



Common Volatility Shocks of ESG Markets

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Title: Common Volatility Shocks of ESG Markets

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Abstract:

This dissertation explores the interconnectedness and common volatility shocks in international ESG markets. Utilizing the MSCI ESG Leader Indices across eight regions, the study investigates whether idiosyncratic volatilities are correlated and identifies events triggering simultaneous movements. By employing the common volatility model proposed by Engle & Campos-Martins (2023), the research measures shared volatility shocks and their drivers, particularly focusing on climate policy uncertainty and transition and physical risks. The results show significant correlations between regional volatilities and identify key events that have caused the highest levels of volatility co-movement. The model also has portfolio implications, as regions have different exposures to the common factor. The most sensitive to volatility shocks are ESG market leaders such as Europe and the US, so emerging ESG markets such as Australia and Korea may be more attractive to risk-averse investors during periods of high ESG common volatility. Additionally, regression analysis shows that climate risks significantly influence these volatility shocks after controlling for global equity market shocks, highlighting the heightened sensitivity of ESG markets to climate dynamics after the Paris Agreement. Uncertainty surrounding climate policy and concerns about climate-related physical risks amplify shared volatility shocks in responsible markets. In contrast, shocks to climate transition risk exhibit a negative relationship with the factor, suggesting reduced exposure within the context of transitioning to a low-carbon economy. These findings provide novel insights for investors and policymakers, highlighting the importance of a stable regulatory environment and the role of ESG assets in the transition to a low-carbon economy.

Keywords: ESG markets, volatility shocks, climate risk, MSCI indices, climate policy uncertainty, transition risk, physical risk.

Título: Choques de Volatilidade Comuns dos Mercados ESG

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Resumo:

Esta dissertação investiga a interconexão e os choques de volatilidade comuns nos mercados ESG internacionais, utilizando o MSCI ESG Leader Indices em oito regiões. O estudo avalia se as volatilidades idiossincráticas estão correlacionadas e identifica eventos que provocam movimentos simultâneos. O modelo de volatilidade comum de Engle & Campos-Martins (2023) é empregado para medir os choques partilhados e seus determinantes, com foco na incerteza da política climática e nos riscos físicos e de transição. Os resultados revelam correlações significativas entre as volatilidades regionais e identificam eventos que elevaram o co-movimento da volatilidade. Os mais sensíveis aos choques de volatilidade são os líderes de mercado ESG, como a Europa e os EUA, pelo que os mercados ESG emergentes, como a Austrália e a Coreia, podem ser mais atrativos para os investidores avessos ao risco durante períodos de elevada volatilidade comum ESG. A análise de regressão confirma que os riscos climáticos afetam significativamente os choques de volatilidade, mesmo após controle para choques do mercado global. A incerteza sobre políticas climáticas e os riscos físicos amplificam os choques, enquanto os riscos de transição apresentam relação negativa com o fator, sugerindo menor exposição no contexto de uma economia de baixo carbono. Essas conclusões destacam a importância de regulamentações estáveis para reduzir incertezas e promovem o papel dos ativos ESG na transição para uma economia sustentável, oferecendo informações valiosas para investidores e formuladores de políticas.

Palavras-chave: Mercados ESG, choques de volatilidade, risco climático, índices MSCI, incerteza da política climática, risco de transição, risco físico.

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1. Introduction

ESG markets are gaining increasing attention from investors and play a pivotal role in the growth of green finance. Critics of ESG investing often argue that prioritising non-financial performance metrics, such as environmental and social impacts, over traditional financial returns may constrain portfolio performance and disrupt overall efficiency. This trade-off, known as the "greenium", reflects investors' willingness to sacrifice higher returns in favour of green assets that support the energy transition and climate action. Despite these concerns, a growing body of literature demonstrates that ESG assets not only yield environmental and societal benefits but also exhibit resilience and superior integration compared to conventional markets, particularly during periods of financial turbulence. Consequently, investors must evaluate not only the initial performance metrics but also the volatility dynamics of these financial assets.

ESG consider all environmental problems, such as biodiversity, climate change, and waste management. However, climate change is the most urgent issue, with several nations committing to tangible short- and mid-term goals. Climate change represents a global challenge that demands collaborative action among nations to align with climate goals. Key initiatives like the Paris Agreement underscore commitments to energy transitions and climate policies. Alongside governmental efforts, investor-driven initiatives, like Climate Action 100+¹, are gaining momentum, reflecting the investment community's heightened awareness of climate risks.

The escalating impacts of climate change, including extreme weather events, have tangible effects on corporate operations, with significant implications for financial markets. Such disruptions highlight the interconnected nature of ESG markets, even across regions with varying national policies and regulatory approaches to environmental and social issues. Recent studies emphasise the interconnectedness and risk spillovers in ESG markets, advancing the understanding of how these markets interact and respond to climate-related risks. Our research contributes to this growing field, examining how climate change influences markets and, in turn, how financial markets may shape climate dynamics.

¹ Climate Action 100+ is a global, investor-led initiative uniting over 600 investors to drive corporate action on climate change by targeting the largest greenhouse gas emitters to improve governance, reduce emissions, and enhance climate-related financial disclosures (*Climate Action 100+*, n.d.).

The primary objective of this thesis is to investigate whether idiosyncratic volatilities in international ESG markets are correlated and to identify events that trigger simultaneous movements. Using the innovative common volatility model proposed by Engle & Campos-Martins (2023), this study measures the common movements in volatility shocks across ESG markets, represented by the MSCI ESG Leader Indices in Europe, the USA, Japan, China, Canada, Australia, Korea, and India.

Our findings reveal significant correlations among country-specific ESG volatilities and identify key events that generated the most pronounced common volatility shocks between 2007 and 2024. The analysis also demonstrates varying levels of regional sensitivity to these shocks, with some markets exhibiting higher exposure to the common variance factor than others.

To explore the drivers of common ESG volatility shocks, the study incorporates regression analysis, projecting the common ESG factor onto text-based climate risk indices, following the methodology of Campos-Martins & Hendry (2024). Specifically, it examines the influence of climate policy uncertainty (CPU) as proposed by Gavriilidis (2021), given the global relevance of climate-related regulations and the impact of climate transition and physical risk indices developed by Bua et al. (2024).

Results indicate that all climate risk indices significantly drive ESG common variance shocks, particularly after the Paris Agreement in 2016, when controlling for global stock market shocks. These findings suggest that ESG markets have become increasingly sensitive to climate-related risks, underscoring investors' importance in carefully considering these factors in their decision-making processes.

2. Literature Overview

2.1. Evolution of ESG markets

The term ESG is an acronym for environmental, social, and governance, which was introduced in a report by 20 financial institutions at the request of Kofi Annan, the former Secretary-General of the United Nations. It represents the integration of the three named considerations into corporate and investment strategies, reflecting a growing focus on sustainable and ethical business practices (Gillan et al., 2021).

The global financial market has witnessed a huge increase in sustainable investing, considering ESG non-financial factors in portfolio selection and asset management. Moreover, ESG stocks, which also represent responsible stocks, became increasingly important in green finance markets due to their rapid boost. During 2016-2020, the ESG market had projected a compound annual growth rate (CAGR) of 12% to 2030, but due to the gold rush, greenwashing, and misleading claims, the growth of the sector slowed significantly to a CAGR of 3.5% to 2030. Nevertheless, the ESG market has shown resilience in expected market growth, with global ESG assets under management exceeding \$30 trillion in 2022 and projected to grow to over \$40 trillion by 2030, representing 25% of total global assets under management². Secondly, since 2011, the number of signatory members in the United Nations of Principles for Responsible Investment has tripled to 3826, while the Asset under Management reached over US\$ 120 trillion in 2021³.

The growth of the market can be explained by the growing popularity of responsible stocks among investors due to the high liquidity that is helpful in market downturns (Lu et al., 2023). Secondly, investors have become increasingly aware of the materiality of non-traditional sources of risk that are not captured in financial statements, including extreme weather events caused by climate change, which can also drive the growth of companies that promote social responsibility and sustainable development (Broadstock et al., 2021).

There is strong and consistent evidence that at the firm-level there is a strong relationship between ESG activities of financial entities and local market characteristics, like social capital (Jha & Cox, 2015) as well as the nature of the industry that the firm operates in (Borghesi et

²<https://www.bloomberg.com/company/press/global-esg-assets-predicted-to-hit-40-trillion-by-2030-despite-challenging-environment-forecasts-bloomberg-intelligence/>, last access: 14/12/2024.

³<https://www.unpri.org/annual-report-2021/how-we-work/building-our-effectiveness/enhance-our-global-footprint>, last access: 14/12/2024.

al., 2014). Geographically, Europe has emerged as the largest ESG market with the USA, all together accounting for around 70% of the global market, while there are smaller but significantly growing ESG markets such as Japan, Canada, and Australia⁴. However, according to Bloomberg (2024), with the recent USA presidential election in 2024 having produced an unfavourable outcome for sustainable markets, the second-largest player's share may be pushed to significantly lower levels, which can influence the whole environment and dynamic of this market. Therefore, the analysis of main players such as the USA and Europe, as well as emerging ESG markets like Japan, Australia, and Canada, are crucial to investors moving forward in climate action.

Despite the political and macroeconomic challenges for ESG markets, they continue to show resilience in terms of assets under management and the number of corporate incentives. The trend for environmentally concerned investors to favour industry leaders that also consider high ESG issues, and the influence of socially responsible financial markets on investors, increases the importance of ESG markets in supporting the transition to a low-carbon economy (Asl et al., 2022; Jednak & Jednak, 2019; Lu et al., 2023).

Overall, ESG markets represent a group of responsible investments and are becoming crucial in the call for climate action and in supporting the transition to a low-carbon economy. Therefore, it is essential to understand the nature of these markets so that investors are engaged in investing by efficiently selecting and managing such financial assets.

2.2. Volatility and interconnectedness of ESG markets

According to the Global Risks Perception Survey, climate and environmental risks will be the main global focus over the next decade, with the world least prepared for them (*Global Risks Report 2023*, 2023). Therefore, climate change concern is likely to create an additional source of risk in financial markets as well, both at the macro and micro-level (Venturini, 2022).

Climate risk is long-term and non-diversifiable, making it difficult to implement traditional financial instruments like futures or insurances to protect the holding portfolio for investors. This is because no party can credibly commit to fulfilling claims in the event of a major catastrophe. As a result, individual investors must insure themselves against these risks (Engle et al., 2020). To highlight the financial risks associated with climate change, many economic

⁴<https://www.bloomberg.com/company/press/global-esg-assets-predicted-to-hit-40-trillion-by-2030-despite-challenging-environment-forecasts-bloomberg-intelligence/>, last access: 14/12/2024.

crises materialised that were triggered by its impact. One of the greatest examples is the bankruptcy of Pacific Gas and Electric Company, often attributed to liabilities from climate-induced wildfires (Macwilliams et al., 2019). This calls for investors to put emphasis on responsible sectors, such as ESG markets that are aligned with global climate action, to mitigate the effects of climate change.

The financial sector has increasingly embraced green finance as a critical response to the challenges posed by climate change, which fuelled the development of a diverse group of green financial instruments. These instruments, such as green bonds, green stocks, green funds, carbon finance, and green loans have been growing rapidly, designed to mitigate environmental risks and have been proven to be more resilient and better integrated than capital markets (Born et al., 2021; K.-H. Wang et al., 2022; Ozili, 2022). The ESG stocks are also a part of the group, as one of the three crucial points is addressing environmental problems. Therefore, my research focuses on ESG markets, as well as their sensitivity to climate change in the aspect of common uncertainty.

The impact of ESG ratings on resilience has been the subject of various theories in the literature. One of them is the stakeholder risk management view, which suggests that companies with high ESG performance are more likely to reduce their riskiness - especially in times of high uncertainty - as they improve their relationship with their stakeholders to benefit their financial stability. On the other hand, the overinvestment theory suggests that enhancing reputation or improving non-financial performance motivates managers to invest in socially and environmentally responsible projects (Anwer et al., 2023).

Previous empirical findings suggest that firms with stronger ESG/CSR profiles are better positioned to mitigate their exposure to systematic risk and have higher investment appeal through mechanisms such as resilience in crisis periods, product differentiation, and a broader investor base (Gillan et al., 2021). During the 2008-2009 financial crisis, high-ESG firms outperformed low-ESG firms, and ESG had a negative relationship with idiosyncratic risk, showing that ESG performance can influence firms' sensitivity to systemic risk, which benefits them with resilience in turbulent times (Lins et al., 2017). In addition, previous literature has shown that certain characteristics of companies with high ESG scores, such as offering differentiated products and lower cost of capital due to a broader investor base, reduce the systematic risk of responsible companies through stable demand, lower sensitivity to market

fluctuations and low litigation risk (Albuquerque et al., 2019; El Ghouli et al., 2011; Hong & Kacperczyk, 2009).

The literature about risk analysis of green and sustainable markets is broad and extensive on the risk and return connectedness of financial instruments and geographies. The modelling and analysis of ESG common volatility (COVOL) factor can help investors to assess new risk sources and events that potentially affect many markets simultaneously and identify opportunities that align with their sustainability goals (Arif et al., 2021). This understanding can be particularly important in times of market turmoil as professionals seek to invest in safe havens and hedging instruments. The results of the return connectedness analysis enable investors to optimise the construction of hedging strategies, while the volatility connectedness analysis helps in the timely decision of rebalancing asset allocation, contributing to more efficient risk management (Toyoshima & Hamori, 2018; Umar et al., 2020).

Umar et al. (2020) investigates the connectedness of the largest ESG equity indices and finds significant and consistent transmission between 2007-2020, especially during international shocks such as the European sovereign debt crisis, systemic Greek problems and the outbreak of COVID-19, with developed markets being the volatility transmitters to emerging markets. Among the general interconnectedness, Iqbal et al. (2022) argues that European countries demand greater compliance compared to other markets, which is also reflected in their adopted framework under the European Green Deal. The region is aiming and committed to be the first continent to achieve carbon neutrality by 2050. In line with the argument, the author finds that Germany, France and the Netherlands are the biggest risk transmitters, while Japan and Taiwan are the primary receivers of the return spillovers. Chen & Lin (2022) is quantifying the extreme spillovers under different market states on worldwide ESG leaders' equity with the quantile-based VAR spillover index method. The authors find that the EU and North America are the main risk transmitters to the global ESG investment market.

Also, the volatility of green markets, including socially responsible stocks, is susceptible to negative news to generate a leverage effect (Lu et al., 2023). The COVID-19 was an event that also increased the volatility and high uncertainty in the sustainable dimension of the market. The authors find that the own-return contribution of the ESG market is low, mainly receiving return spillovers from the other green markets in the period 2014-2022. However, there is a high return spillover between socially responsible indexes, which explains the fact that the correlation between socially responsible funds has increased recently (Rehman & Vo, 2020).

Lu et al. (2023) also conclude that the dynamic net total directional connectedness varies over time. It is not easy to conclude if the socially responsible stocks are shock receivers/transmitters, but they are significant return receivers from the clean energy markets over the whole period. Given that the author finds clean energy to be the source of the largest return and volatility spillovers, investors focusing on green bonds and green stocks can adjust portfolio weights to increase investment in green bonds and reduce investment in green stocks, especially clean energy stocks, to increase portfolio diversification returns and thereby reduce portfolio risk.

The connectedness of responsible investments is proven to exist, and there has been extensive literature analysing the risk spillovers, including the identification of transmitters and receivers. On the other hand, the magnitude analysis of the volatility co-movement/correlation remains absent amongst academic researchers, which could be crucial to historically identify and prepare for events that simultaneously cause volatility shocks in ESG markets. Understanding such volatility shocks can significantly improve the performance of ESG portfolios, therefore making them more attractive financial assets for commercial investors as well, eventually fulfilling financial- but also environmental and societal welfare growth.

The numerical measurement of global financial risk, called COVOL has been proposed by Engle & Campos-Martins (2023) using a multivariate generalised volatility model. The COVOL has proven to be more efficient in explaining the ACWI volatility than the geopolitical indices that rely on text-based analysis. These models can be quickly applied, and they are quicker in capturing changes, therefore it is more useful in the preparation of global shocks. Secondly, numerical models are easier to replicate and thus implement.

2.3. The influence of climate news on ESG market performance

Having understood the nature of responsible markets, it is essential to explore the sensitivity of these markets to the current main risk factors. The "E" in ESG represents a company's focus on environmental issues, including biodiversity and climate change. While biodiversity and other environmental issues have recently gained attention, the lack of established risk measures in finance limits research into their impact on financial performance. In contrast, climate change remains the most pressing global challenge requiring an in-depth analysis of the relationship between responsible markets and climate risk indicators.

Research shows that ESG-focused markets and climate transition stocks demonstrate resilience and integration during periods of financial instability. However, critical questions remain: How do equity markets and investors respond to specific climate-related events? Do events such as

natural disasters, regulatory changes or economic events significantly influence the returns and volatility of these markets? These questions are crucial to understand the pricing mechanisms and investor behaviour in the context of climate risks.

Extreme climate news has been shown to have significant negative influence on stock prices. In 2010, the oil spill of the British Petrol (BP) Deepwater Horizon oil-drilling rig caused an accumulated 42.4% decline in the share price of BP three months after the disaster. The oil spill meant huge ecological value loss in sea wildlife and natural parks and economic damages to the fishing industry and to tourism, which are estimated to materialise in US\$36.9 billion as the cost paid by BP (Smith et al., 2010).

Moreover, in 2011, the disaster of the Fukushima nuclear accident in Japan caused a cumulative abnormal return (CAR) of -45.3% for the plant owner Tokyo Electric Power Company, influencing the whole electricity power utility industry with an average CAR of -15.3% only two days after the happening of the event. However, investors were neutral about whether the electric utility company owns a nuclear plant similar to the Fukushima one, indicating less investor sensitivity to the risk of another nuclear explosion (Kawashima and Takeda, 2012). These events are perfect examples of the significant impact of climate change news on stock performance.

However, responsible company performance should not be only sensitive to extreme events, as good practices should be embedded throughout the whole operation and value chain. Capelle-Blancard and Petit (2019) analyses the impact of 33,000 ordinary ESG news, both positive and negative, on one hundred listed companies- that belong to the Dow Jones Sector Titans indexes between 2002 and 2010. They find an overall significant -0,1% negative effect on firm market value in the case of negative news and no effect of positive news, which is in line with previous literature on asymmetric effects of ESG news (Krüger, 2015). The authors find that positive ESG news can increase firms' reputation, unlocking mitigation effect of the following negative news, and acting as a hedging tool. This indicates that, on average, investors price in negative ESG news; however, they do not consider positive achievements in responsible practices as direct value additions.

2.4. Climate Policy Uncertainty (CPU)

The uncertainty surrounding climate policy continues to evolve due to government responses to new scientific findings, economic pressures, and international agreements. Translating climate policies into practical actions and regulations involves complex implementation

strategies that question their effectiveness and timeliness. Moreover, the politically charged nature of climate change, with different views on the urgency, scope, and methods of tackling it, increases the uncertainty around national long-term trajectory and causes gaps in the uniformity of global climate action (Gavriilidis, 2021).

Frequent policy shifts and changes create an unpredictable and unclear regulatory environment, complicating long-term strategy construction for investors and businesses. The USA withdrawal from the Paris Accord in 2017 illustrates how a policy shift can create instability about a nation's commitment to climate action. Such events create persistent dilemmas regarding the opportunity "cost" and "benefit" of delaying mitigation investments that impact investor confidence in climate-related sectors (Fuss et al., 2008; Gavriilidis, 2021).

Due to this, dynamic Climate Policy Uncertainty influences stock prices and contributes to market volatility through investor perception. Previous empirical research shows positive relationship and risk spillover effects between CPU and volatility of markets for brown assets, like the oil industry. Furthermore, growing evidence suggests that CPU may also significantly impact sustainable and responsible markets.

Studies utilising the GARCH-MIDAS model have shown that CPU significantly increases the volatility of sustainable indices. Raza et al. (2024) argues that any policy changes, particularly those aiming to reduce carbon emissions or promote green investments, can significantly impact investor confidence and market valuations. The author finds that CPU is a significant amplifying factor and displays superior predictive accuracy to the volatility of the S&P Green Bond Index, S&P Global Clean Energy Index, and Dow Jones Sustainability Index. The impact of the uncertainty around climate regulations on the volatility of green assets has an increasing trend since the Paris Agreement in 2016. In line with the previous findings, J. Wang & Li (2023) finds that climate policy uncertainty can significantly drive the ESG market in China, highlighting that climate risk can have an important impact on listed companies with high ESG scores.

The policy effects on global sustainable markets are also pivotal in understanding the systematic risk of responsible markets. After TVP-VAR analysis, Su et al. (2024) conclude that CPU is the most important net transmitter of shocks along green bonds, climate-transition stocks and market volatility (VIX). For ESG markets, where the focus is often on stability and sustainable returns, CPU's role as a shock transmitter reveals a vulnerability that could deter long-term

investors unless mitigated. This underscores the need for investors and policymakers to monitor climate policy developments and their potential spillover effects closely.

On the other hand, CPU should also affect carbon emitters. Climate policies seeking to improve the environment tend to reduce oil exploration, which reduces the oil supply relative to demand and causes oil prices to rise. Salisu et al. (2023) finds evidence for the amplifying and predicting power of CPU also for the oil market volatility using the WTI and Brent oil price data between 2001 and 2021. Campos-Martins & Hendry (2024) finds that climate change news are systematic drivers of common volatility shocks of oil and gas companies. The authors show that increasing transition in energy shocks oil and gas stock prices at the global scale, when controlling for oil price, USA and world stock market shocks. They also find that climate news seems to create turmoil and materialise when the news has a negative global effect on the market. This is in line with the asymmetric nature of news, which can be granted to investor caution or the fact that investors do not see positive climate news as an added value.

This calls for the consensus of nations' governments and regulators to have clearer signalling and action plans on how to tackle climate change to increase investor confidence and prevent market shocks regarding policies to be implemented.

There is strong evidence in previous literature, that the policy uncertainty around climate change and climate action have a significant effect on the volatility of sustainable markets but also of the oil and gas industry. However, it is not clear if the concerns around climate policy could make global responsible stock prices move simultaneously.

2.5. Climate Risk Index as in transition risk and physical risk

The growing body of research underscores the impact of climate risks—both transition and physical—on asset prices, with a particular focus on investor behaviour, regulatory frameworks, and the material risks associated with climate change.

2.5.1. Transition Risk

Transition risk arises from the global shift toward carbon neutrality and encompasses changes in climate policy, market preferences, technological innovation, and reputational impacts. Pástor et al. (2022) highlight the “equity greenium,” where green assets—rated using MSCI ESG scores—exhibit lower expected returns due to investor preferences and their potential to hedge climate risk. This greenium reflects increased investor demand for environmentally friendly assets, which drives down their cost of capital and contributes to broader social impact.

Bolton & Kacperczyk (2021a) identify a carbon premium, whereby investors demand higher returns for carbon-intensive companies due to risks such as carbon pricing, regulatory interventions, and price competition from alternative energy technologies. These findings are bolstered by evidence that the carbon premium has only materialised recently, particularly following the Paris Agreement (COP 21) in December 2015, which significantly altered investor perceptions of long-term climate risks.

Further research, such as Bolton & Kacperczyk (2023), explores the global pricing of transition risk, finding that carbon risk premiums vary by region and are higher in developed economies with stricter climate policies. The study also highlights the importance of long-term versus short-term risks, with the Paris Agreement prompting a re-evaluation of long-term impacts on asset prices, especially in Asia.

Bua et al. (2024) support these findings, emphasising the increasing reliance on firm-level greenhouse gas emissions data to gauge transition risk exposure since 2015. Their analysis reveals that renewable energy demand inversely correlates with oil major stock prices, showcasing the financial impact of the energy transition.

Transition risks, particularly those tied to changes in climate policies and regulatory frameworks, contribute to significant volatility in ESG markets. For instance, post-Paris Agreement developments showed heightened investor sensitivity to climate policies, leading to pronounced price fluctuations in both green and brown assets. When policy directions remain uncertain or rapidly shift, markets can exhibit increased volatility simultaneously. However, there are regional differences across ESG markets in terms of climate transition sensitivity. While ESG markets in developed economies like the USA, Europe, and Japan exhibit stronger co-movement due to aligned policy environments and similar investor profiles, emerging markets with less stringent climate policies may have weaker connections (Bolton & Kacperczyk, 2021a, 2023).

2.5.2. Physical Risk

While less developed, the literature on physical climate risk focuses on the financial consequences of extreme weather events and long-term environmental changes. Addoum et al. (2020) examine high-temperature events and find limited impacts on corporate performance metrics like sales and productivity. In contrast, Hong et al. (2019) document significant effects of droughts on food industry stock returns, while Kruttli et al. (2019) explore the financial uncertainty driven by hurricanes. These findings focus on subtopics of physical risk rather than

focusing on the aggregate impact of physical events. Bua et al. (2024) find that sectoral classification is sufficient in the assessment of broad textual-based physical risk exposure in European financial markets.

Despite these findings, physical risks are often underrepresented in asset pricing models. Bolton & Kacperczyk (2023) observe that transition risk tends to overshadow physical risk in investor priorities, although both are integral to comprehensive climate risk assessments.

While physical risks, such as droughts or hurricanes, tend to impact specific sectors or regions, their effects on supply chains and global commodity markets can create variance co-movement across ESG markets. This is particularly true for sectors heavily linked to physical climate risks, like agriculture, real estate, and energy, which can represent a major part of ESG markets (Hong et al., 2019).

Investor behaviour also plays a critical role. The increasing use of ESG ratings and indices, such as those provided by MSCI, has led to more harmonised investment strategies globally, further enhancing the co-movement of ESG market variances. However, regional differences in policy stringency and investor awareness mean that this co-movement is often stronger in developed economies than in emerging markets (Bua et al., 2024). Physical risks contribute to co-movement primarily through sectoral integration. Disruptions in climate-sensitive industries, such as energy or utilities, can have spilling effects on ESG markets worldwide, especially as these sectors are integral to green portfolios.

The central question driving this study is whether climate change variables, such as climate policy uncertainty, transition risk and physical risk indices, significantly drive ESG market volatility shocks. This is motivated by recent evidence showing that climate-related risks are increasingly priced into asset markets but with varying implications for volatility and co-movement. The findings could provide deeper insights into how ESG markets respond to systemic climate shocks and guide investors in managing climate risk exposures more effectively.

3. Methodology and Data

3.1. Methodology

3.1.1. Volatility modelling with GARCH

The mean model is established by selecting the factors that best explain the log-returns⁵ (r_{it}) of the ESG Leader indices. In line with the approach of Engle & Campos-Martins (2023), the ACWI is utilised as the factor that is most likely to account for the returns of the MSCI indices. The cross-sectional mean (CSM) returns are also considered in the model of the first moment to reduce the contemporaneous correlations to zero. Furthermore, the AR(1) factor ($r_{i,(t-1)}$) is incorporated into the mean model for those indices where the AR(1) test has indicated significant autocorrelation effects. The conditional inclusion of the AR(1) effect is provided by D_i , which is a binary variable taking the value of 1 if the time series of asset i exhibits significant first-order autocorrelation and 0 otherwise. The $u_{i,t}$ represents the residuals from the factor model.

$$r_{it} = c_i + D_i \delta_i r_{i,(t-1)} + \beta_{1i} ACWI_t + \beta_{2i} CSM_t + u_{i,t}, \quad |\delta_i| < 1 \text{ for } i = 1, \dots, N$$

Given the heteroscedasticity of the time series, the residuals are uncorrelated but not independent as they are related through second moments. Therefore $u_{i,t}$ is assumed to follow the first-order generalised auto-regressive conditional heteroscedastic (GARCH) model (Engle & Bollerslev, 1986). More specifically, the volatility of the time series is estimated with a GARCH(1,1) model, which is proven to be the most successful and accurate in previous literature to capture the persistence in the volatility, the most significant feature that needs to be handled (Hansen & Lunde 2005). In this framework, the residual $u_{i,t}$ is multiplicatively decomposed such that $u_{i,t} = h_{i,t} e_{i,t}$, where

$$h_{i,t} = \omega_i + \alpha_{i,1} u_{i,t-1}^2 + \beta_{i,1} h_{i,t-1}$$

and $e_{i,t}$ is a standard normal random variable.

This means that the current volatility of the asset depends on the squared residual of the mean equation but also the volatility of the previous period. The constraints for all i in the model are the following to ensure stationarity:

⁵ Log-returns computed as the natural logarithm of the percentage change in the price of asset i

$$\omega_i, \alpha_{i,1}, \beta_{i,1} \geq 0, \alpha_{i,1} + \beta_{i,1} < 1 \text{ for } i = 1, \dots, N.$$

3.1.2. Measuring co-movements of volatility shocks

After carrying out the volatility model for each time series, the standardised residuals e_t will have zero covariances as they only contain idiosyncratic returns. Assuming that the factor model is correctly specified and explains the cross-sectional correlation, the contemporaneous correlation converges to zero and the variance-covariance matrix, Σ_t is an identity matrix of order N , I_N .

The main finding of the model is that the orthogonal nature of standardised residuals does not imply that the standardised residuals are fully independent, as absolute or squared values can show positive correlation in cross-section (Engle and Campos-Martins, 2023). From the standardised residuals, the volatility shocks to ESG markets are obtained as:

$$\phi_{i,t}^\sigma = e_{i,t}^2 - 1 = \frac{u_{i,t}^2 - h_{i,t}}{h_{i,t}} - 1$$

This leads us to the conclusion that shocks to ESG market volatilities may be correlated as well. Similar to Engle and Campos-Martins (2023)- in order to build the model- the model lets the global ESG variance $f_{ESG,t}^\sigma$ be a latent factor and s_i a parameter interpreted as a factor loading or fixed effects satisfying:

$$\begin{aligned} E_{t-1} (f_{ESG,t}^\sigma) = 1, E_{t-1} (f_{ESG,t}^\sigma - 1)^2 = v_t, f_{ESG,t}^\sigma, v_t > 0 \text{ and } 0 \leq s_i \leq 1 \\ \text{for } t = 1, \dots, T \text{ and } i = 1, \dots, N \end{aligned}$$

So that $f_{ESG,t}^\sigma$ is a positive scalar random variable with the expected value of one. For the random variable, $e_{i,t}$ a data generating process is considered:

$$e_{i,t} = \sqrt{g(s_i, f_{ESG,t}^\sigma)} \epsilon_{i,t}, \quad \epsilon_{i,t} \sim \mathcal{N}(0,1)$$

$$\text{where } g(s_i, f_{ESG,t}^\sigma) \equiv s_i f_{ESG,t}^\sigma + 1 - s_i = s_i (f_{ESG,t}^\sigma - 1) + 1$$

The $f_{ESG,t}^\sigma$ is independent of ϵ_t vector, in which ϵ_i are independently and identically normally distributed with zero mean and unit variance at each time. By choosing this specification, the g function is positive for $t = 1, \dots, T$, satisfying $E[e_{i,t}^2] = 1$ for $i = 1, \dots, N$.

The assumption that the variance of the factor $f_{ESG,t}^g$ is strictly positive, indicates that e^2 are positively correlated over time t and the variance-covariance matrix Σ_{e^2} will not be diagonal due to the cross-sectional dependence of e^2 . The model evaluates the off-diagonal elements of the covariance matrix of the squared residuals: $\Sigma_{e^2}^{ij} = cov[e_{it}^2, e_{jt}^2] = \mathbb{E}_{t-1} [(e_{it}^2 - 1)(e_{jt}^2 - 1)]$ for $i, j = 1, \dots, N$ in which a significant positive correlation indicates the presence of common shocks to the ESG sector.

To assess the significance of ESG common volatility, we use the test statistic proposed by Engle and Campos-Martins (2023):

$$\xi_{e^2} = \frac{\sqrt{\frac{NT}{(N-1)/2}} \sum_{i>j,j=1}^N \sum_{t=1}^T (e_{i,t}^2 - 1)(e_{j,t}^2 - 1)}{\sum_{i=1}^N \sum_{t=1}^T (e_{i,t}^2 - 1)^2}$$

Under the null hypothesis of no common volatility, this statistic follows a standard normal distribution. Empirical evidence of significant correlations among squared residuals supports the existence of shared volatility shocks in the ESG sector.

By iteratively refining the factor model and rigorously testing for shared volatility patterns, this methodology provides a robust framework for identifying and measuring ESG common risks, offering insights into the dynamics of the sector and their implications for portfolio management and risk assessment.

The likelihood function is constructed under the assumption of normality, treating it as if $f_{ESG,t}^g$ were observed. The log-likelihood function for this model is given by:

$$L(s, f_{ESG,t}^\sigma; e) = -\frac{1}{2} \sum_{i=1}^N \sum_{t=1}^T \left\{ \log g(s_i, f_{ESG,t}^\sigma) + \frac{e_{i,t}^2}{g(s_i, f_{ESG,t}^\sigma)} \right\}$$

Since the model involves two sets of unknowns with multiplicative formulation- $f_{ESG,t}^g$ (latent volatility factor) and s_i (factor loadings)- a maximum likelihood estimation approach is applied, where each set of unknowns is estimated conditional on the estimated values of the other. First order conditions for the variables are:

$$\frac{\partial L(s, f_{ESG,t}^\sigma; e)}{\partial s_i} = 0, \quad \frac{\partial L(s, f_{ESG,t}^g; e)}{\partial f_{ESG,t}^\sigma} = 0$$

Given the heteroscedasticity, this involves alternating between cross-sectional and time-series regressions to estimate each parameter set conditionally. The cross-sectional heteroscedasticity relationship is represented as:

$$e_{i,t} = \varepsilon_{i,t} \sqrt{\hat{s}_i} (f_{ESG,t}^\sigma - 1) + 1 \quad \text{for } t = 1, \dots, T,$$

while the time-series counterpart is:

$$e_{i,t} = \varepsilon_{i,t} \sqrt{s_i} (f_{ESG,t}^\sigma - 1) + 1 \quad \text{for } i = 1, \dots, N.$$

Estimation Procedure

1. Cross-Sectional Regression: The initial values of s are obtained using the loadings on the first principal component of the squared standardized residuals. These values serve as a starting point to estimate f for each point in time t .
2. Time-Series Regression: Using the estimated $f_{ESG,t}^\sigma$ values obtained in the previous step, the loadings s_i are estimated across assets.
3. Iterative Optimization: The procedure iterates between cross-sectional and time-series regressions to refine estimates of $f_{ESG,t}^\sigma$ and s_i until convergence. At convergence, the first-order conditions of the log-likelihood function are satisfied, ensuring a joint maximum.

The ESG cross-sectional correlation tests and the estimation of the ESG common volatility factor are done with the *geovol* R package provided by Campos-Martins (2021).

3.1.3. Regression analysis

To see if the common volatility shocks of ESG markets are driven by climate-related concerns, the research uses the same methodology as Campos-Martins & Hendry (2024) to project the $f_{ESG,t}^\sigma$ to climate risk shocks.

$$f_{ESG,t}^\sigma = \alpha \phi_{CR,t}^\sigma + \beta x_t^\sigma + \gamma \{ x_t^\sigma \times \phi_{CR,t}^\sigma \} + v_t$$

The variable of interest is the monthly average ESG common factor centred around its mean, which means that the constant variable is excluded from the model. The v_t has a normal distribution with zero mean and constant variance. The $\phi_{CR,t}^\sigma$ are the independent variable and

the measures for climate-related risks. The x_t^c contains the control variable, which in this research is the world equity volatility shocks ($\phi_{ACWI,t}^\sigma$).

There is evidence provided by Bolton and Kacperczyk (2021b, 2023) and Raza et al. (2024) that climate-related risk materialises only after the Paris Agreement. Therefore, two additional dummy variables are created: $PrePA_t$, which has a value of 1 before April 2016, 0 afterwards and $PostPA_t$ which shows the value 0 until April 2016 and 1 afterwards. To see the effects before and after the event, the following regression is considered to distinguish the pre- and post-event explanatory power of climate risk indices.

$$f_{ESG,t}^\sigma = \alpha_1 PrePA_t \times \phi_{CR,t}^\sigma + \alpha_2 PostPA_t \times \phi_{CR,t}^\sigma + \beta x_t^\sigma + \gamma_1 \{x_t^\sigma \times PrePA_t \times \phi_{CR,t}^\sigma\} + \gamma_2 \{x_t^\sigma \times PostPA_t \times \phi_{CR,t}^\sigma\} + v_t$$

3.2. Data

3.2.1. MSCI ESG Leader Index and the factors

The objective of the research is to assess the co-movements of the volatility of ESG markets. To estimate the time series, the research uses the eight mainstream ESG Leader Indices: USA, Europe, Australia, Canada, Japan, China, India and Korea from MSCI.

To calculate the log returns, the total return index data of the MSCI indices and the ACWI factor was obtained from DataStream, LSEG Workspace. In the determination of the timeframe, the availability of at least two index prices was required. Six out of eight indices start from 01.10.2007, and only the USA have earlier availability, which constrains the sample from starting from the previously mentioned date. Eventually, the timeframe of the ESG-COVOL factor is 01.10.2007-15.11.2024, with only Korea starting later: 15.07.2013. Due to the unbalanced panel of the data source, between 2007 and 2013 the $f_{ESG,t}^\sigma$ is estimated with 8 (excluding Korea) ESG Leader plus the cross-sectional mean (CSM) and between 2013 and 2024 the factor is estimated with 8 ESG Leaders and the CSM. The timeframe covers major financial events, for example, the financial crisis in 2008 and the European debt crisis in 2010 and major climate events, such as the Paris Agreement in 2016; therefore, it is considered sufficient to understand the volatility shocks to ESG markets.

As literature has shown, the advantages of using indices are that they are free of transaction costs, market timing and management skills, and survivorship bias. These natures of indices result in less skewed results, which is ideal for empirical analysis of financial performance.

3.2.1.1. Construction of the index

In line with the assessment of sustainable markets, the paper uses MSCI Indexes that represent a group of companies that have high ESG performance and involvement. MSCI ESG Leaders Indexes are free float-adjusted market capitalization-weighted indexes designed to represent the performance of companies that are selected from an underlying index based on Environmental, Social and Governance (ESG) criteria. These criteria exclude constituents based on involvement in some business controversies, ESG rating lower than 'BB' and ESG controversy rating lower than 3 that are provided by the organisation's ESG research team. These criteria ensure that the list constituents represent a high standard quality of ESG initiatives. The underlying index is the corresponding parent MSCI index, from which the ESG index targets 50% of the free float-adjusted market capitalisation within each GICS sector. This ensures that the systematic and country-specific risks are controlled, which results in a competitive financial performance but also delivers impact. MSCI also maintains the indexes through annual reviews, making sure the sector weights are rebalanced according to the published ESG Research data. After excluding all the securities that were below the standards, the remaining constituents are ranked based on ESG Ratings, ESG Controversies, Climate Change Metrics, and Business Involvement Screening Research (BISR) provided by internal analysis⁶.

A disadvantage can be that the ratings from the MSCI ESG Research department- determining the selection- are internal. Therefore, it can be argued that an external rating framework that is agreed upon among a wider category of stakeholders/ institutions would result in a more realistic index. Luo et al. (2023) find that ESG Scoring ambiguity decreases the demand for green assets, reducing overall welfare, therefore highlighting the importance of establishing a standardised and transparent ESG scoring system to enhance investor trust towards these markets. Disagreement in the scoring of stocks creates noise in ESG ratings, which is an additional source of risk for ESG investors influencing their investment decisions and is the main reason for the existing literature's mixed results on the excess returns on ESG.

However, the Morgan Stanley Capital Index is a globally known and acknowledged leading provider of critical support tools and services for the global investment community, which makes it an experienced and confident player in building more efficient portfolios. As the world's largest provider of ESG ratings, MSCI supports over 1,700 clients worldwide, including pension funds, asset managers, and financial institutions. Among the major ESG data

⁶ For more information, please see: <https://www.msci.com/legal/disclosures/esg-disclosures>

vendors, MSCI's ESG scores are considered the least noisy, with ratings based on diverse sources, updated annually, and enhanced by advanced technologies like AI and machine learning (Berg et al., 2022; Eccles & Stroehle, 2018).

3.2.1.2. Price evolution of the MSCI ESG Leaders

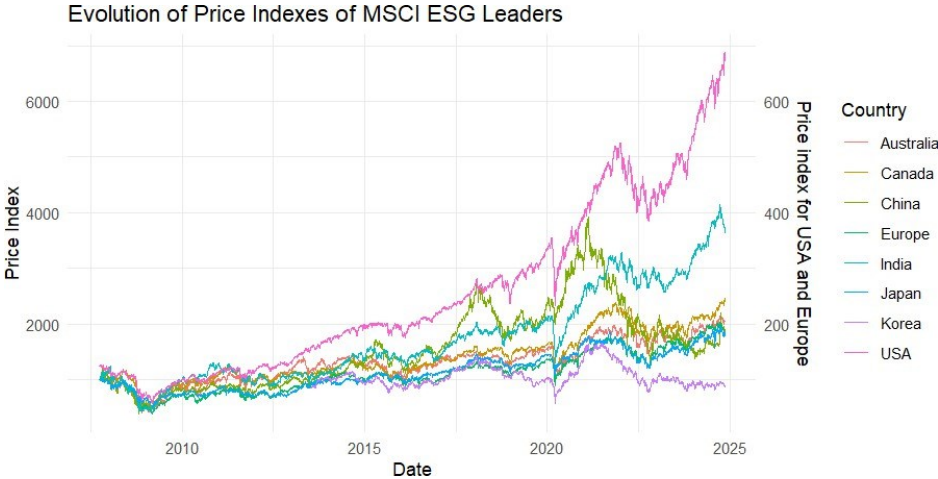


Figure 1- Price evolution of MSCI ESG Leader Index prices between 2007-2024

The starting value for Europe and the USA is 100, whereas for the rest, the starting price index is 1000. We can see in Figure 1 the evolution of Return Indexes in Figure 1 in the timeframe, where the USA and Europe are shown on the secondary axes (right side) to enhance the visualisation of relative price development. Noteworthy that all ESG price indices suffered a sharp decline during COVID-19 in 2020. This is in line with previous literature, arguing that COVID-19 also influenced sustainable markets and responsible investments as the focus quickly shifted from climate action. The USA has the highest relative increase in the price index in the analysed timeframe, followed by Europe, whereas Korea is below the starting level, indicating negative return, which may be caused by challenging investor and capital attraction due to the nature of the Korean sustainable markets.

3.2.2. Climate-related Risk Indices

3.2.2.1. Climate Policy Uncertainty Index

The research uses the textual-based analysis of CPU proposed by (Gavriilidis, 2021). The author uses eight leading US newspapers, including the Wall Street Journal, the New York Times, and USA Today, from January 2000 to March 2021. Since publication, an extended and annotated version of the index has been published, covering earlier periods from 1999.

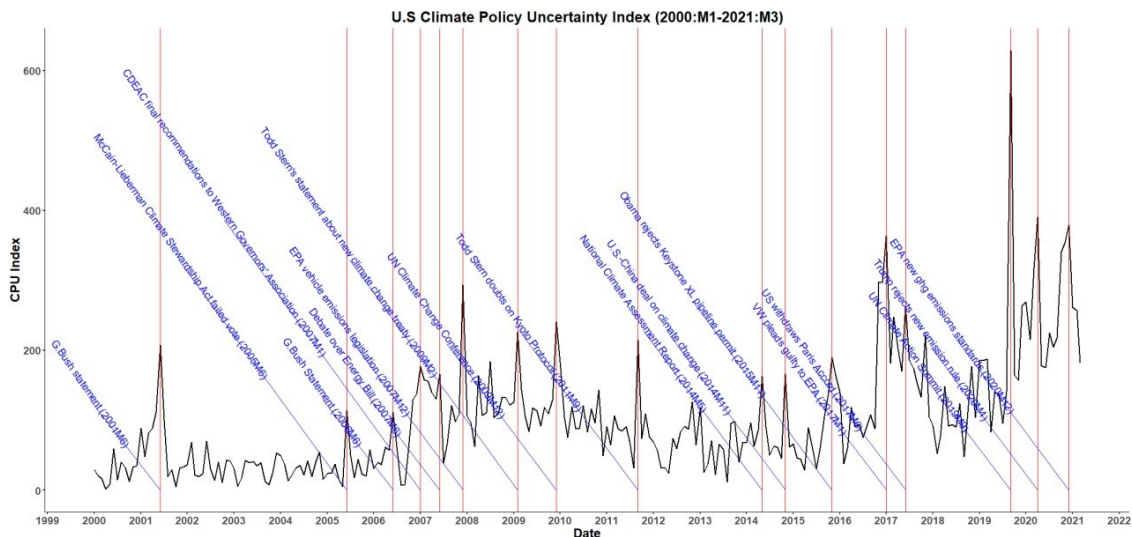


Figure 2- The U.S. Climate Policy Uncertainty Index between 2000 and 2021. Source: Baker, S. R., Bloom, N., & Davis, S. J. (n.d.). Annotated charts: Measuring policy uncertainty. Retrieved from https://www.policyuncertainty.com/media/Annotated_CPU.pdf from dataset provided by Gavriilidis, K. (2021), "Measuring Climate Policy Uncertainty" Available at SSRN: <https://ssrn.com/abstract=3847388>

The index tracks the frequency of articles that contain terms related to uncertainty, regulatory, climatic, and environmental factors. As observed from Figure 2, the index peaks during not only USA climate policy events but also global ones, such as the UN Climate Change Conference in 2009 and the UN Climate Action Summit in 2019. Even though the index is specialised in the USA, these events reflect not only national but global influences, as the USA represents a major share in sustainable and ESG markets. The data is available until November 2024, constraining the number of observations to 204 months.

After obtaining the CPU index, the log-return was computed and winsorized to an absolute value of 50%, reducing the distorting effect of extreme values in the time series, which can be critical in the estimation of GARCH processes.

3.2.2.2. Transition Risk Index (TRI) and Physical Risk Index (PRI)

Textual base climate risk indices, including transition (TRI) and physical risk index (PRI), created by Bua et al., (2024) are used to analyse if the common volatility shocks of ESG markets are driven by levels of climate change concerns. The authors construct the indexes by using scientific literature and policy documents from trusted institutions and categorising these texts into topics specifically aligned with physical risks and transition risks.

The PRI focuses on risks arising from chronic and acute physical events, such as floods, droughts, rising sea levels, and extreme weather events. These risks impact firms through damaged assets, disrupted supply chains, and increased operational costs. By analysing daily

news content and its alignment with physical risk-related terminology derived from scientific and policy texts, the PRI captures unexpected changes or "shocks" in physical risk perceptions within financial markets. The TRI, on the other hand, measures the financial implications of the transition toward a low-carbon economy. This includes risks tied to regulatory changes, technological advancements, and shifts in market or consumer preferences, which can impose significant costs on firms, particularly those reliant on fossil fuels. Using a similar methodology as the PRI, the TRI tracks discussions on transition-related topics like carbon pricing, renewable energy, and emissions regulations to detect unexpected shifts in market concerns.

The climate risk indices specialise in European financial markets, but due to their pioneering role in global ESG markets, shocks in Europe are likely to spill over to other countries, making them global. The TRI and PRI measure changes in the levels of transition risk and physical risk concerns; therefore, time series were used as obtained. The data is available from 2005 until December 2024, which results in 195 monthly observations in the regression analysis.

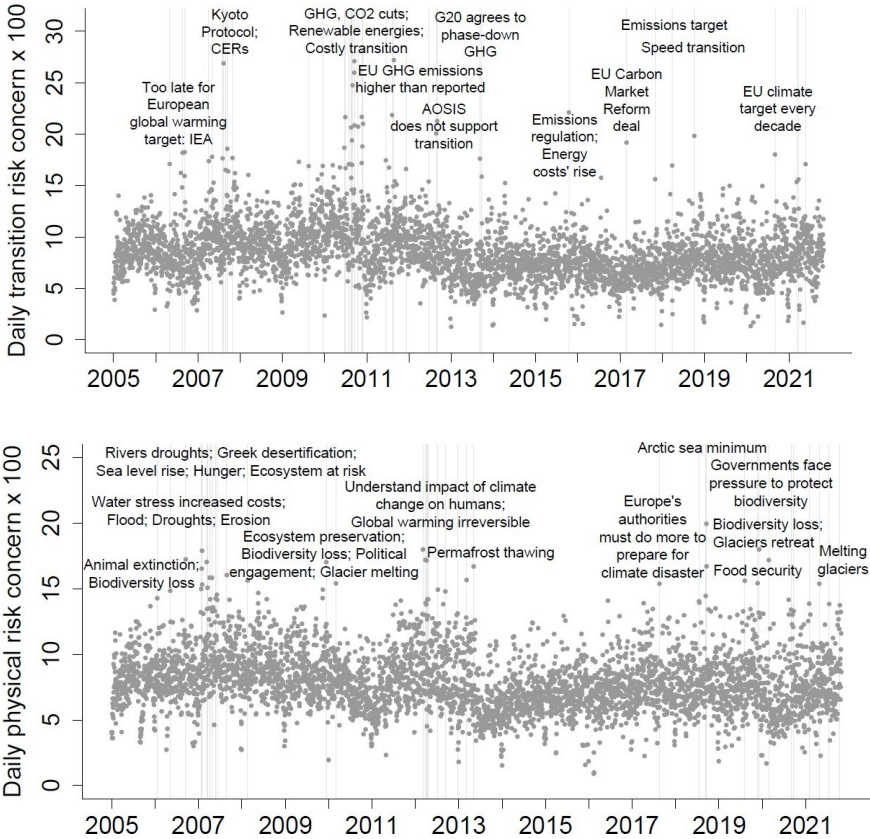


Figure 3-Evolution of transition (upper panel) and physical (lower panel) risk concern with the major risk shock topics between Jan 2005-Oct 2021. Source: "Transition versus physical climate risk pricing in European financial markets: a text-based approach", by Bua et al., 2024, "The European Journal of Finance", 30:17, p. 2084

All measurements are obtained from <https://www.policyuncertainty.com>. For summary statistics, please see the Appendix.

4. Results

4.1. Summary Statistics

The summary statistics of the time series can be found in Table 1. The majority of the log-return series are negatively skewed, although they do not show significantly abnormal results, in the sense of the accuracy of the standard deviation. One noteworthy observation is that only the time series of China shows slightly positive skewness, which indicates right-skewed distribution and overestimation of standard deviation. When looking at the 4th moment of the log return distributions, the kurtosis suggests that our time series are leptokurtic with heavier tails than the normal distribution, indicating a higher probability of extreme cases. The results of the JB-tests reflect the significantly high kurtosis as it rejects the hypothesis that the distribution is normal for all the time series. Tests for AR(1) and ARCH(1) were also conducted, from which we observed significant AR and ARCH effects, indicating time dependence in the first two moments. This verifies the GARCH modelling of the volatility since the volatility at time t is conditional on the volatility at time $t-1$.

Table 1-Summary Statistics of the MSCI ESG Leader Indices and the Factors (AWCI, Cross-Sectional Mean)

	USA	Europe	Japan	Australia	Canada
N	4470	4470	4470	4470	4470
Min	-12.920	-13.628	-9.844	-15.964	-13.918
Mean	0.038	0.013	0.013	0.016	0.020
Max	10.547	10.261	11.682	8.763	11.567
SD	1.263	1.355	1.326	1.551	1.410
Skewness	-0.571	-0.372	-0.194	-0.782	-0.880
Kurtosis	15.480	11.984	9.057	12.467	16.988
JB Stat	29251.094	15136.301	6860.940	17150.026	37021.443
p-value	0.000	0.000	0.000	0.000	0.000
AR(1)	60.973	0.030	63.992	0.715	1.178
p-value	0.000	0.862	0.000	0.398	0.278
ARCH(1)	422.228	120.281	321.744	220.153	498.779
p-value	0.000	0.000	0.000	0.000	0.000

	China	Korea	India	ACWI	CSM
N	4470	2960	4470	4470	4470
Min	-9.930	-14.514	-14.669	-9.997	-9.249
Mean	0.013	0.000	0.029	0.016	0.018
Max	15.649	12.326	19.506	8.903	7.747
SD	1.777	1.466	1.500	1.046	1.032
Skewness	0.321	-0.118	-0.016	-0.713	-0.631
Kurtosis	9.814	11.230	16.482	14.767	12.757
JB Stat	8724.471	8361.517	33854.162	26166.799	18029.013
p-value	0.000	0.000	0.000	0.000	0.000
AR1(1)	0.671	1.824	0.765	42.229	142.412
p-value	0.413	0.177	0.382	0.000	0.000
ARCH(1)	222.057	658.672	136.597	309.079	373.833
p-value	0.000	0.000	0.000	0.000	0.000

4.2. GARCH Volatility Estimation

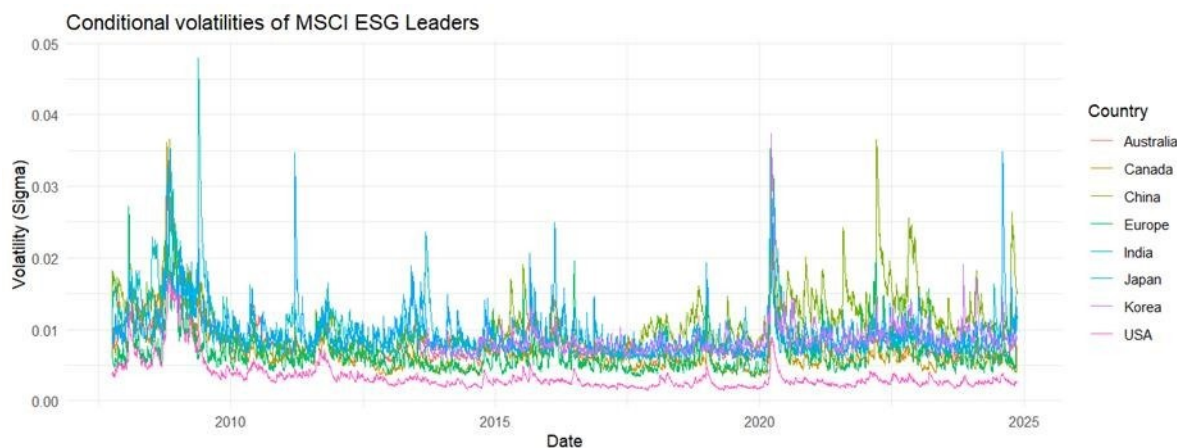


Figure 4- Evolution of GARCH(1,1) volatilities across ESG Leader Indices between 2007-2024

In Figure 4, we can see the volatility evolution of the mainstream ESG indices. In general, we observe that the volatilities are correlated. We can see the spike of the global financial crisis in 2008 and the spike of COVID-19 that significantly shook the financial markets simultaneously, in line with the result obtained when modelling the first moment.

Following the COVID-19 pandemic, the Chinese ESG index has exhibited a trend of reduced correlation with other markets and increased volatility. There are two significant spikes that are specific to a country. One in Japan on 17/11/2011 in which the Japanese Yen hit a record high

against the US dollar due to the rising uncertainty around the impact of Japan's earthquake and tsunami some days earlier. This event is also climate change related since climate change increases the occurrence of such natural disaster events. Secondly, an extreme spike in the Indian index occurred on 18/05/2009, when the Indian Stock Exchange was forced to shut down after the benchmark indices, Sensex and Nifty, hit the upper circuit limit twice. This was driven by the results of the Congress election, which signalled the continuation of previous policies and strengthened the government's ability to implement key reforms without reliance on coalition partners.

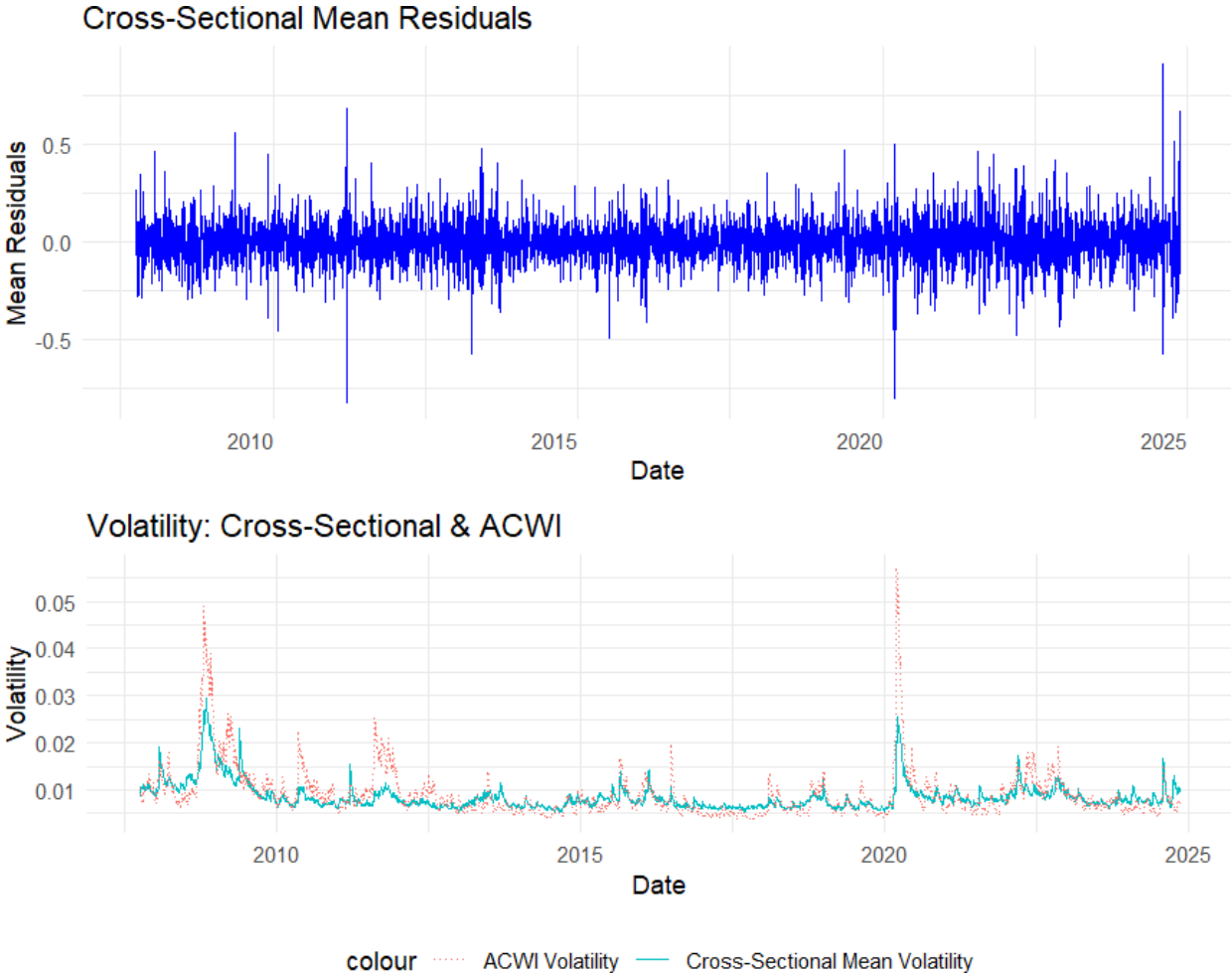


Figure 5- Cross-sectional Mean Residual of ESG Leader Markets (upper panel) and the cross-sectional volatility of ESG Markets with Benchmark (ACWI) (lower panel) between 2007 and 2024.

On average, we can see significant movements during market turmoil that had global impacts, such as the time of the global financial crisis around 2007-2008 and the COVID Crisis. The mentioned pandemic not only slowed down economies but also disrupted the implementation of climate policies, shifting priorities and resources towards addressing the immediate health

crisis. This resulted in decreased investments in green and sustainable sectors and increased perceived risk associated with these markets, contributing to their instability (Raza et al., 2024). It is still noteworthy that the cross-sectional ESG mean volatility was lower during both named events, indicating that ESG assets can offer lower sensitivity to global market shocks and eventually act as safer investments. This can be a particular incentive to commercial investors as well, considering that these assets offer high hedging value to investors.

4.3. Common volatility shocks to ESG markets

4.3.1. Testing for common volatility movements

H0: There is no cross-sectional correlation between standardised residuals

The average correlation of standardised residuals ($\bar{\rho}_e$) is -0.01 with a p-value of 1, showing no correlation. This is in line with the fact that when the factors sufficiently explain the first moment, the average of the non-diagonal elements of the variance-covariance matrix is 0. However, it does not mean that they are independent, as the shocks to the ESG markets (ϕ) may still be correlated. For this reason, one must execute the same hypothesis for the shocks to the time series ($e_t^2 - 1$).

H0: There is no cross-sectional correlation between shocks to volatility

The average correlation of the volatility shocks is $\bar{\rho}_{e^2-1} = 0.1253$, which is notably higher than the correlation of standardised residuals. The resulting t-statistics of the hypothesis is 102.6301 with a p-value of 0, which clearly indicates the rejection of the null hypothesis. Therefore, there is an existing factor of co-movements of ESG common risks that needs to be extracted with a multivariate GARCH model.

4.3.2. Estimating ESG common volatility shocks

After obtaining the daily co-movements of volatility shocks, we compute the monthly ESG COVOL to simplify the results analysis. The frequency of climate risk indices is also monthly; therefore, the regression will have the same number of observations.

Following the pattern of the first and the second moment, COVID-19 caused the highest co-movement of volatility shock among the ESG markets. We can also observe the effects of the Great Recession and the Global Financial crisis as common volatility shocking events, as we saw the trend of higher conditional volatility for the ESG Indices. The stock market crashes increased the factor frequently, especially in the USA equity market. A great example is the

stock market crash in August 2024, which resulted in significantly high implied volatility (VIX) and risk spillovers in international ESG markets. We can also see the effects of geopolitical and political events, such as the Brexit in Europe, the re-election of Xi Jinping in China and events from the Russian Invasion of Ukraine.

From the aspect of climate change events and concern, we can only see influence when coupled with a financial event. In May 2010, the well-known European Debt Crisis was disrupting the markets; however, by that time, the scale of the explosion of Deepwater was becoming clearer. The USA was also involved in this issue, affecting the ecosystem and coastal communities in that area and making it an international event. The same applies to January 2016, when oil prices had a sharp decline, and in parallel, the Paris Agreement was signed some days before, causing a high level of uncertainty around the implementation of climate action that could have caused high levels of ESG market uncertainty around the policy. One could argue that the sharp decline in oil prices was the consequence of the decision to adopt the Paris Agreement, shifting towards alternative and clean energy instead of carbon emitters. However, we do not observe high common volatility around other key moments related to the Paris Agreement, like the signing of the global framework in April 2016 or in November 2016, when it entered into force. Additionally, in November 2009, the legislation in carbon taxes took place in Australia that may have caused the uncertainty for energy-intensive sectors; however, due to the European Debt crisis, we cannot fully grant the high ESG COVOL to the climate policy event.

The only natural event that individually shook the markets simultaneously was the Fukushima Nuclear Disaster in Japan, which occurred after several natural catastrophes, including earthquakes and tsunamis. The event caused global reconsideration of the reliance on nuclear energy, driving the uncertainty around the ESG-linked clean and alternative energy sectors.

Moreover, it is noteworthy that in November 2023, the underlying event of the high ESG volatility factor was not harmful, as there was a global positive trend in the equity market in terms of growth. This highlights the fact that volatility shocks are not necessarily consequences of market turmoil or economic downturns, as they may be the product correlation of abnormal positive performance.

Table 2- The highest levels of monthly ESG variance factor (f_{ESG}^{σ}) with the dates and events. For further implications, the cross-sectional mean (r_{CSM}) return and the lowest return (r_{min}) are also shown.

Date	f_{ESG}^{σ}	r_{CSM}	r_{min}	Region with r_{min}	Event
Mar 2020	4.50	-18.1%	-35.3%	Australia	COVID/ Severe bushfire in Australia
Jan 2008	2.42	-10.2%	-14.2%	China	Great Recession: 1%. Interest rate cut
May 2009	2.00	15.0%	5.2%	USA	Global Financial Crisis: Bailouts
Sep 2008	1.96	-9.0%	-17.3%	China	Great Recession: The Fall of Lehman Brothers
Oct 2008	1.94	-39.2%	-49.5%	Canada	Global Financial Crisis: Market Crash
Aug 2015	1.35	-6.0%	-11.3%	China	Flash Crash, Chinese Black Monday
Mar 2011	1.09	-1.0%	-9.2%	Japan	Fukushima Nuclear Disaster
Jan 2022	1.01	-7.5%	-13.3%	Korea	Rising Concern around Russia attacking Ukraine
May 2010	1.00	-9.2%	-18.0%	Australia	European Debt Crisis / BP Deepwater Horizon
Aug 2011	0.95	-12.6%	-19.6%	India	Black Monday Global stock market crash
Jan 2016	0.92	-8.3%	-12.7%	China	Sharp oil price decline / Post COP 21 period
Aug 2024	0.92	4.0%	1.6%	India	US Black Monday: Stock Market Crash
Jun 2013	0.91	-5.7%	-9.7%	China	FED announcement to reverse quantitative easing causing global market fear
Dec 2018	0.84	-5.4%	-9.2%	USA	US Stock market and cryptocurrency crash
Feb 2020	0.80	-8.9%	-11.5%	Korea	COVID
Mar 2022	0.80	1.0%	-8.7%	China	Russian Invasion of Ukraine intensifies
Jun 2016	0.79	-3.9%	-11.0%	Europe	Brexit
Oct 2022	0.71	1.4%	-21.7%	China	20th National Congress of the Communist Party of China after re-election of Xi Jinping/ European energy crisis due to Russian Ukraine war
Nov 2009	0.64	1.4%	-4.9%	Australia	European Debt Crisis / Commodity price volatility / carbon tax legislation passed in Australia
Nov 2023	0.62	8.5%	1.7%	China	Positive trend in global equity markets / Sharp decline in commodity prices

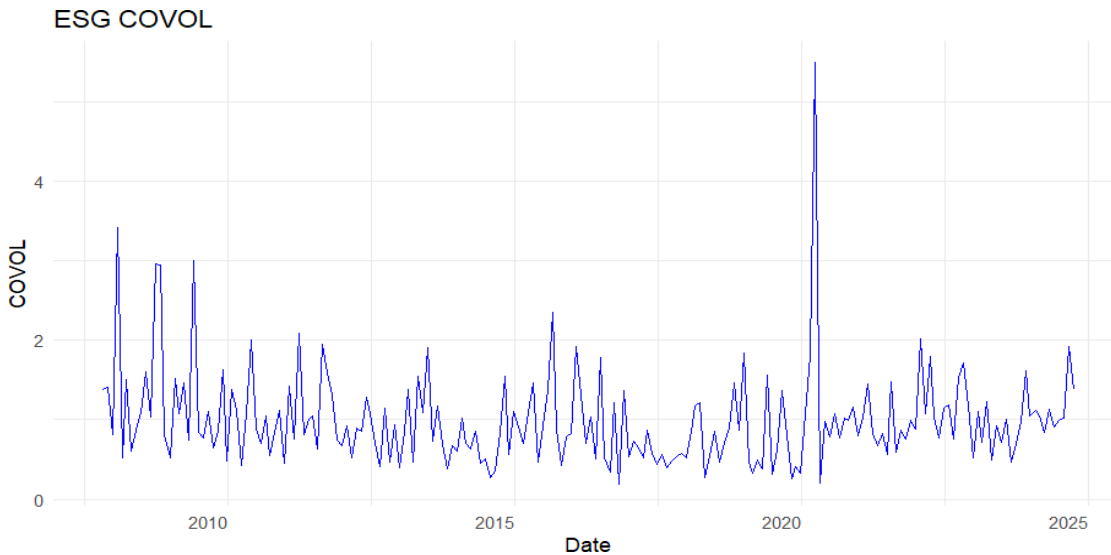


Figure 6-Evolution of the monthly ESG COVOL factor between 2007 and 2024

There are some indications that the ESG COVOL factor is sensitive to climate events, including severe natural disasters and climate policy changes, however this analysis should be further investigated with regressions, controlling for global equity market shocks, to detangle the two effects.

When looking at the region with the lowest return during high levels of f_{ESG}^{σ} we can see that the most common countries are China and Australia. These markets have suffered the most in returns during high levels of common volatility shocks, even when the causal event occurred in Europe or the USA. This verifies the fact that there is severe risk and return spillover from developed markets to emerging markets, which often results in the most disruption in developing markets. Whereas Europe was only the worst-performing market during Brexit in 2016, and Canada also only appears once in the table as the worst-performing market. These results can lead to portfolio implications, as some markets seem to be more immune in times of high volatility shock correlations, acting as a hedging tool for negative returns.

4.3.3. Factor Loadings

Table 3- Estimated factor loading (\hat{s}) for the ESG COVOL factor

<i>Region/Country</i>	\hat{s}
<i>Europe</i>	0.3832
<i>USA</i>	0.3765
<i>CSM</i>	0.3440
<i>India</i>	0.3407
<i>China</i>	0.3308
<i>Japan</i>	0.3209
<i>Canada</i>	0.3077
<i>Korea</i>	0.3074
<i>Australia</i>	0.2744

The estimated factor loadings show how much the regions contributed to the ESG common volatility shock factor. In Table 3, we can see the ESG loadings in decreasing order in magnitude of proportion of the factor’s impact on the ESG Leader’s variance. While they were not the usual worst performers in return during the highest common volatility shocks among the 8 ESG Leaders, the variance of Europe and the USA was the region that was impacted by the factor the most- in fact, more than the CSM. This is in line with the fact that many of the most severe events were taking place in the previously named developed markets, causing the highest level of uncertainty and exposure among the analysed markets. Additionally, these markets may have high exposure to the common volatility factor due to their high liquidity.

The first place of the EU is most likely granted by its dominance and recognition as a pioneer in the global ESG investment market, as it was the first region to require ESG disclosure in the financial statements of listed companies (Chen & Lin, 2022). The asymmetric effect of risk and return can be argued with the fact that as the EU leads the world in sustainable finance and investment, non-EU ESG indices are influenced by EU ESG indices.

4.3.4. Testing for correlation after extracting the ESG common variance factor

To test the goodness of the model, we carry out a third hypothesis test for the correlation of the shocks after extracting the ESG COVOL.

H0: There is no cross-sectional correlation among ESG Leader volatility shocks after estimating the COVOL.

The result of the test $\bar{p}_{s^2-1} = -0.0593$, $tstat = -21$, $p - value = 1$ indicates clearly that we cannot reject the null. This means we do not observe cross-sectional positive correlation for the squared residuals, eliminating the idiosyncratic conditional correlation and leaving only country-specific risk in the ESG markets in the standardised residuals.

4.4. Regression Analysis

4.4.1. Climate Policy Uncertainty (CPU) shocks as drivers of ESG common shocks

Figure 7 illustrates the climate policy uncertainty (CPU) levels and ESG COVOL shocks on the same graph. A noticeable shift in CPU levels occurred in November 2016, when the Paris Agreement came into force, characterised by significantly higher levels of uncertainty and more frequent spikes. Additionally, the index demonstrates an increased correlation with the ESG markets' COVOL shock factor, reinforcing the importance of further analysing CPU's impact on the common variance factor.

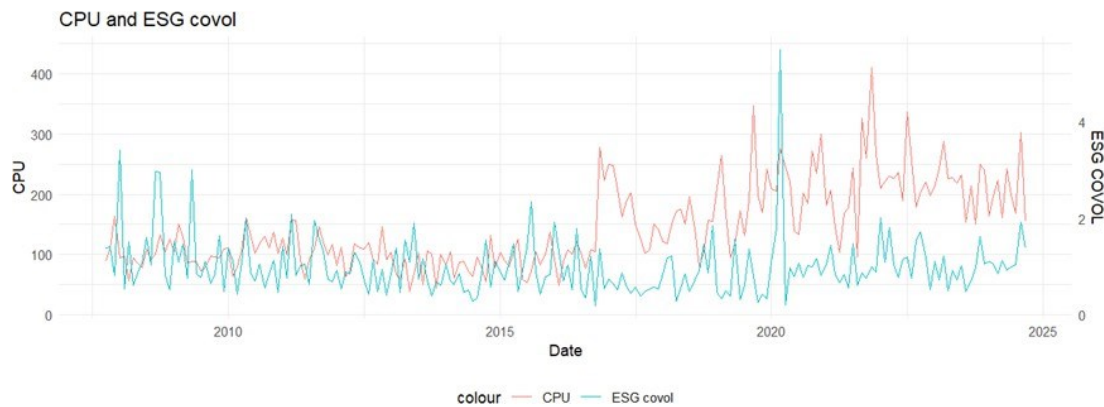


Figure 7-Evolution of CPU and the monthly ESG COVOL shocks between 2007-2024

In Table 4, we can see the results of the regression analysis of the projection of the common ESG variance on the variance shocks to climate uncertainty policy. We can observe that the CPU shocks do not seem to systematically drive the ESG Leaders variance shocks, as they are not significant, even when we separate the effects of the CPU to Pre-Paris Agreement and Post-Paris Agreement. These results indicate that CPU alone may not be a sufficient determinant of volatility in ESG markets without accounting for broader global influences.

The shocks to ACWI seem to improve the explaining power of the CPU but still do not have significant effects on the ESG common variance factor. This suggests that global market trends, while important, are not the sole mechanism through which climate policy uncertainty affects ESG volatility. A critical turning point emerges when interaction effects between global shocks and CPU shocks ($\phi_{CPU,t}^\sigma * \phi_{ACWI,t}^\sigma$) are introduced. These interaction terms reveal a significant relationship between CPU and ESG variance shocks, particularly after accounting for global events and policy-driven uncertainty. This indicates that climate policy uncertainty drives ESG market volatility more prominently when coupled with broader global financial shocks, emphasising the interconnected nature of these risks.

In columns (5) and (6), we can see that when we separate CPU effects to Pre- and Post-Paris Agreement, CPU only seemed to globally move the ESG leader markets after the climate event. This indicates that when we control for global shocks and global events that caused high policy uncertainty around climate action, CPU tends to drive the variance of global ESG markets after the Paris Agreement.

Campos-Martins and Hendry (2024) shows that media climate change concerns around regulations significantly drive the common variance movements of oil and gas share prices, as one would expect that brown companies are the most exposed to climate regulatory effects. However, our findings are also in line with the findings of Raza et al. (2024), which state that climate regulatory changes affect the volatility of sustainable markets as well through investor perception and market valuations. Given that the sustainable market is a part of ESG markets, ESG markets should also be sensitive to regulatory uncertainty. The findings verify that even though CPU should significantly impact the dynamics of brown financial assets, like the stocks of oil and gas companies, regulatory changes around climate action are also affecting the simultaneous volatility shocks of responsible markets.

These results carry important implications for regulators and policymakers. The significant impact of CPU on ESG markets, particularly post-Paris Agreement, indicates that regulatory uncertainty can destabilise markets intended to promote the transition to a low-carbon economy. Inefficient or inconsistent signalling from policymakers exacerbates volatility, potentially discouraging investment in responsible markets. Regulatory bodies should aim to provide stable and predictable policy environments to enhance investor confidence and ensure that ESG markets remain resilient and aligned with the goals of a low-carbon transition.

Table 4-Projecting the centred common ESG variance $f_{ESG,t}^\sigma$ on the variance shocks to climate uncertainty policy index

	(1)	(2)	(3)	(4)	(5)	(6)
$\phi_{CPU,t}^\sigma$	0.001	0.029			0.062**	
$\phi_{CPU,t}^\sigma * PrePA$			0.049	0.028		0.026
$\phi_{CPU,t}^\sigma * PostPA$			0.055	0.029		0.126***
$\phi_{ACWI,t}^\sigma$		0.155***		0.155***	0.168***	0.169***
$\phi_{CPU,t}^\sigma * \phi_{ACWI,t}^\sigma$					0.103***	
$\phi_{CPU,t}^\sigma * PrePA * \phi_{ACWI,t}^\sigma$						0.086***
$\phi_{CPU,t}^\sigma * PostPA * \phi_{ACWI,t}^\sigma$						0.184***
Obs	204	204	204	204	204	204
Adj. R ²	-0.292%	22.480%	0.616%	22.094%	27.741%	28.563%
F Stat	0.718	30.775***	1.640	20.415***	27.294***	17.436***

4.4.2. Climate transition- and physical risk shocks as drivers of ESG common shocks

The regression analysis in Table 5 reveals nuanced relationships between climate risk indices- specifically transition and physical risk- and the ESG common variance factor. When examined as aggregated drivers, transition and physical risks do not appear to influence the ESG factor significantly. However, when these effects are disaggregated over time, a notable shift emerges after the Paris Agreement. This time segmentation reveals significant impacts from both transition and physical risk, underscoring the evolving sensitivity of ESG markets to climate-related concerns.

The results indicate a negative coefficient for transition risk, highlighting that periods of heightened transition concerns correspond to a decrease in the ESG common variance. Campos-Martins and Hendry (2024) finds a positive coefficient for transition climate risk measures for the common variance factor of oil and gas companies, verifying that ESG markets are, in general, safer investments than brown assets in times of high transition risk. This finding indicates that responsible markets, represented by ESG Leader Indices, may act as a safe haven during the global shifts toward a low-carbon economy. Despite the increased uncertainty that the transition risk might impose- particularly for companies actively engaged in energy transition efforts- ESG markets appear to provide stability. This could be attributed to the resilience of ESG-focused investments, which benefit from diversification across industries and alignment with investor preferences for sustainable assets.

Additionally, transition risk most likely includes climate policy shifts, therefore the opposite sign of coefficient of CPU is noteworthy to mention. The reason may be that while transition risk encompasses a broad spectrum of factors, including technological advancements, regulatory shifts, and investor sentiment, it may stabilise ESG markets by aligning them with long-term climate goals, as reflected in its negative coefficient. In contrast, CPU, with its narrower focus on the unpredictability of climate-related policies, may introduce immediate volatility due to its short-term nature and direct impact on market expectations, resulting in a positive coefficient.

On the other hand, physical risk exhibits a positive relationship with ESG common variance. This finding suggests that natural disasters and other physical climate events increase the co-movement of ESG market volatilities. While physical risks are typically localised in nature, their effects extend beyond immediate regions due to the increasing interconnectedness of global markets. For instance, extreme weather events can disrupt energy supply chains and lead

to volatility in energy prices, which can cascade through ESG indices closely tied to energy-intensive sectors.

The globalisation of news and investor sentiment may amplify this effect. Localised disasters quickly become global concerns as information spreads, influencing investor behaviour and triggering risk spillovers across markets. Financial interconnectedness exacerbates the systemic nature of physical climate risks, which, although regional in origin, can drive financial volatility on a global scale.

The findings are robust, controlling for global market shocks in column (4) and (6), confirming the systematic link between climate risks and ESG markets after the Paris Agreement. Interestingly, in column (6), the explanatory power of global shock factors diminishes when interaction terms between global shocks and climate indices are included. This suggests that the primary drivers of ESG market volatility may be specific events that simultaneously elevate global uncertainty and intensify concerns about energy transitions or climate-related disasters.

Table 5-Projecting the centred common ESG variance $f_{ESG,t}^\sigma$ on the variance shocks to Climate Risk Indexes- transition risk and physical risk

	(1)	(2)	(3)	(4)	(5)	(6)
$\phi_{TRI,t}^\sigma$	-0.074		-0.073		-0.164	
$\phi_{PRI,t}^\sigma$	0.087		0.101		0.196	
$\phi_{TRI,t}^\sigma * PrePA$		0.362		0.182		0.129
$\phi_{TRI,t}^\sigma * PostPA$		-1.188***		-0.915**		-0.981***
$\phi_{PRI,t}^\sigma * PrePA$		-0.288		-0.195		-0.158
$\phi_{PRI,t}^\sigma * PostPA$		1.366***		0.948**		1.082***
$\phi_{ACWI,t}^\sigma$			0.155***	0.145***	0.667***	0.436
$\phi_{TRI,t}^\sigma * \phi_{ACWI,t}^\sigma$					-0.125	
$\phi_{PRI,t}^\sigma * \phi_{ACWI,t}^\sigma$					0.733***	
$\phi_{TRI,t}^\sigma * PrePA * \phi_{ACWI,t}^\sigma$						0.266
$\phi_{TRI,t}^\sigma * PostPA * \phi_{ACWI,t}^\sigma$						-0.678***
$\phi_{PRI,t}^\sigma * PrePA * \phi_{ACWI,t}^\sigma$						0.107
$\phi_{PRI,t}^\sigma * PostPA * \phi_{ACWI,t}^\sigma$						1.079***
Obs	195	195	195	195	195	195
Adj. R2	-0.917%	4.761%	22.163%	24.317%	30.149%	35.636%
F Stat	0.114	3.424***	19.639***	13.625***	17.969***	13.106***

5. Limitations

5.1. Limited number of ESG markets

The analysis relies on MSCI ESG Leader Indices from nine regions, constrained by data availability. While these regions provide a robust representation of global ESG markets, incorporating indices from additional regions could enhance the accuracy and representativeness of the global ESG co-movement factor. Expanding the dataset to include emerging markets or regions with unique environmental challenges may offer a more comprehensive understanding of global ESG market dynamics.

5.2. Absence of other environmental risk measures

The climate risk measures used in this study are country-specific, with CPU reflecting conditions in the United States and transition and physical risk indices focused on Europe. While these regions are fundamental in shaping global ESG markets, the reliance on localised measures may limit the explanatory power of the analysis for global ESG markets. Global climate risk measures could provide a more holistic perspective, capturing risks that exceed national boundaries and better reflecting the interconnected nature of ESG markets.

5.3. Country-specific climate-related risk measures

The "E" in ESG encompasses a wide range of environmental concerns, yet this study focuses solely on climate-related risks due to data availability and the maturity of the field. Emerging issues such as biodiversity loss and other nature-based risks are increasingly recognised as critical components of environmental sustainability. However, the underdeveloped nature of research and metrics in this area constrains the ability to incorporate these factors into the analysis. Future research could benefit from including broader environmental risk measures to provide a more comprehensive assessment of ESG market sensitivity to environmental challenges.

These limitations highlight areas for potential improvement in future studies, including broader regional representation, the development of global climate risk indices, and the integration of additional environmental risk measures. Addressing these gaps would strengthen the robustness and generalizability of findings, offering deeper insights into the factors driving ESG market volatility.

6. Future research ideas

A valuable continuation of the research would be constructing portfolios designed to hedge ESG-related risks inspired by the portfolio optimisation strategies explored in Engle & Campos-Martins (2023). By identifying assets with lower sensitivities to common volatility shocks, such portfolios could mitigate the impact of systemic ESG risks. An empirical evaluation of the performance of such ESG risk-hedging portfolios would provide practical insights for impact investors aiming to balance returns and risks with sustainability objectives. This research could also explore whether ESG-specific hedging strategies outperform traditional diversification approaches, particularly during periods of heightened global uncertainty. These advancements would deepen the understanding of risk management in ESG markets while aligning investment strategies with the transition to a sustainable economy.

In addition, an interesting continuation of the thesis would be to investigate how the sensitivity of ESG market volatility to climate-related risks evolves over time, particularly in response to major regulatory or geopolitical developments. This would help identify whether market resilience to climate risks improves with advancing ESG frameworks and policies. To illustrate the time-varying relationship between ESG volatility and climate-related risks, DCC-GARCH or GARCH-MIDAS analysis could be considered.

The DCC-GARCH model could uncover dynamic correlations between ESG markets and climate-related risks, offering insights that may improve ESG portfolio performance for impact investors. Similarly, GARCH-MIDAS analysis could examine whether climate-related risks have predictive power over ESG market volatility. Both approaches can contribute significantly to portfolio diversification and risk mitigation strategies, benefiting investors, policymakers, and portfolio managers.

7. Conclusion

This dissertation comprehensively analyses the interconnectedness and volatility dynamics within international ESG markets, emphasising their unique sensitivity to climate-related events and policy changes. By applying advanced econometric techniques, such as the common volatility model proposed by Engle & Campos-Martins (2023), the study identifies significant correlations in volatility shocks across ESG markets and investigates their primary drivers. The results confirm that ESG markets are not isolated entities but are influenced by global economic, environmental, and policy developments.

The estimated factor loadings for the ESG COVOL factor, detailed in Table 3, reveal the varying contributions of regions to the ESG common volatility shock factor. Europe and the USA emerge as the most significantly impacted, with factor loadings of 0.3832 and 0.3765, respectively, higher than the CSM factor loading of 0.3440. These results are consistent with the emergence of severe climate events and regulatory changes in these developed markets, which have increased uncertainty and market exposure. Europe's prominence can be attributed to its leadership in sustainable finance, being the first region to mandate ESG disclosures in financial statements of listed companies. In times of high ESG volatility co-movement, impact investors may use this implication and increase their portfolio weight in regions that are less sensitive to this factor, such as Australia or Korea, to increase the efficiency of rebalancing asset allocation and risk management.

This research highlights the profound influence of the Paris Agreement on ESG market dynamics, marking a turning point where all climate-related risks became significantly impactful in the aftermath of the event. The first key finding of the research is the role of climate policy uncertainty (CPU) in driving shocks to common ESG market volatility. The analysis reveals that regulatory ambiguities, particularly following the landmark agreement of the Paris Accord, can significantly increase ESG volatility co-movements. This underscores the importance of stable and predictable regulatory frameworks to minimise market disruptions and foster investor confidence in responsible markets.

Furthermore, transition and physical climate risks were shown to differentially impact ESG markets, with transition risks often acting as stabilising forces and physical risks driving heightened volatility due to their systemic nature and global interconnectedness. Transition risks were found to have a significant negative coefficient when regressed on the ESG common volatility factor after the Paris Agreement. This suggests that ESG markets, which align closely

with the transition to a low-carbon economy, act as safe investments. Notably, Campos-Martins & Hendry (2024) found the opposite for oil and gas companies, where transition-related risks positively influenced their common variance factor. This contrast emphasises that while traditional, carbon-intensive sectors face increased risk during the energy transition, ESG markets offer long-term systemic risk mitigation benefits. On the other hand, physical risk showed a positive coefficient, indicating that severe climate events still cause market disruptions by causing higher levels of global uncertainty in ESG markets. Even though the local nature of physical risk events, the influence seems to expand to several other markets, on average increasing the ESG COVOL factor after the Paris Agreement, highlighting the interconnectedness of responsible markets.

However, the research may have some limitations. The notable constraints are the reliance on region-specific climate risk indices, the limited number of ESG markets, and the focus on climate-related risks over other environmental issues like biodiversity. These gaps present opportunities for future research to deepen our understanding of ESG market dynamics and broaden the scope of risk factors. Future research could be constructing ESG risk hedging portfolios given the asymmetrical factor loadings of the COVOL and the dynamic analysis of the ESG COVOL and climate-related risks.

From a practical perspective, the findings carry critical implications for policymakers, investors, and market participants. For policymakers, the study highlights the need for coherent and transparent climate policies that align with global sustainability goals. Regulatory instability not only undermines market confidence but also poses a barrier to achieving a low-carbon transition. The results emphasise the importance of factoring climate risks into portfolio construction and risk management practices for investors. By doing so, investors can better navigate the complexities of ESG markets and capitalise on their hedging potential against global shocks.

In conclusion, this thesis contributes to the growing body of literature on ESG markets by providing novel insights into their volatility dynamics and the influence of climate-related risks. It reaffirms the critical role of ESG investments in advancing global sustainability objectives and calls for collective efforts to address regulatory and environmental challenges. As ESG markets continue to grow and evolve, their integration into mainstream finance will not only enhance market resilience but also drive meaningful progress toward a sustainable future.

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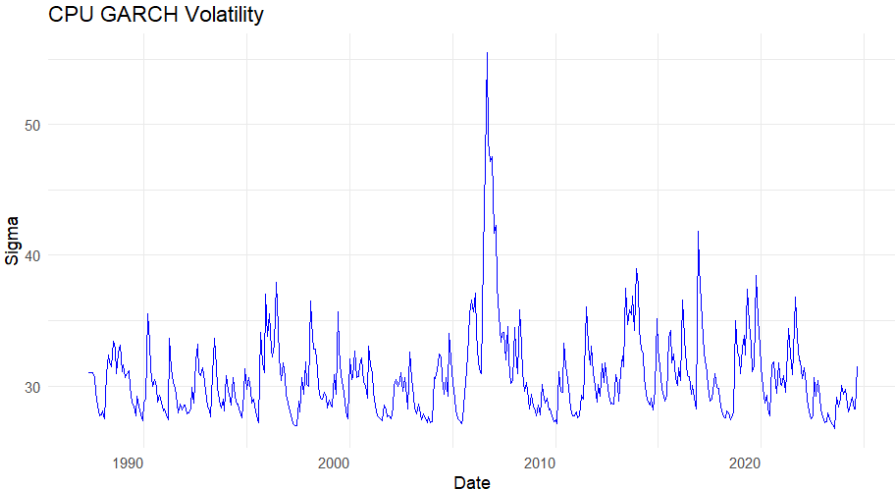
Appendix

1. Summary statistics of climate risk indices

	CPU	TRI	PRI
N	449	4952	4952
Min	-94.387	-8.148	-6.831
Mean	0.610	0.008	-0.013
Max	97.703	19.073	12.251
SD	34.997	2.386	2.117
Skewness	-0.043	0.927	0.694
Kurtosis	2.731	6.898	4.359
JB Stat	1.487	3843.853	778.634
p-value	0.475	0.000	0.000
Ar(1)	-	40.102	24.753
AR(3)	-0.929	-	-
p-value	0.051	0.000	0.000
ARCH(1)	5.736	92.576	23.551
p-value	0.017	0.000	0.000

2. GARCH volatility of the climate risk indices

a. Climate Policy Uncertainty (CPU)



b. Transition Risk Index and Physical Risk Index

