bonds.

H: 2 *The level of volatility and strength of correlation in the green bond portfolio is comparatively smaller when compared to the conventional bond portfolio.*

Even though green bond-stock market correlations follow similar patterns to conventional bond-equity market correlations, authors such as Sisodia, Anto, and James (2022) and Naeem et al. (2021) show how in long-term green bond prices are less vulnerable to market volatility. This way green bonds seem to be less volatile during various market conditions. Authors including Baker, Bergstresser, Serafeim, and Wugler (2018) suggest that this is partly due to the investor base, which is driven by environmental preferences, and thus also focuses on long-term performance rather than purely financial aspects. Thus, the second hypothesis states that long-term correlations are more stable and lower when investing in bond portfolios including green bonds, stocks market indexes, and energy market indexes. This way the diversification benefit obtained from the green bond portfolio is more efficient in the long term.

H :3 *During market turbulence, the conventional bond portfolio offers greater diversification advantages*

Even though green and conventional bonds are shown to perform similarly during long-term, recent research results have shown green bonds to correlate positively with other assets in the market turbulence. Sisodia et al., (2022) and Naeem, et al. (2021) find that in downturn green bonds are less volatile compared to conventional bonds during COVID-19 crisis. Furthermore Pham and Nguyen (2021) and Haq, Chupradit, and Huo (2021) find that otherwise small or negative correlations between green bonds and stocks increase during market turbulence. Liu et al. (2021) also investigate the correlation between green bonds and clean energy and find that spillover from clean energy to green bonds is high during downturns causing even higher correlations during market turbulence. This way, the conventional bond portfolio is expected to provide better diversification benefits for investors during market turbulence.

1.3 Structure of the paper

The first chapter presents the purpose of the thesis, how the topic chosen brings new findings for the existing literature, and briefly goes through the background of the subject. The hypotheses are also stated in the first chapter based on the previous literature findings. Chapter 2.1 provides an overview of financial markets, encompassing the general features of stocks and bonds, including pricing, volatility, and the evolution of responsible investing. Furthermore, chapter 2.2 presents the history of green bond markets and how they have become significant instruments in responsible investing.

The third chapter examines previous literature findings of stock-bond correlations in developed markets. Chapter 3.1.1 reviews the long-term findings and chapter 3.1.2 the short-term findings. Part 3.1.3 furthermore examines the generally recognized factors driving the correlation changes in the long- and short-term. The fourth chapter goes through the data and the methodology used in this paper. Chapter Five presents the empirical results of the study. In chapter six, the paper presents the conclusion and the implications of the results obtained in the study. Further suggestions for the future literature and investors are also presented in chapter 6.

2 Theoretical background

This chapter first goes through the basic theory of financial markets and the nature of equity and debt instruments. In Chapter 2.1.1, a thorough analysis of the stock market is conducted, while Chapter 2.1.2 focuses on bonds. This examination is crucial for understanding why they are influenced by similar factors and how their movements become interconnected. In Chapter 2.1.3 the paper expands the basic financial market theory by introducing the growth of responsible investing. As the main focus of the thesis is on green bonds, the green bond market is covered in its own chapter 2.2. Overall, chapter 2 provides important knowledge for chapter 3 where the main factors causing the correlation, the correlation generally between stocks and bonds, and finally, the new findings of the co-movements between green bonds and other asset classes are covered.

2.1 Financial markets

Financial markets channel the economy's savings into monetary assets by connecting market participants such as intraday traders, sovereign wealth funds, pension funds, and governments (Arif et al., 2021; Bradford, 2008, p.3). Financial assets, which are traded in the markets, represents contracts between the parties (Bradford, 2008). They can be generally divided into four groups: *equities, debt instruments, cash instruments* and *derivative instruments.* Financial markets can be further divided into two parts based on the parties, intermediaries, and trading time (Dubil, 2012, p.1-2). The transfer of money from capital suppliers to capital demanders takes place in the *primary market*. In the securities market, the intermediary is an investment bank while in the credit market it is a bank or an insurance company. In the *secondary market* the capital suppliers lend instruments already issued to the other suppliers. Intermediaries in the securities markets are broker-dealers and banks in the loan markets.

Financial markets are a complex system featured by non-linear patterns, which makes it somewhat difficult to predict and make unambiguous models of the prices of instruments (Bartimoro, 2011). Exogenous and endogenous factors constantly affect the pricing of instruments causing clear trends but also random drops and peaks in the occurring trend lines. An example of a market trend is a growth trend, which occurs during periods of positive investor sentiment and reduced unemployment, leading to an uptrend in financial markets (CenterPoint Securities, n.d.). Term uptrend can be used for several time periods, where *bull market* refers to longer-term uptrend, lasting even more than months. It is generally linked to benchmark indexes such as the S&P500 index. Since 1932 there appears a total of 14 bull markets with an average of 3.8 years, but the latest one from 2009 to 2020 turns out to be the longest. On the other hand, decreasing economy and a more pessimistic investor atmosphere refer to a bear market (CenterPoint Securities, n.d.; Ni & Huang, 2015, p. 4504). Market declines worth more than -20% and lasting at least 60 days refer to a bear market, and intraday declines of -20% or more from the benchmark can be considered signals of a crash.

2.1.1 Stocks

Stock markets play a fundamental role in facilitating company financing, thereby fostering business activity, and stimulating economic growth (El Wassal, 2013, p. 606–607). Stocks can be traded privately, or on the stock market in public stock exchanges (Bradford, 2008, p. 3,5). Stock market indexes, including the previously mentioned S&P500 index, reflect the price movements of stocks within a particular market or segment (Parameswaran, 2011, p. 131–141). Index creation can be approached in several ways. A price-weighted index is established by dividing the current stock prices by an arbitrary value, such as the number of shares included in the index. On the other hand, a value-weighted index assigns stocks based on market capitalization, giving more weight to stocks with larger market values and exerting a dominant influence on the index. Lastly, an equal-weighted index grants an equal allocation to each stock within the index.

The valuation of a stock relies on a fundamental approach where dividends are discounted to their present value (Foerster & Sapp, 2005, p.55–57, 69–72). Several fundamental valuation models exist for pricing stocks, with the Dividend Discount Model (DDM) being one of the most popular choices (Foerster & Sapp, 2005, p.55–57, 69–72). Due to its ability to provide accurate estimations of future stock prices, the dividend discount model has gained significant adoption as a fundamental valuation model in real-world applications.

(1) Stock pricing: Dividend discount model

$$E_t[P_t] = \sum_{i=t+1}^{T} E_t[D_i]/(1+r_i)^{i-t} + E_t[P_T]/(1+r_t)^{T-1} , \quad (1)$$

According to the equation presented by Foerster and Sapp (2005, p.57), the expected return E_t at time t is determined based on current information about the share, the dividend, D_i, and the discount rate chosen by investors r_t. However, not all data about the dividends are always available at the time t if the investment horizon is long. In such cases, the valuation model incorporates a terminal value denoted as $E_T[P_T]/(1+r_t)^{T-1}$. This component describes the remaining part of the pricing model when precise information about future dividends is not available. Alternatively, if it is known that dividends grow at a constant annual rate g_t the price of the stocks can be calculated with the Gordon Growth Model (GGM) which is presented below (Foerster & Sapp, 2005, p.57).

(2) Stock pricing option 2: Gordon Growth Model

$$E_t[P_t] = E_t[D_{t+1}]/(r_t - g_t) , \quad (2)$$

Initially, the pricing of stocks is influenced by stock-specific risks and capital structure, as highlighted by Machdar (2016, p. 150-153). Author states that risk associated with stocks can be divided into two components: systematic risk and unsystematic risk. *Systematic risk* reflects the riskiness of the stock relative to the market. The risk is affected by the company's fundamentals and how the stock type typically correlates with market changes, and thus cannot be eliminated. The stock's return is strongly influenced by its beta, a parameter that captures the level of market risk associated with it. On the other hand, *unsystematic risk* is associated with a particular asset or group of assets. This risk is company-specific so the risk can be eliminated by diversifying the portfolio for example by industry. Finally, in the case of a company's capital structure, an excessive amount of debt relative to equity typically correlates positively with the stocks' return requirement.

The discount rate used to calculate the stock’s price is generally derived using the *Capital Asset Pricing model* by Sharpe (1964), Lintner (1965) and Mossin (1966) (Bali et al., 2013, p.122; Foerster & Sapp, 2005, p. 56–57) The model creates the expected return $E[R_{i,t}]$on the basis of the stock-specific risk factors where $R_{f,t}$ illustrates the return of a risk-free rate, which is typically treasury bond rate. $E\left[R_{m,t}\right] - R_{f,t}$ represents the market risk premium in a certain time period t (Bali et al., 2013, p.122). β refers to the afore-mentioned beta, and a higher beta implies higher risk, which further leads to higher expected return (Machdar, 2016, p.150–151). Furthermore, there exist more intricate models which include factors such as *market capitalization*, *book-to-market ratio*, *momentum,* and *liquidity* and this way attempting (Bali et al., 2013, p. 122–123). Nonetheless, the CAP model is still the most widely used.

(3) Stock return: CAPM

$$E[R_{i,t}] = R_{f,t} + \beta_i(E[R_{m,t} - R_{f,t}] \quad , \qquad (3)$$

Stock market risk is illustrated with volatility. Cochran & Mansur (2002, p.82) define stock market volatility as “(1) the standard deviation of return and (2) large single-day price changes”. Volatility refers to the deviation from the expected value of an asset, which therefore increases the riskiness of the asset. The methodologies employed for volatility calculation vary depending on the desired level of accuracy sought by investors. However, the standard deviation is generally employed as a common measure to estimate volatility. The magnitude of volatility indicates how significantly the price varies around the average price. The more the value deviates from zero the more possible outcomes might emerge below or above the central value. The following equation presented by Daly (2011, p.48) illustrates how standard deviation is calculated.

(4) Stock risk: Standard deviation

$$\sigma = \sqrt{\sum_{i}^{T} (R_t - \bar{R}_f)^2 / (\mathrm{T} - 1)} \quad , \tag{4}$$

The primary source causing the volatility is news about the fundamental value of the asset (Daly, 2011, p.47). News of trading turbulence, commonly referred to as noise, causes volatility changes at high-frequency intervals. Furthermore, changes in macroeconomic factors such as interest rates and inflation, cause price changes as they directly impact on the formation of the discount rate (Moya-Martínez, Ferrer-Lapeña & Escribano-Sotos, 2015). Changing economic circumstances cause fluctuations in stock prices as well (Cochran & Mansur, 2002). Studies from the 20th century show that stock market prices react more strongly to economic recessions, such as in the 1930s and 1980s than to expansions, such as in the 1950s and 1960s. Furthermore, as the price of the stock deviates from the typical value during recessions, the deviation tends to take some time before normalization.

As the following figure shows, the most substantial surges in stock market volatility during the 20th century originated from notable economic crises, such as the stock market crashes of 1929 and 1987, the Great Recession in 1933, and the global financial crisis in 2008 (Baker, Bloom, Davis, Kost, Sammon and Viratyosin, 2020, p.743). These increases in volatility are mainly due to economic incidents, but none of the pandemics such as Spanish influenza in 1918-1919 or influenza in 1957-1958, and 1968 caused similar effects. However, the notable surge in stock market volatility witnessed in 2020 was due to the unprecedented impact of the COVID-19 pandemic. In addition to being the first pandemic to have a significant impact on the stock market, the overall impact on the market is the third largest during the last 120 years of history. In more detail, the results of Baker et al. (2020) also show that from 24-03-2020 to 24-03-2020 markets jumped more than in any other 22-day trading window in history. They suggest that the notable reaction of the stock market in 2020 is due to the substantial constraints imposed on economies, which led to a deterioration of corporate performance, and induced significant challenges to the overall economic conditions.

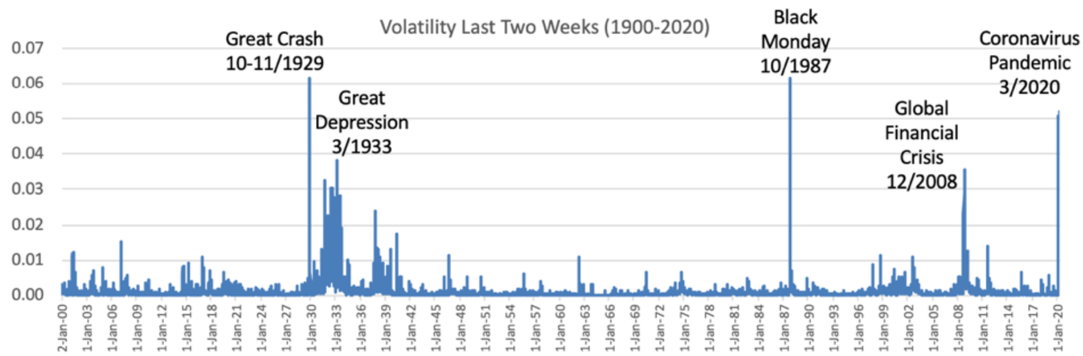


Figure 1. Stock return volatility past century (Baker et al, 2020, p.743).

2.1.2 Bonds

Debt instruments offer governments, banks, supranational institutions, municipalities, and companies an alternative way to raise funds to finance operating expenses (Bradford, 2008, p.9-18; Parameswaran, 2011, p.167). In this thesis, the focus is on bond instruments, which represent one form of debt instrument issued by a company or government (Bradford, 2008, p.9–18). Bonds are listed in primary markets but like stocks, they can also be traded in secondary markets. In the secondary market, investment banks trade bonds mostly on the over-the-counter market rather than on the stock exchange. Like equities, secondary market bond prices fluctuate according to supply and demand and depend on changes in the economy and the views of investors about the debt issuers' financial conditions.

Bonds are characterized by principal value, maturity, and coupon rate (Parameswaran, 2011, p.167–168). Firstly, bonds vary by their features depending on how they pay interest. The most typical debt is the *straight bond*, also the so-called *plain vanilla bond*, where the coupon rate remains the same throughout the maturity and the repayments follow typical repayment periods (Bradford, 2008, p. 9–15). The focus of this thesis is on these bonds as green bonds, which are explained later more in detail, issue mainly fixed rates. There are also other bond types such as *Floating-rate-note bonds* with varying coupons, *zero-coupon bonds*, *convertible bonds,* and *bonds with warrants attached*. Bonds furthermore vary according to their maturity (Goyenko et al., 2011, p. 117). In general, short-term debts with a maturity of one year or less are called *bills or T-bills*. If the maturity is more than 2 years but less than 10 years, the debt is called a *note* or *t-note*. In the case of debt with a maturity of more than 10 years, or according to some other studies with a maturity of more than 20 years, the debt is called a *bond or t-bond*.

The price of a bond is calculated by discounting all coupons and the face value to the present (Andersson et al., 2008, p. 145). In the following equation, C represents the coupon, FV is the face value, Y_t is the bond yield at time t, and T is the time at the end of the maturity.

(5) Bond price

$$B_t = E_t\left[\sum_{t=1}^{T} \frac{C_t}{(1+Y_t)^t} + \frac{FV}{(1+Y_T)^t}\right], \tag{5}$$

Bond yield Y_t is affected by various firm-specific, external, and bond-specific factors (Bradford, 2008, p.18–20; Goyenko et al., 2011; Viceira, 2012). Firstly, the liquidity of a bond plays a significant role in determining its yield rate. The relation between maturity and liquidity is negative which is why short-term bonds are typically required to yield less than long-term bonds. Under such circumstances, the liquidity premium is diminished, indicating a reduced yield that investors demand for carrying the liquidity risk. Secondly, credit ratings issued by a public credit rating agency illustrate the quality of bonds, and this way impacts bond yields (Bradford, 2008, 9, 18–19; Li et al. 2017). Different rating agencies have their own rating marks. The higher the rating the better the ability of the bond issuer to repay the debts and thus the lower yield and the higher the price of the bond. Ratings typically vary from D to AAA depending on the company providing the rating and bonds rated above BBB are so-called “Investment-grade” bonds and bonds below BBB- are “high-yield” or “speculative bonds” (Hilscher & Wilson, 2017, p. 3422). Thirdly, macroeconomic variables like short rates and inflation impact positively the yields of bonds (Viceira, 2012).

(6) Bond yield

$$Y_n = Y_n^r + \pi_n^e + \theta \quad , \tag{6}$$

The equation above presented by Andersson et al. (2008, p.145) elucidates how short rates and inflation contribute to the determination of the bond yield. In this formula Y_n^r is the real interest rate, π_n^e expected inflation, n the time period, and θ is the term premium, which is a variable whose value depends on the bond-related risk. Furthermore, the yield curve illustrates the development of bond yields in terms of maturity growth (Bradford, 2008, 18-19; Heinen, 2012). The yield curve is typically positive and upward because longer-maturity bonds have a higher repayment risk and thus they require higher returns. The curve might also be flat or inverted, depending on the economic situation. In good economic times, typically after recessions or during economic growth, the yield curve is upward. Alternatively, when there is an inverted yield curve, characterized by long-term yields being lower than short-term yields, it could be a signal of a worsening economic situation.

In terms of volatility, bonds are relatively neutral compared to stocks (Heinen, 2012; Viceira, 2012). Changes in bond yields exhibit a time-dependent nature and are predominantly influenced by fluctuations in general macroeconomic factors, such as interest rates and short-term interest rates. As illustrated in the previous equation 6, inflation and short rates positively predict bond return volatility, and the more they fluctuate the more bond yields change. This way the slope of the yield curve is also an important tool to predict the future volatility of bonds (Heinen, 2012).

Bond market risk can be measured by calculating the covariance between bond market returns and stock market returns (Viceira, 2012). Bond beta represents this relationship, in which the risk of the bond market is based on the degree of covariance between the bond yields and the stock portfolio yields. As the following figure (Viceira, 2012) illustrates, the bond risk is mainly positive from the 1960s to the early 2000s, though it varies considerably during this period. After the beginning of the 21st century the bond beta shows to be mainly negative.

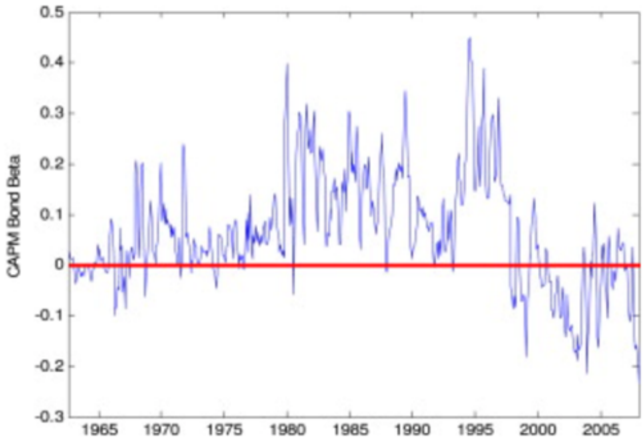


Figure 2. Evolution of bond beta 1962-2007 (Viceira, 2012).

The figure also illustrates the sharp booms of bond betas during times of economic uncertainty (Viceira, 2012). For example, crises such as the recession of the 1990s appear to have had a significant impact on the volatility of bonds.

2.1.3 Responsible investing and growing popularity of green assets

The heightened concerns regarding social and environmental issues in the 21st century prompted a shift in the evolution of financial instruments, with a notable emphasis on the development of assets intended to mitigate these challenges (Pástor, Stambaugh & Taylor, 2022). Especially the growing threat posed by climate change, and the possible difficulties people would face due to the problems in the ecosystem, have pushed companies and governments to improve ways to support sustainable development. Furthermore, the 2015 Paris Climate Agreement, the European Green Deal, and the implementation of carbon taxes were remarkable factors accelerating this development of green assets (Arif et al., 2021). The growing emphasis on sustainable thinking has led to the development of new assets, which has furthermore created a new distribution between securities in the financial markets (Pástor et al., 2022). In this new categorization "green securities" refer to assets contributing to sustainable projects and "brown securities" refer to opposite assets.

Green securities belong to the security-specific risk and render environmentally-friendly opportunities to diversify investment portfolios (Tiwari et al., 2022). The number of green investments in stock exchanges has expanded globally in the 21st century, and they have become one of the most efficient ways for investors to support environmentally friendly projects (Tiwari et al., 2022). Furthermore, empirical research conducted by Arif et al. (2021), Broadstock et al. (2020), and Tiwari et al. (2022) demonstrate that in addition to supporting sustainable development, assets concentrating on environmental, societal, and economic issues seem to overperform "brown" securities. Authors, including those mentioned earlier, have observed that green investment solutions have attracted significant capital inflows, driven by their ethical perspective and strong and consistent performance. This way, green assets are expected to experience further growth in popularity also in the future.

Companies providing green investment opportunities are typically functioning in environmentally dependent industries such as in energy sector, clean transportation, water or waste management, and recycling (Liu et al., 2021). Green stocks are shares of companies that have a positive impact on the environment (Tiwari et al., 2022). In order for the company's stocks to be listed as green, stocks must pass stringent environmental examinations before being listed (Gao, Zhao, Sun & Zhao, 2022). After this, firms have to repeatedly prove the acts towards environmental protection and provide the information on time. In the fixed-income markets, green bonds, which will be reviewed in the next chapter, are also featured with strict regulations concerning their use of proceeds and third-party verification (Climate Bonds Initiative, n.d.). In order to assess the effectiveness of different entities, such as corporations and governments, in supporting sustainable development, there occurs various metrics in the markets (Chang, Fu, Jin, & Liem, 2022; Gillan, Koch, & Starks, 2021). Typical measures used are the Environmental, Social, and Governance (ESG) factor and the Corporate Social Responsibility (CSR) factor. In addition to stocks receiving these ratings, thematic bonds such as green bonds are also known as ESG-rated assets (Hussain, 2022, p.2).

As mentioned, improved environmental practices are shown to be reflected positively in companies' financial performance (Dyck, Lins, Roth & Wagner, 2019; Sassen, Hinze & Hardeck, 2016). This is noticed to be valid both in the long- and short-term. Researchers such as Broadstock et al. (2020) show that high ESG stocks both mitigate risk and outperform low ESG stocks during financially uncertain times. Investigations show that ESG factors impact on stocks' systematic, idiosyncratic, and total risk. In addition to the equity market, the positive relationship between higher ESG rating and the asset's performance can also be seen in the green bond market, especially during market downturns and long-term (Arif et al., 2021; Broadstock et al., 2020; Tiwari et al., 2022). Flammer (2021) illustrates how a better ESG rating improves the bond's performance and enhances new investors who value the long-term performance and the environmental perspective. Reaction in the stock markets for the bond issuance is also noticed to be greater when the firm issues green bonds (Thang and Zhang, 2020).

According to Cahn, Fu, Jin, and Liem (2022), the value of sustainable assets under management in the financial markets reached $37.8 trillion by the end of 2021, and it is projected to exceed $53 trillion by 2025. Governance & Accountability Institute stated that in 2018 86% of the firms belonging to S&P500 published their sustainability or corporate responsibility report, which was 66% more than in 2011 (Gillan et al., 2021). Solely in 2019, a total of $20 billion were collected by 300 mutual funds with ESG mandates (Gillan et al., 2021) and the capitalization of ESG-focused portfolios in global markets surpassed

$30 trillion USD in 2019 (Broadstock et al., 2021). In March 2021 there were approximately 3404 investors and 122 service providers managing more than US$121 trillion in assets, who were committed to Principles of Responsible Investing (PRI) (Gillian, Koch & Starks, 2021; Principles for Responsible Investing, n.d.). The commitment includes taking social and economic aspects considerations in their investment research and decision-making processes (Gillian, Koch & Starks, 2021). The leading countries in terms of signatories were the 1st UK and Ireland, the 2nd Nordics, and the 3rd US. Overall, the number of signatures has increased to around 1000 signatures worth US$30 trillion in 2011 (Principles for Responsible Investing, n.d.). This trend highlights the growing involvement of individual investors, corporations, investment funds, and governments in directing resources toward sustainable assets.

2.2 Green bonds

In the early 2000s, as a solution to the growing need for new assets supporting a low-carbon economy, "green bonds" were introduced (Tiwari et al., 2022). Green Bond Principles published by International Capital Market Association (2021) define green bond as "*any type of bond instrument where the proceeds or an equivalent amount will be exclusively applied to finance or re-finance, in part or in full, new and/or existing eligible Green Projects ... and which are aligned with the four core components of the GBP*". As a criterion for the green bonds is, that the proceeds from green bonds must be used on projects which are beneficial for the environment (Sisodia, Anto, & James, 2022). According to the International Renewable Energy Agency (IRENA), between 2010 and 2019, green bond proceeds (USD) were allocated as follows: 23% to renewable energy, 19% to energy efficiency, 14% to clean transport, 12% to sustainable water supply, 9% to green buildings, and 7% to pollution prevention (Naeem et al., 2021). This allocation distribution has remained consistent through the years (Climate Bonds Initiative, 2022). The first green bond issued was by the European Investment bank in 2008 called “climate awareness bond” (Sisodia, Anto and James, 2022) and the first corporate green bond was introduced in 2013 (Boutabba & Rannou, 2022).

The voluntary guidelines, "Principles of Green Bond" (GBP), published by the International Capital Markets Association (ICMA) in January 2014, offer additional clarity on the framework for green bonds (Tiwari et al., 2022). The Green Bonds principles encompass the analysis of four key areas: 1) the utilization of proceeds, 2) processes for evaluating and selecting green projects, 3) the management of proceeds, and 4) a commitment to ongoing environmental performance reporting (Bloomberg Barclays Indices, 2021). After this, there have emerged several acknowledged authorities in the markets providing the certification for green bonds and the not-for-profit organization Climate Bonds Initiative (CBI) has become the leading one (Lacker & Watts, 2020; Sisodia, Anto & James, 2022). CBI has further-more defined three different labeling methods for green bonds (Climate Bonds Initiative, n.d.). The first option is self-label where the issuer gives a name for the bond such as “Green bond”. The second option is self-label with a second-party opinion to add credibility to the bond. The third option and the most credible one is “Certified Climate Bond” -labeling where the bond must be gone through an independent evaluation process of the Climate Bond Certification system. CBI’s standards are globally accepted, and CBI also provides approvals for companies such as KPMG and Deloitte qualifications as third-party verifiers.

After the publication of the GBP, the Paris Climate Agreement in 2015, and new certification standards, more academics, investors, and policymakers have become increasingly interested in green bonds (Tiwari et al., 2022). Certifications have made it easier to assure that the issuances are in line with the Paris 2015 agreement and that the proceeds raised from the green bond issuance will be used only for environmentally friendly projects (Lacker & Watts, 2020; Sisodia, Anto & James, 2022). Furthermore, green labels have made it easier for investors to find credible green bonds from platforms (Climate Bonds Initiative, c). Since the first time the green bonds were introduced to the markets in 2007 the market size has rocketed from $0.8 billion to $349.1 billion in 2020 (Naeem et al., 2021; Tiwari et al., 2022). Till the second quarter of 2022, the cumulative number of global green bond issuance has reached USD $2 trillion from $4.2 billion in 2012 (Climate Bond Initiative, 2022a; Sisodia, Anto, & James, 2022).

2.2.1 Green bond issuance

European markets have played a leading role in the expansion of the green bond market since the introduction of the first green corporate bond in 2013, as highlighted by Boutabba and Rannou (2022). According to the authors, in 2020 European markets represented a total of 48% (total of 156bn) of the volumes of green bond issuances. Climate Bonds Initiative (2022c) reported in June 2022, that leading European countries in terms of the total amount of green bonds issued were Germany, France, Netherlands, Sweden, and Spain. Furthermore, according to Wass, Isjwara, Wu & Ahmad (2022), in terms of the number of issuances by area, North America and the Asia-Pacific regions are the leading markets. According to the annual report of CBI (2022c) leading area in yearly green bond issuance is the US, followed by China and then the European countries Germany and France. Moreover, institutions, such as The World Bank have issued a total of 196 green bonds for several countries (Hussain, 2022, p.xi). Also, several well-known companies such as Unilever in 2014 and Apple in 2017 have also issued green bonds worth billions of dollars, and (Flammer, 2021).

The popularity of green bonds is partly supported by the advantages during their issuance. Statistics from green bond issuance have shown that green bonds benefit investors with higher cumulative abnormal returns around the issuance of bonds when they are issued for the first time (Thang & Zhang 2020). The stock prices of the companies are furthermore shown to increase due to the announcement and the liquidity improves after the issuance. This is supported by the research results of Thang and Zhang (2020) from 28 different markets around the world, and by the results of Wang, Chen, Li & Zhong, (2020) from the Chinese markets.

Related to the issuance of green bonds, Lacker, and Watts (2020) and Flamer (2021) further discover that green bond seems to have a 12%–20% lower level of ownership concentration. Flamer (2021) furthermore shows, that after green bond issuance, both the number of long-term investors and green investors have increased in the company's investor base. These can possibly be caused by increased media exposure due to issuance

(Lacker and Watts, 2020). As mentioned, green bond issuers also need to be more transparent about information related to green bonds. Due to increased media coverage, it can be expected to attract precisely these long-term, environmental preferences driven investors (Baker et al., 2018). These are factors that can possibly also impact the green bond-stock market correlation results compared with the conventional bond market-stock market results which are examined later.

2.2.2 Green bond liquidity

As the size of the green bond markets has boomed during a comparably short time period, the liquidity of the markets has also improved (Febi, Schäfer, Stephan, & Sun, 2018). Even though the markets have grown rapidly, the size of the green bond market compared to conventional bond markets remains still relatively low (Climate Bonds Initiative, 2022b). Climate Bonds Initiative (2022b) announced that the total amount of green bonds issued in the 2nd quarter of 2022 reached $2 trillion. However, compared to the size of global fixed markets, which Corporate and Investment Bank (2022) announced it to be is approximately $130 trillion, green bond markets size is relatively small. The shortage of issuances in the green bond market might increase the bid-ask spread and thus insert the risk of illiquidity and its impact on pricing (Boutabba & Rannou, 2022). Due to this, research has focused on potential liquidity concerns surrounding green bonds, which can affect the broader development of liquidity in the green bond market.

Before going into the analysis of liquidity studies, it is essential to take into account certain factors that influence the liquidity of green bonds in comparison to those associated with traditional bond assessments. As mentioned, green bonds are typically investment grade ranked and thus, when measured by credit risk, green bonds are substitutes (Boutabba & Rannou, 2022). Thus, it can largely be assumed that green bonds differ mostly only by their maturity. This way, issuers can target different investor groups by their risk preferences by issuing short-term or long-term green bonds. For this reason, in the case of green bonds, the term structure of liquidity premia is an efficient way to investigate the impact of liquidity risk.

Febi et al., (2018) investigate the impact of the liquidity risk on the yield spread of green bonds. Authors find that risk has become negligible as the markets have matured. Researchers Boutabba & Rannou (2022) investigated the liquidity in the green bonds market in regarding the size, term structure, and the main determinants of the liquidity premium. They examine 200 green bonds issued in the most active exchange (LGX) for green bonds in Europe and bonds are maturing from 1 to 20 years during five years. The examination period begins in December 2014 as most corporate bonds were issued in 2014 by Supranationals, Sovereigns, Agencies, and Corporates. All bonds are AAA or AA rated. Using the bid-ask spread authors among others find the following results: short-, medium-, and long-term premia are comparable to ones of the Ger-man government bond market and of the US treasury market. They, however, find liquidity clientele effect from the ask side, suggesting that short-term and long-term investors may face difficulties in selling bonds before they reach maturity. Thus, although the green bond market has grown and there are various liquidity-enhancing market indices, the market's relative stability could be attributed in part to its lower liquidity.

2.2.3 Green premium and greenwashing

The green bond literature also includes studies on whether green bonds are traded at higher prices compared to their non-green counterparts (Tiwari et al. 2022; Lacker & Watts, 2020). This so-called greenium occurs if assets issued by the same issuer on the same date have pricing differences. The literature presents mixed results about this possible benefit obtained from investing in a green bond. Some theories such as of Löffler, Petreski, and Stephan (2021) present that there are differences in how green bonds are valued compared to conventional bonds. The authors present that there are two possible reasons causing the difference in the valuation. First, green bonds can be valued differently compared to conventional bonds because of their environmental preferences and “green label”, due to why investors are willing to accept lower yields. The second theory suggests that green bonds provide lower risk compared to counterparts as they are regularly monitored by third parties to ensure the use of proceeds. These might lower the likelihood of default and thus some researchers present green bonds to be evaluated differently.

Baker, Bergstresser, Serafeim, and Wurgler (2018) investigate municipal and governance green bonds issued between 2010 and 2016. They find that green bonds are priced at a higher value than their face value, and yields are lower by several basis points. Similarly, Löffler et al. (2021) investigate 2000 green bonds and 180 000 conventional bonds using coarsened exact matching and propensity score matching to make the sample of conventional bonds more comparable to the sample of green bonds. They also find that green bonds are traded with premiums in both primary and secondary markets, and yields are 15 to 20 basis points lower than the yields of comparable conventional bonds. Similar findings are made by Gianfrate, and Peri (2019) from the European markets and Kanamura (2020) from the global markets.

On the contrary, other group of researchers illustrate that the premium does not occur. Lacker and Watts (2020) examine total of 640 different green and non-green bond pairs issued by the same municipality with the same maturity and rating, and the results show that there are no pricing differences for green and brown bonds. They also consider the impact of CBI certification which also proves to have no beneficial effect. Overall, their findings strengthen the notion that investors' non-financial preferences are unlikely to be the primary determinant of differences in asset pricing. Authors state that asset values are much more likely to be affected by how ESG-focused performance affects future business profitability and risk, rather than the other way around. These similar findings are found in the paper of Flamer (2021) as well.

Furthermore, Sisodia, et al. (2022) and Flammer (2021) show how issuing green bonds rather causes more costs in the form of compliance costs. This is against the greenium claim as well. Due to this third-party verification, the administrative and whole compliance costs, including for example annual reports about sustainability, are also higher than for the conventional bonds. Furthermore, green bonds have a higher underwriting cost compared to non-green bonds in general. In particular, borrowing costs for green assets are often 10% higher than borrowing rates for nearly equivalent non-green securities (Larcker and Watts, 2020). Furthermore, the limitations for proceeds limit the investment policies and this way increase the overall cost of capital (Flammer, 2021; Sisodia et al., 2022).

Authors such as Flammer (2021), and Sisodia et al., (2022) furthermore state that there are also several speculations on whether green bonds represent a type of greenwashing. Flammer (2021) points out, that criteria for issuing certified green bonds, as well as the continuous assessment of the use of proceeds, are however seen as significant signals of the company's commitment to the environment. Even though the issuers of green bonds can credibly signal with the third-party verification of their commitment, there occur also speculations about whether the issuances genuinely advance sustainability (Flammer, 2021; Sisodia et al., 2022; Tang & Zhang, 2020). According to research by Flammer (2021), the issuance of green bonds positively impacts on a company's environmental rating when assessed using the Thomson Reuters ESG score. Additionally, these results show to be associated with the reduction of Co2 emissions of companies. Similar observations of the connection between reduction of Co2 emissions and increased environmental ratings are discovered by Tang and Zhang (2020), Sisodia et al. (2022), and Mamun, Boubaker, and Nguyen (2022). Mamun et al. (2022) furthermore state that the effect is more provident in countries with advanced credit markets and the susceptibility to climate change is greater. The findings strongly support the argument that green bonds are not a form of greenwashing.

3 Previous research

Academic stock-bond literature dating back to the 19th century reveals that there occur notable temporal variations in this relationship (Yang et al., 2009). Studies from several decades present different proposals for effective diversification, varying based on continents and countries under examination, as well as according to the time period. Furthermore, differences in asset characteristics, such as sovereign debt based on credit ratings, contribute to variations in their sensitivity to market conditions. Consequently, these variations influence the level of regional correlations. In general, the global market is divided into developed markets and emerging markets, where the correlations, but also the factors driving the price changes of stocks and bonds, are noticed to be similar.

Financial markets have experienced developments in the 21st century by further dividing the assets according to their environmental commitment. This has shifted the literature to investigate the relation and co-movement of “green” and “conventional” assets. As the main purpose of this thesis is to investigate whether using green bonds instead of conventional ones is more beneficial, the chapter first introduces the results obtained from the typical stock-bond correlation studies. Chapter 3.1 provides the results of the long-term and short-term correlations in developed markets over the past few decades. After this, chapter 3.2 goes through the findings of how green bonds are noticed to correlate with other financial assets, which bases the research part of this thesis.

3.1 Stock-bond correlation in developed markets

Chapter 3.1.1 provides evidence of the long-term stock-bond correlation trends observed from the beginning of the 1980s. After this, chapter 3.1.2 introduces how the short-term correlations change due to the so-called flight-to-quality phenomenon. Chapter 3.1.3 furthermore examines common factors that are generally recognized to affect the stock-bond correlation.

3.1.1 Long-term correlation

Stock-bond correlations are noticed to vary greatly over time, but especially during the long-term period, there can be observed clear trends. Studies from the developed markets show how the stock-bond correlations follow mostly similar positive long-term trends until the early 2000s (Pericoli, 2018, p.7; Skintzi, 2019). After the turn of the 21st century, correlations fall slightly below zero or remain around it in most developed market countries (Aslanidis & Christiansen, 2012; Pericoli, 2018, p. 7). Figure 4 (Pericoli, 2018, p.7) below illustrates how all the correlations in the US, and in core European countries during 1980-2017 follow this similar pattern. These results of the developed market correlation trends are consistent with the findings of Johnson et al. (2013) who study the long-term correlation in the US, and with the findings of Baur & Lucey (2009) who study the correlation in the US, the UK, German, France, Australia, Italy, and Canada.

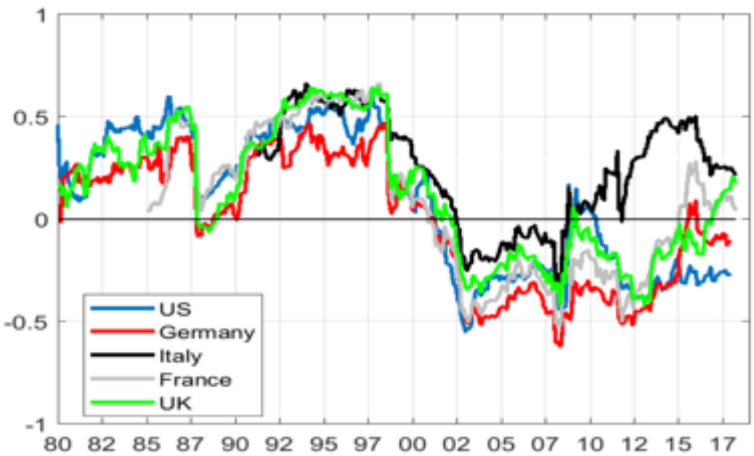


Figure 3. Stock-bond correlations in the US and Europe (Pericoli, 2018, p.7).

What can be furthermore noticed from Figure 3 (Pericoli, 2018, p.7), is that the correlation trend in Italy differs from the correlation trends observed in other countries. Skintzi (2019) also investigates the correlation concentrating on European countries. The author further divides countries into core countries; Austria, Belgium, Finland, France, Germany, Netherlands, and peripheral countries; Greece, Ireland, Italy, Portugal, and Spain. A similar different trend is observed in the long-term correlations of peripheral European countries. Due to the global financial crisis as well as the European debt crisis, bonds of peripheral European countries became riskier which explains those highly positive correlations in the remote European countries. Figure 5 (Skintzi, 2019) illustrates how the correlations of the peripheral European countries start to differ after the turn of the 21st century.

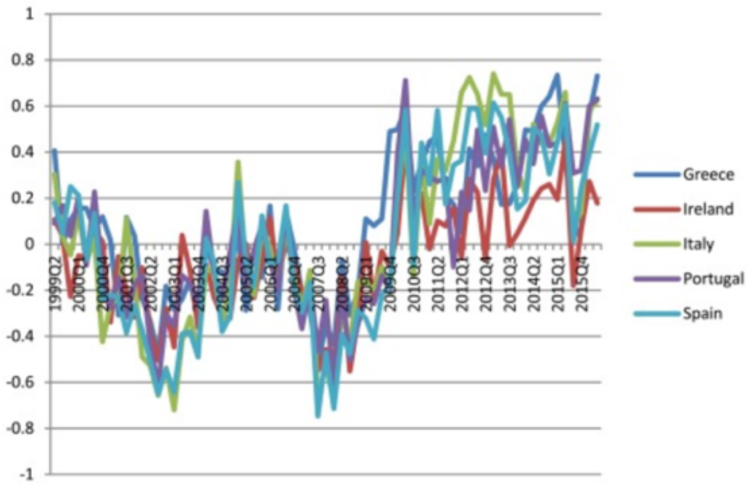


Figure 4. Long-term stock-bond correlations in peripheral European countries (Skintzi, 2019).

As stated in Chapter 2.2.1, based on the 2022 report (Climate Bonds Initiative, 2022c) the leading countries in green bond issuance are Germany ($218 billion), France ($202 billion), Netherlands ($116 billion), Sweden ($70 billion), and Spain ($62 billion). Even though Spain is included in this category, the percentual part of the total amount of bonds issued is comparably small. So even though the data is going to gather bonds issued in the European Union, where Spain also is a substantial issuer, this result is not expected to significantly distort the study and the comparability.

3.1.2 Short-term correlation

Previous Figure 4 presented by Skintzi (2019) well illustrates how short-term stock-bond correlations deviate remarkably from long-term trends. These short-term correlations are noticed to be mainly negative in most developed markets during the 21st century

(Connolly et al., 2007; 2016; Skintzi, 2019). Short-term deviations from the long-term trend are mainly due to various disruptions that cause uncertainty in the market (Aslanidis & Christiansen, 2012). In times of financial market turbulence investors tend to re-allocate their assets as the yields of stocks and bonds move in opposite directions (Baur & Lucey, 2009). This movement, where increased market uncertainty drives investors to shift assets from high-risk stocks to low-risk bonds is called the “flight-to-quality” -phenomenon (Baur & Lucey, 2009; Skintzi, 2019).

The study by Baur & Lucey (2009) shows that the flight-to-quality phenomenon does not occur on just one continent, but usually simultaneously in different market areas. Their study shows that the crises of the 21st century were coupled with considerable market uncertainty. This led to simultaneous declines in stock-bond correlations in the US, UK, Germany, France, Italy, Australia, Canada, and Japan. These results are consistent with the findings of authors such as Andersson et al. (2008), Aslanidis & Christiansen (2012), and Skintzi (2019), who illustrate how increasing market uncertainty plays a significant factor in causing negative stock-bond correlations. Their results show that especially the rise of the global market uncertainty index appears to lead to simultaneous flight-to-quality phenomena in all developed market countries.

3.1.3 Factors driving correlation changes

Numerous research papers from different decades have concentrated on identifying factors most significantly explaining the correlation changes (Dimic et al., 2016). Papers have come up with different results, which vary depending on several factors (Skintzi, 2019). The way how factors affect the stock-bond correlation varies between papers and furthermore by how factors are seen to affect the correlations. This chapter represents the factors most correlation studies have agreed to impact the long- and short-term changes. Since this thesis focuses on developed markets, the following chapter will be a general overview of the developed market correlation drivers.

Determinants of the stock-bond correlation are typically divided into *macroeconomic* and *uncertainty factors* (Dimic et al., 2016). Studies highlighting the ability of macroeconomic factors to influence the stock-bond correlation particularly emphasize the importance of inflation, interest rates, and economic conditions (Aslanidis & Christiansen, 2014; Baele, Bekaert & Inghelbrecht, 2010). Papers such as of Skintzi (2019), (Andersson et al. (2008, p. 140-141), Yang et al. (2009), and Viceira (2012) find, that inflation is one of the key factors influencing the long-term correlation in the US, UK, and Europe. Authors illustrate that inflation has a rising effect on the short-term interest rates and thus has a positive effect on the stock-bond correlation. Similarly, Baele et al. (2010), d'Addona and Kind (2006), Kiley (2012), Pericoli (2018), Skintzi (2019), and Viceira (2012) indicate that short rates cause strong positive correlations in the US, UK, and Europe, as they impact negatively on both discount rates of bonds and stocks. Moreover, Aslanidis and Christiansen (2012) and Yang et al. (2009) indicate that interest rates are typically higher during expansions when the co-movement of stocks and bonds is also stronger In Figure 3 below the x-axis represents the correlation and the y-axis the strength of variables (Aslanidis & Christiansen, 2012).

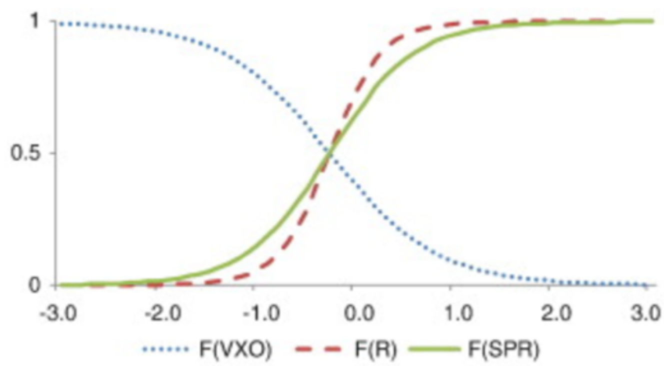


Figure 5. Impact of VIX (VXO), short rates (R) and yield spread (SPR) (Aslanidis & Christiansen, 2012).

Investigations such as Skintzi's (2019) states that short-term interest rates reflect also economic conditions, and this way impact on the stock-bond correlation. Skintzi (2019) presents that the output gap has negative relation with stock-bond correlation during crisis period between 2007-2016. Furthermore, in the study of Yang et al. (2009) monetary policy and short rates are considered as one unified factor. Short interest rates are one way of conducting monetary policy, which also links monetary policy as a factor influencing the long-term stock-bond correlation (Aslanidis & Christiansen, 2012; Boivin, 2006, p.1152; Skintzi, 2019; Viceira,2012). These factors, however, are not important for this study, as the interest is to study factors causing significant sudden changes in correlations. For this reason, the concentration is in uncertainty factors.

Uncertainty in the market can be further classified into two categories: uncertainties that occur within domestic and global markets, as well as uncertainties specific to the stock and bond markets (Dimic, 2016; Skintzi, 2019). There are however comparably few results about the vitality of uncertainty in bond markets and its role in the stock-bond correlation in developed markets. On the other hand, several studies, such as those presented in chapter 3.1.2, illustrate the significant impact of market uncertainty on stock-bond correlation (Andersson et al., 2008, p. 142; Aslanidis & Christiansen, 2012; Conolly et al., 2007).

Several research papers such as of Andersson et al. (2008, p.141), Aslanidis & Christiansen (2012), and Skintzi (2019), use the VIX index to describe the previously mentioned global market uncertainty. The VIX index is the Chicago Board Options Exchange volatility index which describes the volatility of options of the S&P500 index (Aslanidis & Christiansen, 2012). Results show that the stock-bond correlations react similarly negatively to the rise of the VIX index in the US, the UK, and core and peripheral European markets, with both high- and low-frequency data (Andersson et al., 2008, p. 142; Aslanidis & Christiansen, 2012; Conolly et al., 2007; Skintzi, 2019). As the previous figure 5 (Aslanidis & Christiansen, 2012) on page 36 presents, during a low VIX index the stock-bond correlation is high, but as the index rises the correlation plunges.

Furthermore, Skintzi (2019) also investigates the effect of domestic stock market uncertainty in European markets. Domestic stock market uncertainty measured with VSTOXX is a significant factor during tranquil long-term periods especially in core European countries, causing strong negative stock-bond correlations. According to this result, the VIX index seems to drive turbulent market correlation changes, where the domestic market uncertainty impacts correlations during the long term.

3.2 Correlation between green bonds and financial markets

The correlation between stocks and bonds has gained new insights in the 21st century due to the development of sustainable investing. For both bond and stock markets, there are invented more specified categories that focus on preventing and restraining growing environmental issues. Especially green bonds have become one of the most efficient ways for obtaining funding for large-scale environmental projects. These ESG-rated assets are furthermore noticed to overperform traditional "brown" assets due to their more stable performance over time. This has shifted the interest to examine how green assets co-move with other financial assets. Examinations concentrates especially on the connectedness of green bonds with conventional bond markets, and also on the connectedness with stock markets and more specifically green equity and energy markets.

This chapter goes through the recent findings of the performance of green bonds, and how these assets correlate with other financial asset classes. As illustrated in the previous chapter, in the conventional stock-bond portfolio, bonds are receiving significant spillovers from stock markets during turbulent times. This flight-to-quality phenomenon occurs in all developed markets. During the next two chapters, the thesis goes through how the previous literature finds green bonds to behave in different periods. Chapter 3.2.1 first provides an overview of the long-term and turbulent time correlations between the green bond market and the conventional bond market. After this, chapter 3.2.2 goes through the findings of the correlations between green bonds and stock markets. The chapter divides furthermore the stock markets into conventional stock markets, green stocks, energy markets, and clean energy markets.

3.2.1 Correlation with conventional bonds

Recent literature findings illustrate how green bonds tend to act similarly to conventional bonds in the long-term. Reboredo (2018) investigates the co-movement between green bonds and fixed-income markets between 2014 to 2017. It is observed that green bonds receive significant spillover effects from treasury and corporate bonds, resulting in a positive correlation between assets. Nguyen et al. (2021) also investigate the correlation between green bonds and conventional bonds between 2008 and 2019 and finds strong correlation as well. Similar results of the positive long-term correlations from global green bond markets are observed in the research papers of Ferrer, Shahzad, and Soriano (2021b) and Reboredo et al., (2020).

This observed connection between the green bonds market and the conventional bonds market does not hold true with all conventional bond classes. Authors such as Reboredo et al. (2020) and Arif, Hasan, Alawi, and Naeem (2021) furthermore shed more light on the types of conventional bonds in the correlation examinations. They observe that the correlation varies depending on whether bonds are high-yield or investment-grade bonds. Reboredo et al. (2020) compare the green bond correlation with fixed-income instruments like treasury, investment-grade corporate, and high-yield corporate bonds. According to the results obtained from both the EU and US markets, treasury, and investment-grade corporate bonds are shown to substantially co-move with green bonds over a variety of time horizons. On the other hand, green bonds bring allocation benefits when combined into the same portfolio with high-yield bonds. This way, it is highly dependent on whether the green bonds are examined together with high-yield or investment-grade bonds. These results can be largely explained by the characteristics of bonds, as green bonds typically belong to investment-grade bonds, and this way behaves similarly to conventional investment-grade bonds (Ferrer, Shahzad, and Soriano, 2021b; Reboredo et al., 2020).

Naeem et al. (2021) examine the correlation between conventional bond markets and green bond markets both prior to 2020 and during the market turbulence caused by the

COVID-19 pandemic. Authors illustrate that green bonds shield value erosion more in turbulence. One possible explanation for this phenomenon is the investor base of green bonds, which is found to have a greater long-term orientation (Flamer, 2021). Consequently, these investors place a stronger weight on longer-term environmental commitments and strategic planning. Also, as mentioned, green bonds have a less concentrated investor base, which can further decrease asset's volatility (Lacker & Watts, 2020). Similar results of the more stable performance of green bonds are found in the investigation of Sisodia, Joseph, and Dominic (2022). They investigate non-financial firms in China, the US, France, Sweden South Korea, and Japan, that issued green bonds before the end of 2019. The findings indicate that during economic shocks, companies issuing green bonds are more resilient in preserving their value compared to companies operating in brown industries. Moreover, firms belonging to industries with stronger environmental innovation capabilities are able to protect themselves from value erosion best in times of crisis.

3.2.2 Correlation with stocks

Since green bonds tend to behave similarly to conventional bonds over the long term, the correlation between green bonds and conventional stocks also turns out to be similar. Reboredo (2018) examines the connection of global green bond markets with stock markets and energy markets during the years 2014-2017, and Reboredo et al. (2020) EU and US markets during 2014-2018. Both results illustrate weak co-movement and thus green bonds provide diversification benefits when combined with stocks and energy stocks. Similarly, when concentrating purely on environmentally friendly assets, Nguyen et al. (2021) illustrate that the correlation between green bonds and green stocks is negative. Pham & Nguyen (2021) also find that the connection is weaker during normal conditions where green bonds act like other fixed-income assets and green stocks like other stock markets. Tiwari et al. (2022) also obtain similar weak co-movement when examining the connection between the green bond and green stock markets with quantile cross-spectral and cross-quantilogram estimation techniques during 2008-2020.

Moreover, it is crucial to analyze the correlation between green bonds and clean energy markets (CE) individually. As mentioned, a substantial part of the green bond proceeds is allocated to renewable energy (Liu et al., 2021). According to the findings of Liu et al., (2021), there occurs a significantly stronger connection with green bonds and clean energy stocks than with green stocks or energy markets. This is seen both in the long- and short-term. Authors find that the spillover from CE to GB is especially high during downturns, and thus the correlation is higher during market turbulence. Similarly, Chatziantoniou, Abakah, Gauber, and Tiwari (2022) find that both green bond markets and global clean energy markets are net receivers of shocks both during the short and long term. This way the diversification between green bonds and clean energy markets seems to be inefficient.

However, the results obtained from periods of market turbulence reveal that stock-bond correlations behave differently depending on whether the bonds used are green or conventional bonds. Pham & Nguyen (2021) investigate the dependency between green bonds, energy markets, and stock markets with the cross-quantilogram approach during 2014-2020 in the EU and US markets. The findings suggest that during periods of extreme market movements, such as the COVID-19 pandemic, investors experience a loss of diversification benefits when combining green stocks with other financial assets. They suggest that it is more beneficial to invest in conventional treasury bonds, as the co-movement with green bonds and stock and energy markets increases significantly. Similar results of the greater connectedness between green bonds and financial markets during COVID-19 are obtained by Arif et al. (2021). Tiwari et al. (2022) also notice that during market downturns, there is a strong correlation between Green Bonds and returns to environmental assets. Thus, in times of market turbulence, the flight-to-quality phenomenon theory does not seem to hold true for green bonds and equity markets.

4 Data and methodology

The main objective of this thesis is to investigate whether green bonds provide a more efficient diversification of the stock-bond portfolio compared to conventional bonds. The investigation involves comparing two different market portfolios: one constructed from conventional bonds and equity market indexes, and the other constructed from green bonds and equity market indexes. The study includes both long-term and turbulence period analysis periods, during which the focus is on identifying the most efficient portfolio. The study concentrates solely on developed markets, and there in the EU and US markets, to ensure optimal comparisons with existing stock-bond correlation literature. Through this analysis, the thesis aims to contribute new empirical evidence on the most effective approach to portfolio diversification, both in the long term and during periods of market turbulence.

This thesis is motivated by the recent study of Pham and Nguyen (2021) and Reboredo et al. (2020) who examine the interdependencies between the green bond market and other asset classes, such as treasury and corporate bond markets, energy markets, and stock markets. The focus of these studies is to analyze the relationship and spillover effects of other financial markets on the green bonds market in both the European Union and the United States. This thesis uses the same EU and US market data used also in these studies. The purpose is to examine the correlation with the DCC-GARCH model, which for example Broadstock and Cheng (2019) have also used in the correlation examinations before the COVID-19 pandemic. Furthermore, other previous stock-bond correlation papers such as of Andersson et al., (2008,) and Saleem (2011) have used this model in the correlation examinations as well. In addition, in the short-term correlation part, the thesis furthermore uses a linear regression model to examine the impact of uncertainty measures on the stock-bond correlations.

The chapter is constructed followingly. Chapter 4.1 goes through the data sample in more detail, presents the indexes used, and the descriptive statistics for the correlation studies. In chapter 4.2 the methodologies used in the investigations are presented. The empirical results of the examinations are presented in the 5th chapter.

4.1 Data

The data used in this study encompasses the timeframe spanning from December 2014 to December 2021. Boutabba & Rannou (2022) noticed in their research that most corporate bonds were issued during 2014. During the year 2014, green bonds furthermore started to gain more popularity due to more detailed definitions and regulations for green bonds. Also, green bond indexes used in this thesis were created in November 2014 (Bloomberg Barclays Indices, 2021). For these reasons, to get more accurate data with a greater data sample, the examination period begins on the 31st of December 2014. The dataset includes two different study periods: the long-term period between 2015-2021, which includes the long bull phase between 2014-2020, and the short-term period in March 2020, which covers the most recent stock market crash. The market areas under examination encompass both the United States and European markets, as they represent leading countries in terms of green bond issuances. The stock and bond market data are obtained from the Refinitiv DataStream and Bloomberg database. Furthermore, the market uncertainty index data is obtained from the Federal Reserve Economic Data database and The Wall Street Journal Markets page.

To illustrate whether there is a benefit of using green bonds instead of conventional bonds in the stock-bond portfolio, this study further continues previous literature by comparing the performances of two different portfolios. The study investigates a total of six bond indexes from both European and US markets, including two green bond indexes, two corporate bond indexes, and two treasury bond indexes. Regarding stock market indexes, the study includes a total of 4 indexes from the European and US markets: 2 capturing the performance of large- and midcap stocks and 2 indexes following the energy market performance. The data is collected at a daily frequency, with each index consisting of 1827 observations.

In order to track the price development of the green bond market, the study incorporates indexes that follow the performance of the US and EU green bond markets. Paper uses *Bloomberg Barclays MSCI EUR Green Bond Index* (GBEU) for European markets and *Bloomberg MSCI US Green Bond Index USD* (GBUS) for the US markets. All the bonds belonging to green bond indexes are investment graded. Furthermore, all bonds included are independently evaluated by MSCI ESG Research which asses the bonds based on the guidelines of Green Bond Principles (Bloomberg Barclays Indices, 2021). Bloomberg MSCI indexes might also include self-labelled green bonds, as long as they fall within a qualifying MSCI Green Bond category and there is adequate transparency on the use of proceeds (Bloomberg MSCI, 2021). Indexes have collected data from November 2014 and include bonds issued in USD or EUR worth of minimum 300 million. The first portfolio includes the green bond data, whereas in the second portfolio, the green bond market indexes are replaced with the conventional bond market indexes.

The second portfolio is constructed from conventional bonds, including conventional Treasury bonds and investment-grade corporate bonds. Green bonds, as mentioned earlier, are characterized by fixed coupons and an investment-grade ranking. In order to ensure comparability, conventional bonds included in the study also have fixed coupons and an investment-grade ranking. For the treasury market, the thesis uses *Bloomberg EuroAgg Treasury Total Return Index Value Unhedged EUR* (TTREU) and *Bloomberg US Treasury Total Return Unhedged USD* (TTRUU). These indexes are used to illustrate the performance of bonds issued by the governments of the European Union and the US governments. Furthermore, investment grade ranked corporate bonds are included in the second portfolio as well. The performance of European corporate bonds is illustrated using the *Bloomberg Euro Aggregate Corporate Total Return Index Value Unhedged EU* (CPTREU), while the *Bloomberg Global Agg Corporate Total Return Index Value Unhedged USD* (CPTRUU) is utilized for the US bond markets.

The equity indexes chosen from the EU and US markets are the same for both portfolios. To follow the European stock markets the thesis uses the *MSCI Europe (MSEROP)* index and for the US market the *MSCI USA (MSUSA)* index. MSCI USA index follows the performance of large and mid-cap stocks in the US markets, and the MSCI Europe Index of 15 developed market countries in Europe (MSCI Inc., 2023a; MSCI Inc, 2023 b). They both cover approximately 85% of the float-adjusted market cap in their markets. Furthermore, portfolios also include energy market indexes *MSCI Energy Europe* (Energy EU) and the *MSCI Energy U.S.* (Energy US) which reflect the performance of energy companies in European and U.S market areas.

As previous studies state, the uncertain market condition measured with high VIX index turns out to be the main driver for the correlation changes in developed markets. Similarly to Phan and Nguyen (2021), this thesis uses the Chicago Board Options Exchange volatility (VIX) index data (Federal Reserve Economic Data, n.d.). Data is publicly available and is acquired from Federal Reserve Economic Data. The database contains updated US macro and regional economic data at annual, quarterly, monthly, weekly, and daily frequencies. Furthermore, the thesis also incorporates the European market uncertainty index VSTOXX to investigate the significance of domestic market uncertainty in European markets. This is inspired by the research of Skintzi (2019). Due to the limited access to databases, the data is obtained from The Wall Street Journal Markets (The Wall Street Journal Markets, n.d.).

The table below describes the statistics for the presented equity and bond market indexes. There are in total of 1827 observations in each index. In line with previous studies that utilize the GARCH model, logarithmic returns are employed to calculate stock market returns (Banerjee, 2022; Chiang, Li & Yang, 2015). As it is assumed, when stock prices follow geometric Brownian motion, the logarithm of the price follows the Wiener process (Alexander, 2008, 90–110). This process demonstrates that price changes are constant and fluctuate randomly over time. This way the changes are assumed to be normally distributed and thus log returns are more symmetrical. In addition, in the simple return calculations, the total yield of the investment does not include time consistency but adds returns from various periods. On the other hand, log returns are additive, and this way better for the GARCH model to capture the dynamic correlation structure between assets (Alexander, 2008, 90–110).

Table 1. Descriptive statistics for stock and bond index returns

	Mean	Median	Max	Min	Std. Dev	Skewnes	Kurtosis	Observations
Equity market								
Stock market indexes								
MSEUROP	0,000	0,001	0,085	-0,141	0,011	-1,596	20,809	1827
MSUSA	0,000	0,000	0,090	-0,129	0,011	-1,120	22,234	1827
Energy stock indexes								
M1UREU	0,000	0,000	0,181	-0,190	0,018	-0,660	20,084	1827
MXUS	0,000	0,000	0,150	-0,227	0,019	-1,013	20,119	1827
Debt market								
Green bond indexes								
GBEU	0,000	0,000	0,011	-0,020	0,002	-1,008	7,746	1827
GBUS	0,000	0,000	0,010	-0,024	0,002	-1,332	13,879	1827
Conventional bond indexes								
TTREU	0,000	0,000	0,015	-0,017	0,002	-0,619	5,346	1827
TTRUU	0,000	0,000	0,017	-0,019	0,003	-0,105	7,142	1827
CPTREU	0,000	0,000	0,009	-0,022	0,002	-2,541	35,145	1827
CPTRUU	0,000	0,000	0,018	-0,039	0,003	-1,851	21,571	1827

Table 1. Shows the statistics related to equity and debt market indexes. Equity indexes are furthermore divided into stock- and energy indexes, and debt market indexes green bond- and conventional bond market indexes. The index data is obtained on a daily frequency. Sample period is from 31.12.2014 to 31.12.2021.

4.2 Methodology

To understand the underlying connectedness between green bonds and other financial assets, the study performs a correlation calculation for both long and short periods. Correlation calculations and the determination of portfolio risk rely on the analysis of both individual asset returns and volatilities, as well as the relationships between asset returns and volatilities (Alexander, 2008, p. 90–99). To conduct a comprehensive portfolio risk analysis, a covariance matrix is employed to measure both volatility and correlation among assets. The construction of this matrix can vary based on assumptions regarding of the constency of variables, independency and identical distribution of asset returns, the data period, and this way the statistical model used in the examination.

Moving averages, which assume that returns are independent and identically distributed, are one way of conducting correlation analysis. One type of a moving average model is the *rolling window correlation approach* which gives equal weights to historical data (Andersson et al., 2008, p.142; Alexander, 2008, p. 100–120). Method divides the time horizon into equal size windows, and future values are calculated periodically based on the current window. However, there are certain limitations that can induce challenges when using the model for making forecasts (Alexander, 2008, p. 115–130). Because the rolling window correlation gives the same weight to all observations in the estimation window, in short-term it ignores significant volatility deviations in the observation sample (Alexander, 2008, p. 120-130). On the other hand, in long-term estimates even a one-day shock has a far-reaching effect on future forecasts. After the volatility jump is out from the window, the moving average volatility estimation might change significantly causing inaccuracy in the forecast. Other moving average model is Exponentially weighted moving average which concentrates on more recent occasions and this way improved version for equally weighted window approach (Alexander, 2008, p. 120–130).

The development of time series analysis has created models, such as the GARCH model, which assumes that returns are more likely connected and not normally distributed (Alexander, 2008, 131). *Generalized Autoregressive Conditional Heteroscedasticity* (GARCH) models assume autocorrelation, meaning there occurs similarity between the variable's current value and past value. GARCH models take into consideration the volatility clustering, where a day of great volatility is probably followed by another high volatility day. Volatility clustering impacts greatly on portfolio risk and pricing, and the model is especially useful for correlation calculations with high-frequency data. This thesis is going to utilize the Dynamic Conditional Correlation -GARCH model (DCC-GARCH), which is a multivariate extension of the univariate GARCH model (Andersson et al., 2008, p. 142–145;

Saleem, 2011; 73–77, 80). This choice is motivated by the use of high-frequency data and the interest in examining both short-term and long-term correlations.

The first step in the DCC-GARCH model is to estimate the univariate GARCH model for each asset. The equation below illustrates the formation of the GARCH model, which estimates the volatility of an asset's return, assuming it is a function of the previous day's return and volatility (Alexander, 2008, p. 135; Andersson et al., 2008, p. 142–145).

(7) GARCH (1,1) model

$$\mathrm{r_{i,t}} = \gamma_{\mathrm{i}} + \phi_{\mathrm{i}} \mathrm{r_{i,t-1}} + \varepsilon_{\mathrm{i,t}}$$
$$\sigma_{\mathrm{i,t}}{}^{2} = \omega_{\mathrm{i}} + \alpha_{\mathrm{i}} \varepsilon_{\mathrm{i,t-1}}{}^{2} + \beta_{\mathrm{i}} \sigma_{\mathrm{i,t-1}}{}^{2} \quad , \tag{8}$$

The first line represents the so-called auto regressive (AR) model (Alexander, 2008, p. 120–140; Andersson et al., 2008, p. 142-145). In the AR model return of the asset on a given day $r_{i,t}$ is adjusted with the constant term, and the delayed return captures the possible autocorrelation of the asset's return (Andersson et al., 2008, p. 142-145). The next row represents the GARCH (1,1) model. In the GARCH model omega ω represents the unconditional volatility of an asset, followed by the AR component $\alpha\varepsilon^{2}{}_{i,t-1}$, where alpha a_i measures the degree of lagged squared realized volatility, $\varepsilon^{2}{}_{i,t-1}$ the previous day's lagged squared residual. Moreover, beta β_i again represents the persistence of previous day's conditional variance $\sigma^{2}{}_{i,t-1}$. Model estimates parameters mu μ, alpha α, and beta β for each index by using maximum likelihood estimation. The higher the alpha and beta, the more immediate impact the disturbance has on the volatility and the more persistent the conditional volatility is. Parameters are presented below:

Table 2. GARCH model parameters

	mu μ	omega ω	alpha α	beta	Long-run volatility
Equity market					
Stock market indexes					
MSEUROP	0,000	0,000	0,156	0,817	0,012
MSUSA	0,001	0,000	0,232	0,735	0,012
Energy stock indexes					
M1UREU	0,000	0,000	0,102	0,894	0,027
MXUS	0,000	0,000	0,107	0,886	0,022
Debt market					
Green bond indexes					
GBEU	0,000	0,000	0,071	0,869	0,002
GBUS	0,000	0,000	0,097	0,805	0,002
Conventional bond indexes					
TTREU	0,000	0,000	0,068	0,888	0,003
TTRUU	0,000	0,000	0,089	0,817	0,003
CPTREU	0,000	0,000	0,101	0,817	0,001
CPTRUU	0,000	0,000	0,104	0,809	0,003

Table 2. presents the GARCH model parameters for each index. Parameters omega, alpha and beta are obtained from the GARCH process.

Comparable higher beta values for each asset indicate that when predicting future volatility, the model allocates relatively more weight to past conditional variances compared to past returns. This way the returns can be assumed to recover back near to mean values more slowly. What is also noteworthy, is that green bonds seem to have slightly smaller beta values compared to conventional bonds. These values together with standard deviation values in Table 1 suggest that green bonds do have lower volatility compared to conventional bonds. This is in line with previous research results. Significantly low omegas imply that the model assumes a low long-run average volatility in the data sample. Thus, the model assumes that the data sample volatility is significantly driven by past system shocks rather than by any long-run variables or trends.

After conducting the GARCH model for each index, the conditional correlation matrix Q_t is estimated. The equation below presented by Gabauer (2020) illustrates the formation of the conditional correlation matrix.

(8) Conditional correlation matrix

$$Q_t = (1 - \alpha - \beta)\bar{Q} + \alpha(\varepsilon_{i,t-1}\varepsilon_{j,t-1}) + \beta Q_{t-1} \quad , \tag{9}$$

The long run estimated unconditional correlation matrix between asset returns is denoted as $\bar{Q}$ (Engle, 2002; Gabauer, 2020). The conditional correlation model is adjusted with the immediate disturbance which is constructed from the standardized residuals $\varepsilon_{i,t-1}$ $\varepsilon_{j,t-1}$ of assets i and j. These are multiplied by the alpha that represents again the immediate disturbance to correlation. Furthermore, beta again represents the persistence. This way the DCC model estimates the conditional correlations by updating the unconditional correlation matrix using the prior conditional correlation matrix and the current normalized residuals.

After this the next step is to calculate the dynamic correlation matrix R_t(Gabauer, 2020). Matrix is computed by first calculating first the diagonal matrix ${Q_t}^* = diag\{\sqrt{q_{ii,t}}\}$, which represents the matrix of square roots derived from the diagonal elements of the Q_t matrix. After this the dynamic correlation matrix R_t is calculated by multiplying the inverse ${Q_t}^*$ matrixes with the Q_t.

(9) Dynamic correlation matrix

$$R_t = {Q_t}^{*-1} Q_t {Q_t}^{*-1} \quad , \tag{10}$$

The results of the DCC-GARCH are next presented in the empirical part.

5 Empirical results

In the Empirical results section, chapter 5.1 first reviews the results of the long-term time-varying correlations. A portfolio with conventional bonds is marketed as "Portfolio A" and a portfolio with green bonds as "Portfolio B". Furthermore, the conventional bond portfolio is divided into "Portfolio A.1" including solely treasury bonds, and into "Portfolio A.2" including solely corporate bonds. This is done in case there might appear significant differences in the correlations of treasury and corporate bonds with equity markets during the investigation. After the long-term examination, chapter 5.2 continues with the short-term results observed during market turbulence. Chapter 5.2.2 furthermore test how increased market uncertainty impacts on the changes in correlations.

5.1 Long-term stock-bond correlations

Before going to the main results of the thesis, the correlation between conventional bonds and green bonds is examined. The table below presents the statistics of the long-term correlations obtained using the DCC-GARCH model, and Appendix 1 furthermore illustrates how the correlations evolve over time.

Table 3. Bond market correlations

	mean	std	min	25%	50%	75%	max
Bond market correlations							
Treasury–Green bond correlation							
TTREU–GBEU	0,880	0,148	-0,227	0,867	0,932	0,969	0,995
TTREU–GBUS	0,497	0,221	-0,668	0,380	0,529	0,661	0,905
TTRUS–GBEU	0,587	0,166	-0,150	0,475	0,603	0,723	0,918
TTRUS–GBUS	0,935	0,114	0,117	0,947	0,973	0,987	0,998
Corporate–Green bond correlations							
CPTREU–GBEU	0,872	0,136	-0,396	0,837	0,917	0,956	0,994
CPTREU–GBUS	0,494	0,225	-0,619	0,392	0,528	0,653	0,917
CPTRUU–GBEU	0,559	0,188	-0,338	0,459	0,590	0,687	0,924
CPTRUU–GBUS	0,930	0,090	0,049	0,925	0,956	0,975	0,994

Table 3. represents statistics of green bond-conventional bond correlations. Conventional bonds are furthermore categorized into treasury and corporate bonds.

The results show that overall green bond-conventional bond correlations seem to remain at a high level. Especially country-specific correlations between green bonds and conventional bonds are significantly high. Treasury bond-green bond correlations are on average 0,73 whereas corporate-green bond correlations are 0,71. These results of the strong co-movements between investment grade bonds and green bonds are in line with the previous literature findings. Furthermore, what can be noticed is that by allocating between European and US bond markets, investors may obtain short-term diversification advantages due to significant temporary drops in long-term correlations. Especially correlations between TTREU–GBUS -0.668 and CPTREU–GBUS -0.619 represent strong time-varying correlations. However, in general, and during long-term periods, the average level of correlations also remains comparably high (0,72). This way, even though the correlations might drop momentarily, green bonds tend to behave similarly to conventional bonds in the long term in developed markets.

Figure 6 below illustrates the long-term correlations of both portfolios estimated with the DCC-GARCH model. As can be noticed in the first figure, the stock-bond correlations of the conventional bond portfolio follow long-term trends, which previously the previously developed market literature has shown the stock-bond correlation follows. Long-term correlations between investment-grade corporate bonds and equity markets, and between treasury bonds and equity markets, are slightly negative and vary greatly around zero. Results are consistent with previous findings of such as Aslanidis & Christiansen, (2012) and Pericoli (2018) of the correlations in the US and Europe.

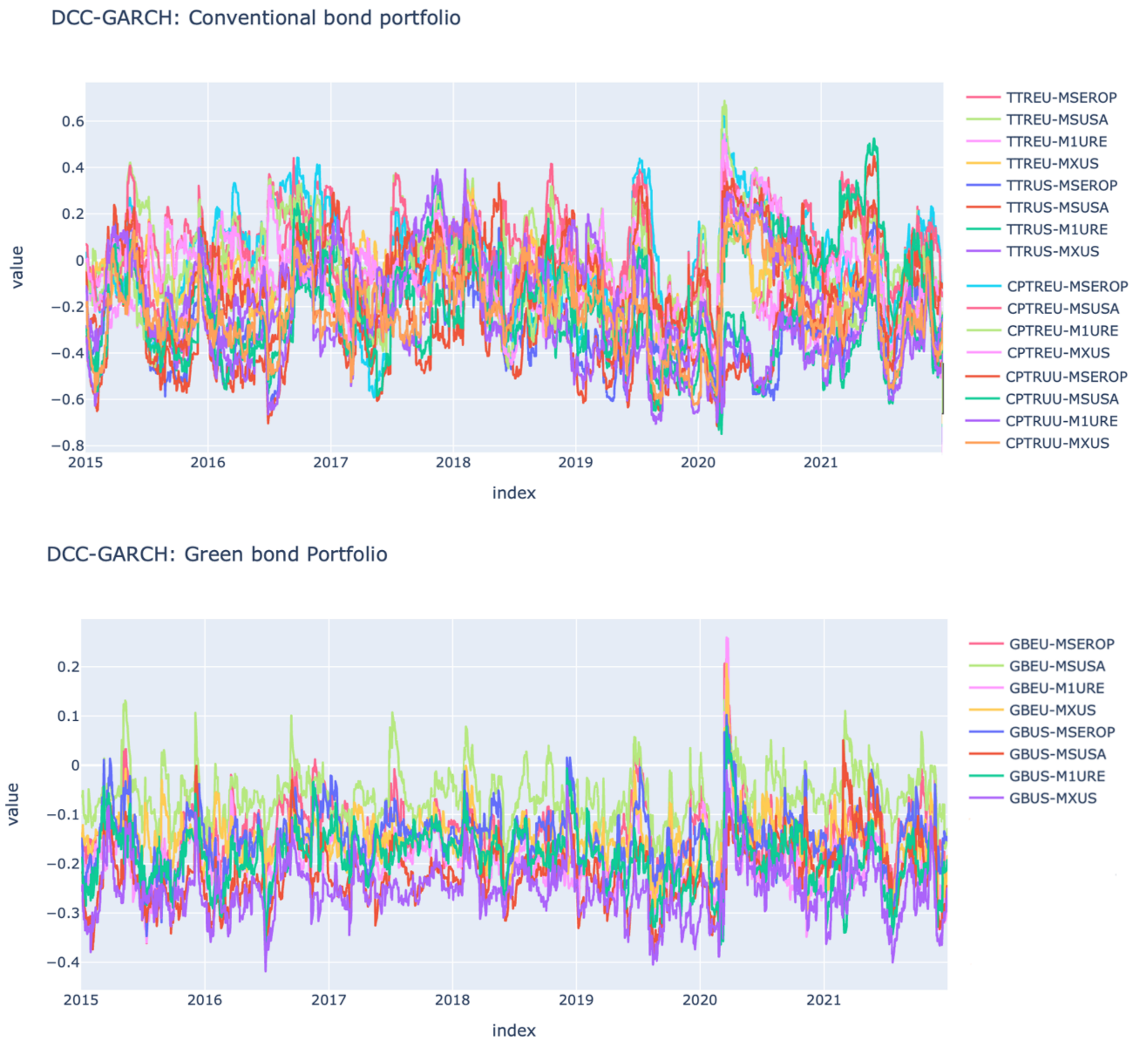


Figure 6. DCC-GARCH long-term correlations

Furthermore, another notable observation when comparing portfolios is that throughout the whole sample period, most correlations in the green bond portfolio remain under zero. Similarly, correlations seem to be less volatile in the green bond portfolio. These results were expected, as the previous literature states that green bonds are less volatile over time, which further impacts the levels of equity-bond correlations. Also, in the short term, both portfolios exhibit similar time-varying correlation patterns. However, it is notable that the dips and peaks from the average correlation are significantly higher in the conventional market portfolio. In addition, it can be noticed, that the greatest peaks in the correlations occur between corporation bonds and energy stocks, while the most remarkable drops emerge in the correlations between US Treasury and EU energy stocks. The statistical analysis of the conventional and green bond portfolio results is presented in Table 4 below.

Table 4. Statistics of the long-term correlations of portfolio A and B

	mean	std	min	25 %	50 %	75 %	max
Portfolio A: Conventional bond portfolio							
Treasury bonds							
TTREU–MSEROP	-0,038	0,182	-0,465	-0,169	-0,041	0,092	0,416
TTREU–MSUSA	-0,010	0,160	-0,481	-0,122	-0,012	0,097	0,421
TTREU–M1URE	-0,114	0,170	-0,506	-0,243	-0,105	0,016	0,419
TTREU–MXUS	-0,104	0,141	-0,488	-0,201	-0,091	-0,015	0,309
TTRUS–MSEROP	-0,045	0,174	-0,467	-0,151	-0,051	0,060	0,543
TTRUS–MSUSA	-0,312	0,219	-0,716	-0,477	-0,361	-0,195	0,449
TTRUS–M1URE	-0,268	0,193	-0,749	-0,402	-0,285	-0,149	0,379
TTRUS–MXUS	-0,335	0,163	-0,705	-0,440	-0,347	-0,243	0,162
Corporate bonds							
CPTREU–MSEROP	-0,004	0,218	-0,592	-0,144	-0,012	0,127	0,658
CPTREU–MSUSA	0,039	0,174	-0,424	-0,078	0,037	0,171	0,462
CPTREU–M1URE	-0,061	0,192	-0,465	-0,215	-0,062	0,057	0,687
CPTREU–MXUS	-0,045	0,174	-0,467	-0,151	-0,051	0,060	0,543
CPTRUU–MSEROP	-0,063	0,185	-0,477	-0,198	-0,058	0,081	0,351
CPTRUU–MSUSA	-0,158	0,220	-0,585	-0,347	-0,175	0,008	0,524
CPTRUU–M1URE	-0,115	0,199	-0,589	-0,263	-0,122	0,033	0,391
CPTRUU–MXUS	-0,217	0,176	-0,624	-0,320	-0,230	-0,105	0,235
Portfolio B: Green bond portfolio							
GBEU–MSEROP	-0,139	0,063	-0,361	-0,180	-0,141	-0,104	0,257
GBEU–MSUSA	-0,063	0,053	-0,225	-0,097	-0,067	-0,034	0,167
GBEU–M1URE	-0,195	0,057	-0,360	-0,228	-0,197	-0,166	0,259
GBEU–MXUS	-0,148	0,050	-0,304	-0,176	-0,149	-0,122	0,206
GBUS–MSEROP	-0,149	0,061	-0,383	-0,185	-0,146	-0,114	0,102
GBUS–MSUSA	-0,219	0,064	-0,398	-0,260	-0,224	-0,181	0,051
GBUS–M1URE	-0,188	0,058	-0,364	-0,221	-0,186	-0,152	0,079
GBUS –MXUS	-0,256	0,054	-0,418	-0,287	-0,257	-0,226	-0,010

Table 4. presents the results of DCC-GARCH model examination. Portfolio A summarizes the results from the correlations between conventional bond markets and stock and energy markets. Portfolio B represents the statistics related to correlations between green bonds and stock and energy markets.

As the statistics illustrate, the observed standard deviations are significantly lower in the green bond portfolio. This way, the outcomes presented in Table 4 are consistent with the expectations stated in the earlier stages of this study. Furthermore, these findings are in line with previous literature that has shown that green bonds have significantly lower long- and short-term volatility. Due to these previously presented assumptions, it was expected that the correlation between green bonds and equity markets would be lower. Furthermore, the table also shows that the correlations between green bonds and energy markets behave similarly to correlations between green bonds and stock markets. These are also in line with the previous literature findings. In general, the average values in the green bond portfolio seem to remain at a lower level. When considering the most efficient individual equity-bond correlations, the allocation to US Treasury and US stock markets, as well as US Treasury and energy markets, yields the most substantial long-term diversification benefits. However, when comparing bond and financial market correlations at the portfolio level, correlations on average seem to remain at a lower level in the green bond portfolio.

Furthermore, the last table 4 compares the portfolios when each stock-bond correlation receives equal weight in the portfolio. The table also presents separately the correlations in Treasury bond and corporate bond portfolios.

Table 5. Long-term equally weighted portfolios

	mean	std	min	25 %	50 %	75 %	max
Portfolio A: Conventional bond portfolio	-0,12	0,18	-0,75	-0,25	-0,12	0,01	0,69
Treasury Portfolio 1	-0,15	0,18	-0,75	-0,28	-0,16	-0,04	0,54
Corporate bond portfolio 2	-0,08	0,19	-0,62	-0,21	-0,08	0,05	0,69
Portfolio B: Green bond portfolio	-0,17	0,06	-0,42	-0,20	-0,17	-0,14	0,26

Table 5 provides a concise overview of the statistical measures for the portfolios, facilitating a comparison of average values across the portfolios. The min and max values for the portfolios are directly obtained from the extreme values of each portfolio. Portfolios compared are green bond portfolio, conventional bond portfolio, and furthermore solely treasury bond portfolio and corporate bond portfolio.

When giving equal weights for each stock-bond correlation, the average correlation in the conventional portfolio is -0,12 whereas the average in the green portfolio is -0,17. The average in the green bond portfolio is also lower when compared to the Treasury bond portfolio -0,15 exclusively. Also, the standard deviation of portfolio B 0,06 is significantly lower when compared to one of portfolio A, 0,18, but also when comparing to volatilities of portfolio A.1 0,18 and A.2 0,19. In this manner, investing in a green bond portfolio enables investors to realize more stable and efficient long-term diversification benefits across the bond and equity markets in Europe and the United States. Furthermore, previous literature has stated that green stocks behave similarly to conventional stocks. Based on this finding, it is reasonable to anticipate, that also purely green portfolio would give equally efficient long-term allocation benefits. This observation is valuable particularly for investors constructing portfolios based on the environmental impact of the assets.

What can be furthermore assumed based on the results of Table 5 and Figure 6, is that the treasury-equity market portfolio delivers the best short-term diversification benefits. In the treasury portfolio, the minimum value is the lowest -0,75 when compared to other portfolios. Conventional bond portfolio volatilities are significantly higher compared to one in the green bond portfolio. This way, both treasury and corporate bond portfolios reach also comparably higher peaks (0,54, 0,69) than portfolio B (0,26). More specifically, the most efficient allocation benefits in the conventional market portfolio are achieved by investing in the US Treasury index, MSUSA, and both European and US energy market stocks.

In the following chapter, the analysis proceeds to examine short-term correlations in more detail by employing the same DCC-GARCH model. In addition, the chapter examines the effects of the VIX and VSTOXX indexes on the stock-bond correlations with a linear regression model. This produces a comparison of how market uncertainties, which are shown to influence changes in the typical stock-bond correlation, impact the correlations within the green portfolio.

5.2 Portfolio correlations during market turbulence

Previous literature shows that market uncertainty is a significant factor causing simultaneous flight-to-quality phenomena in developed markets. For this reason, the short-term examination period concentrates solely on the period characterized by heightened market uncertainty. The turbulent market period is identified using market uncertainty indicators VIX and VSTOXX. The length of the period is defined as 22 trading days, which papers such as of Connolly et al., (2006) and Andersson et al., (2008) also use to examine short-term correlations. Most of the highest values (21 out of 22) for the VIX and VSTOXX indexes occurred primarily in March 2020 and early April 2020. On average, the median values for the VIX and VSTOXX were 17,79 and 20,39, but during the turbulent market phase, VIX reached values ranging from 45.41 to 82.69, and VSTOXX from 45.88 to 85.62. During the period, there were also significant declines in the market indices, for example, the 22.7% drop of MXUS on March 9th. This way, the thesis uses an examination period ranging from September 3, 2020, to April 7, 2020.

5.2.1 Short-term correlations

Table 6 below represents the results obtained from the short-term analysis. Again, the conventional bond portfolio is divided into the treasury bond portfolio section and the corporate bond section.

Table 6. Statistics of the short-term correlations of portfolio A and B

	mean	std	min	25%	50%	75%	max
Portfolio A: Conventional bond portfolio							
Treasury bonds							
TTREU–MSEROP	0,357	0,002	0,354	0,356	0,357	0,357	0,362
TTREU–MSUSA	0,232	0,002	0,228	0,231	0,232	0,232	0,238
TTREU–M1URE	0,294	0,002	0,291	0,293	0,294	0,294	0,299
TTREU–MXUS	0,289	0,002	0,286	0,288	0,289	0,289	0,293
TTRUS–MSEROP	-0,201	0,002	-0,204	-0,202	-0,202	-0,201	-0,197
TTRUS–MSUSA	-0,510	0,002	-0,514	-0,511	-0,511	-0,510	-0,506
TTRUS–M1URE	-0,082	0,002	-0,087	-0,083	-0,082	-0,082	-0,077
TTRUS–MXUS	-0,327	0,002	-0,331	-0,328	-0,327	-0,326	-0,320
Corporate bonds							
CPTREU–MSEROP	0,533	0,002	0,528	0,532	0,533	0,533	0,537
CPTREU–MSUSA	0,409	0,002	0,404	0,408	0,409	0,409	0,414
CPTREU–M1URE	0,504	0,002	0,498	0,503	0,503	0,504	0,507
CPTREU–MXUS	0,510	0,002	0,505	0,509	0,510	0,510	0,514
CPTRUU–MSEROP	0,485	0,002	0,482	0,485	0,485	0,486	0,489
CPTRUU–MSUSA	0,180	0,002	0,175	0,180	0,180	0,181	0,185
CPTRUU–M1URE	0,492	0,001	0,489	0,491	0,492	0,492	0,495
CPTRUU–MXUS	0,322	0,002	0,319	0,321	0,322	0,323	0,328
Portfolio B: Green bond portfolio							
GBEU–MSEROP	0,307	0,001	0,304	0,306	0,307	0,307	0,310
GBEU–MSUSA	0,208	0,001	0,206	0,208	0,208	0,208	0,212
GBEU–M1URE	0,278	0,001	0,275	0,277	0,277	0,278	0,280
GBEU–MXUS	0,238	0,001	0,236	0,238	0,238	0,238	0,241
GBUS–MSEROP	0,283	0,001	0,281	0,282	0,283	0,283	0,285
GBUS–MSUSA	-0,075	0,001	-0,077	-0,076	-0,075	-0,075	-0,072
GBUS–M1URE	0,331	0,001	0,329	0,330	0,331	0,331	0,334
GBUS–MXUS	0,122	0,001	0,120	0,121	0,122	0,122	0,126

Table 6. presents the short-term correlation results obtained from the turbulent market period from 9th of March to 7th of April. Conventional bond portfolio is divided further into treasury bond section and corporate bond section.

As can be noticed, the flight-to-quality phenomenon occurs solely in the treasury bond portfolio, but not in the corporate bond portfolio. In general, correlations remain mainly above zero in the green bond portfolio, and also the short-term variations are comparably moderate in the green bond portfolio. These are in line with the previous research results of the short-term correlations between green bonds and equity market indexes. However, after correlations in the green bond portfolio increased during the turbulent period, the correlation between GBUS and MSUSA remained still slightly negative at -0.075. In this manner, short-term investors were able to still obtain some diversification benefits during periods of market turbulence when diversifying between the US green bond and US stock markets. Nevertheless, more significant negative correlations were observed when diversifying between US treasury bonds, stock, and energy markets (-0,20131, -0,51050, -0,08217, -0,32697). Table 6 furthermore shows the portfolio results, when each bond-equity correlation gets equal weights in the portfolio.

Table 7. Short-term equally weighted portfolios

	mean	std	min	25%	50%	75%	max
Portfolio A: Conventional bond portfolio	0,218	0,002	-0,514	0,217	0,218	0,218	0,537
Treasury Portfolio 1	0,006	0,002	-0,514	0,006	0,006	0,007	0,362
Corporate bond Portfolio 2	0,429	0,002	0,175	0,428	0,429	0,430	0,537
Portfolio B: Green bond portfolio	0,211	0,001	-0,077	0,211	0,211	0,211	0,334

Table 7. shows the average portfolio values during the turbulent market period. Again, each value represents the average value in the portfolio, except min and max which represent the extremum values.

As table 7 also illustrates, investors obtain the best short-term diversification benefits by investing in a treasury bond portfolio. Furthermore, the most effective option is to diversify purely between US treasury bonds and US stock markets, where the correlations remain significantly negative throughout the whole short-term sample period. When comparing the equally weighted portfolios, it can be seen that the conventional bond portfolio constructed from corporate bonds does not provide diversification benefits during turbulence. In the case of the green bond portfolio, even though investors maintain their minor diversification opportunities when diversifying between US green bonds and MSUSA, correlations increased and in general are positive as expected.

Despite the growth of the green bond market, as indicated in the section on green bond liquidity, there might still exist challenges concerning market liquidity, particularly from the ask perspective. Consequently, due to liquidity problems, even small buy and sell offers have a significant impact on green bond price movements. This might be one possible explanation for why correlations between green bonds and stock markets increase during market turbulence. Another possible reason for the increased correlations is the previously mentioned long-term investor base, due to why the prices of green bonds may remain relatively stable. Therefore, when stock prices plunge during turbulence, this might lead to an increase in correlations between green bonds and equity markets.

5.2.2 Impact of market uncertainty on the short-term correlations

As noticed in the previous part, correlations during market turbulence remain negative mainly in the US Treasury portfolio, while correlations in other portfolios increase. In this section, the aim is to analyze how the rising VIX and VSTOXX indexes affect the correlations between stocks and bonds. This investigation is done by using the multilinear regression model. The response variables for this analysis consist of the equity-bond correlations obtained in the previous section by using the DCC-GARCH model. The predictor variables utilized are VIX and VSOXX. The data of the VIX and VSTOXX indexes are collected at a daily frequency, as well as the data obtained from the stock and bond indexes. The data period is the same as in the short-term examination part.

(10) Multilinear regression model

$$DCorr_{i,j} = \alpha + \beta VIX + \beta VSTOXX \quad , \tag{13}$$

In the equation, $DCorr_{i,j}$ refers to the correlation between assets *i* and *j*, VIX is the factor for the US market volatility and VSTOXX for the EU market volatility.

As the purpose of this thesis is to compare how generally using green bonds in a stock-bond portfolio benefits investors, it is not worth dividing stock-bond correlations only by country. Instead, the central objective is to separately explore the impact of the VIX and VSTOXX indexes on the various equity-bond correlations. Thus, the response variables in the conventional portfolio A are TTREU–MSEROP, TTREU–MSUSA, TTREU–M1URE, TTREU–MXUS, TTRUS–MSEROP, TTRUS–MSUSA, TTRUS–M1URE, TTRUS– MXUS, CPTREU–MSEROP, CPTREU–MSUSA, CPTREU–M1URE, CPTREU– MXUS, CPTRUU–

MSEROP, CPTRUU–MSUSA, CPTRUU–M1URE, and CPTRUU–MXUS. In the green bond portfolio B the response variables are GBEU–MSEROP, GBEU–MSUSA, GBEU–M1URE, GBEU–MXUS, GBUS–MSEROP, GBUS–MSUSA, GBUS –M1URE, and GBUS –MXUS.

Table 8. Linear correlation results

	α	VIX	VSTOXX	R square
Portfolio A: Conventional bond portfolio				
Treasury bonds				
TTREU–MSEROP	0,357***	-0,000**	0,000***	0,328**
TTREU–MSUSA	0,233***	-0,000	0,000	0,062
TTREU–M1URE	0,293***	-0,000***	0,000***	0,468***
TTREU–MXUS	0,289***	-0,000	0,000*	0,190
TTRUS–MSEROP	-0,202***	-0,000	0,000	0,140
TTRUS–MSUSA	-0,510***	-0,000	0,000	0,019
TTRUS–M1URE	-0,084***	-0,000	0,000	0,088
TTRUS–MXUS	-0,328***	-0,000	0,000	0,076
Corporate bonds				
CPTREU–MSEROP	0,534***	-0,000***	0,000***	0,319**
CPTREU–MSUSA	0,411***	-0,000	0,000	0,089
CPTREU–M1URE	0,504***	-0,000***	0,000***	0,429***
CPTREU–MXUS	0,511***	-0,000*	0,000**	0,189
CPTRUU–MSEROP	0,487***	-0,000	0,000	0,079
CPTRUU–MSUSA	0,182***	-0,000	0,000	0,038
CPTRUU–M1URE	0,492***	-0,000	0,000	0,053
CPTRUU–MXUS	0,322***	-0,000	0,000	0,066
Portfolio B: Green bond portfolio				
GBEU–MSEROP	0,306***	-0,000**	0,000**	0,305**
GBEU–MSUSA	0,209***	-0,000	0,000	0,068
GBEU–M1URE	0,276***	-0,000**	0,000***	0,403***
GBEU–MXUS	0,237***	-0,000	0,000*	0,183
GBUS–MSEROP	0,283***	-0,000	0,000*	0,152
GBUS–MSUSA	-0,075***	-0,000	0,000	0,073
GBUS–M1URE	0,331***	-0,000	0,000	0,120
GBUS–MXUS	0,121***	-0,000	0,000	0,141

Table 8 presents the short-term regression results obtained from portfolios A and B with the multilinear regression model. Markings *, **, *** illustrate the statistical significance levels, where the * refers to 10% significance level, ** to 5% significance level, and *** to 1% statistical significance level.

Based on the findings, it is observable that market uncertainty significantly impacts on the stock-bond correlations in both conventional bond and green bond portfolios. Global uncertainty VIX appears to impact solely negatively on the stock-bond correlations in both portfolios. Furthermore, results illustrate that VIX and European market uncertainty VSTOXX influence statistically significantly on the European bond-energy market correlations. Overall, the rise of the VIX index appears to be generally more related to changes in the correlations between conventional bonds and equity indexes. The rise of the VSTOXX impacts positively but also significantly on several correlations in green and conventional bond portfolios. VSTOXX impacts significantly positively on 6 out of 16 correlations in conventional market portfolio, and 4 out of 8 in green bond portfolio.

Although market uncertainty significantly impacts the correlations, the model can only explain a small portion of the correlation changes. As referred to the investigation by Baker et al. (2020), the stock market jumped more than in any other 22-day trading period in the 120-year measurement period. These unpredictable volatility spikes may be partly due to the aforementioned "noise" which further increased investor sensitivity. Thus, it was partly expected, that the regression model would have a lower explanatory power. To bring more comparability to this turbulent period analysis, Appendix 2 presents linear regression model results from period 01-03-2020 to 31-03-2020, beginning slightly before the most severe volatility jumps. As can be noticed, the regression model now significantly explains correlation changes in both portfolios. Once again, the VIX index has a significant negative effect, and the VSTOXX has a significant positive impact. VIX and VSTOXX also appear to be more significantly related to correlation changes in a traditional bond portfolio. This could be explained by previous findings, which suggest that the green bond investor base is less concentrated, and investors are more focused on long-term returns. Thus, during turbulent times, the portfolio is not re-balanced in the same way as with ordinary bonds.

6 Conclusion

In recent years, the development of the financial markets has given rise to new investment trends that influence the construction of risk-adjusted portfolios. In the 21st century, increased concerns related to environmental issues, such as climate change and global warming, have made investors pay more attention to sustainable development. This has led to the rapid growth of securities prioritizing sustainable aspects. Among these securities, green bonds have proven to be the most effective instrument for financing environmentally friendly projects. The popularity of green bonds has surged over the past decade, witnessing a remarkable growth from $4.2 billion to $2 trillion by 2022. As investors increasingly seek to participate in the promotion of sustainable development and further integrate their values into investment decisions, incorporating such securities into investment portfolios has become a strong trend in the financial markets.

Several studies over the years have investigated the correlation between stocks and bonds. Studies conducted in developed markets proves the correlation to be time-varying, but clear trend periods can also be observed. Due to the new asset divisions in the financial markets, recent studies have increasingly concentrated on the co-movement between green bonds and financial markets. Results show that green bonds tend to behave similarly to conventional bonds in the long term, but in turbulence, they correlate positively with other assets. Nevertheless, there are still unanswered questions regarding whether incorporating green bonds, or conventional bonds in an equity-bond portfolio offer more significant diversification benefits. Given this research gap, this study aimed to provide new insights into the stock-bond correlation literature by examining the performance of a green bond-equity portfolio in comparison to a conventional bond-equity portfolio. In this way, the research aimed to illustrate the advantages of employing green bonds and their potential to diversify the equity bond portfolio.

The data sample consisted of European and US bond and stock market indexes, and each of the ten indexes contained 1827 daily values. The study period covered both the long bull phase from the end of 2014 to the beginning of 2020, and the latest market crash in

March 2020 caused by the global pandemic. The indexes were divided into two portfolios, where the green bond portfolio consisted of green bonds and stocks and the conventional portfolio was constructed from conventional bonds and stocks. The research method used was the DCC-GARCH model, which describes both asset volatility and dynamic conditional correlation between stocks and bonds. The last part of the thesis examined short-term correlations during the 22-day turbulence period. After this, the thesis reviewed how the market uncertainties, measured with the rise of VIX and VSTOXX, impacted on the stock-bond correlations using a linear regression model.

Before entering the main investigations, the correlation between the green bond market and the conventional bond market was briefly examined. The findings demonstrated a robust correlation between the green bond market and the conventional bond market. Co-movement was especially high for the debt instruments issued within the same country. On the other hand, short-term diversification benefits were obtained by allocating the portfolio with both EU and US bonds. Overall, results were consistent with previous findings, and there seems to occur a strong long-term connectedness between green bond markets and conventional bond markets.

The primary finding of the paper provides new insights into stock-bond correlations when conventional bonds are replaced with green bonds. Consistent with previous findings, correlations between green bond and equity markets were found to behave similarly to correlations in the conventional portfolio. Also, the correlations between green bonds and the energy markets were similar to the correlations of green bonds with other stock markets. These results were also in line with previous research results. Furthermore, empirical part illustrated that green bond portfolio in general provided more efficient long-term diversification benefits. It was observed that within the green bond portfolio, the average correlation remained at lower level and the volatility was significantly smaller. This way, when diversifying into bond and equity markets, most efficient diversification benefits from the EU and US markets were acquired from diversifying between green bond markets and stock and energy markets.

The second main finding of the thesis relates to correlation in turbulence. Volatility was revealed to be more significant in the conventional bond portfolio and the most effective diversification benefits were obtained from the Treasury bond portfolio. These findings are also consistent with the previous findings, which state that green bond prices vary less due to their stable investor base. Thus, the volatility of correlations in the green portfolio was lower, but at the same time, the correlations were also at a higher level than the correlations in the Treasury bond portfolio. Furthermore, rising market uncertainty seemed to have a significant impact on both conventional bond and green bond portfolios. However, rising VIX and VSTOXX indexes explained more the changes in the correlations between conventional bonds and stock markets.

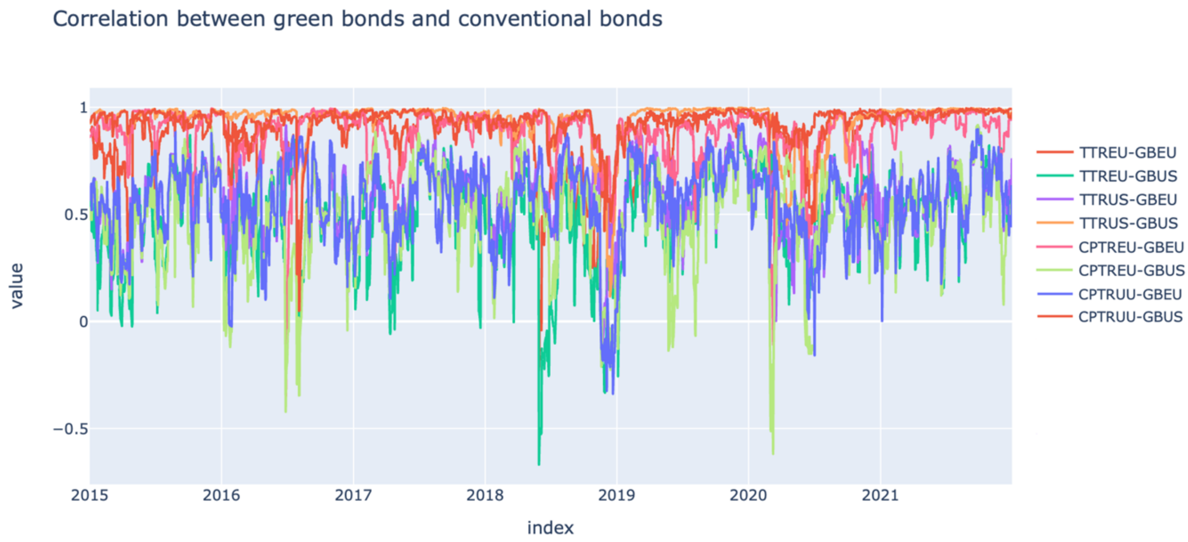
The first hypothesis stated that the correlation trend in the green bond portfolio largely follows the correlation trend observed in the conventional bond portfolio. As the long-term comparison illustrated, this hypothesis was proven to hold true. The second hypothesis furthermore suggested that the green bond-equity market portfolio is going to provide more efficient long-term diversification benefits in general. This was also illustrated to be true. Lastly, the third hypothesis stated that most efficient short-term diversification benefits are obtained from conventional market portfolio. The long-term analysis confirmed that conventional bond-equity correlations offered the most efficient diversification benefits during the short-term.

Overall the comparison of conventional and green bond portfolios produced new results for the impact investing literature. Previous papers have focused on examining the overall performance of green bonds in financial markets. The purpose of this thesis was to track the correlation between stocks and bonds, and whether green bonds can provide more efficient diversification benefit compared to conventional bonds. From the results of the thesis, it is shown that green bonds do provide more stable and moderate long-term diversification benefits in bond-equity portfolio. These results can be furthermore used in portfolio constructed solely from green assets. One possible explanation for this lower correlation may be related to the prevalence of long-term investors in the investor base. In addition, green bonds are proven to have lower investor concentration, which is expected to reduce green bond market's volatility. However, the existing literature has also presented that there might occur some liquidity challenges, particularly in the demand side. These can partially explain the more consistent performance of bonds and this way their lower correlation with equity markets.

The primary objective of this thesis was to examine whether investors would experience greater benefits by incorporating green bonds in a stock-bond portfolio instead of traditional bonds. The findings presented in this paper are valuable for diverse investor groups, including private investors who aim to make portfolio diversification decisions while also prioritizing environmental benefits. Additionally, these results are significant for governments that are committed to utilizing investment strategies that promote sustainable development. Furthermore, companies considering issuing green bonds to attract new and stable investor base can also benefit from these findings. Future research could expand the research of green bonds to include other GSS bonds and how they correlate with other green assets. This would expand sustainable development studies to include other areas as well, such as social sustainability. These findings could be further compared to the performance and correlations of “brown” assets. Also related to this topic, another suggestion for future research is that studies could investigate the correlations between different GSS bonds and, furthermore, correlations between GSS bonds and conventional bonds.

Appendices

Appendix 1. DCC-GARCH Conventional bond - green bond correlation



Appendix 2. Short-term impact of market uncertainty

Index	α	VIX	VSTOXX	R Square
Portfolio A: Conventional bond portfolio				
Treasury bonds				
TTREU–MSEROP	0,377***	-0,001	0,002	0,356*
TTREU–MSUSA	0,213***	-0,003**	0,003***	0,363**
TTREU–M1URE	0,242***	0,001	0,001	0,286**
TTREU–MXUS	0,281***	0,000	0,000	0,022
TTRUS–MSEROP	-0,157***	0,001	-0,000	0,010
TTRUS–MSUSA	-0,376***	-0,001*	0,001	0,304**
TTRUS–M1URE	-0,107**	0,004*	-0,004**	0,225*
TTRUS–MXUS	-0,260***	0,002	-0,003*	0,322**
Corporate bonds				
CPTREU–MSEROP	0,473***	-0,001	0,002**	0,601***
CPTREU–MSUSA	0,335***	-0,003**	0,003***	0,536***
CPTREU–M1URE	0,503***	0,000	0,002	0,510***
CPTREU–MXUS	0,496***	-0,002**	0,003***	0,422***
CPTRUU–MSEROP	0,423***	-0,001	0,001*	0,377**
CPTRUU–MSUSA	0,231***	-0,001	0,001	0,156
CPTRUU–M1URE	0,430***	0,000	-0,000	0,061
CPTRUU–MXUS	0,318***	-0,001	0,001	0,265*
Portfolio B: Green bond portfolio				
GBEU–MSEROP	0,279***	-0,000	0,003	0,366**
GBEU–MSUSA	0,195***	-0,003*	0,004**	0,328**
GBEU–M1URE	0,195***	0,002	0,001	0,282**
GBEU–MXUS	0,221***	-0,001	0,001	0,057
GBUS–MSEROP	0,169***	-0,001	0,003*	0,484***
GBUS–MSUSA	-0,064**	-0,002*	0,003**	0,265*
GBUS–M1URE	0,176***	0,000	0,001	0,218*
GBUS–MXUS	0,069**	-0,002	0,001	0,095

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