HEC MONTRÉAL

Investigating the Effect of Climate Events on Stock Market Over Time

by

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Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Applied Financial Economics (M.Sc.)

Mémoire présenté en vue de l'obtention du grade de maîtrise ès sciences en Économie Financière Appliquée

August 2023

ABSTRACT

This thesis investigates the effect of climate events and financial market dynamics, aiming to understand how these events influence market informativeness. The study analyzes the informativeness of various climate events, their implications for return and volatility of stock market, and provides policy recommendations for investors and policymakers. A novel diagnostic approach called the unbiasedness regression analysis is used to measure market informativeness around climate events. The analysis delves into essential variables, encompassing trade volume, S&P 500 return, market volatility gauged by the VIX index, and proxies representing the energy sector. This comprehensive examination serves to capture the intricate interplay between market reactions and specifically the energy sector's responsiveness to climate events. The study examines changes in R^2 from unbiasedness regressions for various periods after the events, ranging from the event day to 30 and 63 trading days afterward. The results reveal mixed effects of different climate events on the stock market. Flooding events exhibit significant excess information flow on the event day and during specific subsequent windows, indicating their considerable impact on the stock market. However, other events, such as tropical cyclones and droughts, do not show statistically significant excess information flow, suggesting a limited immediate influence on market movements. The research also explores the implications of the market's relative lack of reaction to certain climate events. Portfolio managers can prioritize their decisions and data, focusing on other critical risks in the short term, given that some climate events do not provide significant market information. This thesis contributes by helping investors and risk managers discern between climate events with varying degrees of market impact. It advocates for enhanced market surveillance and analysis of specific climate event categories to understand their influence on financial markets better. Policymakers can use the findings to encourage sustainable investment decisions and design climate-resilient financial systems.

RÉSUMÉ

Cette thèse étudie l'effet des événements climatiques sur la dynamique des marchés financiers, dans le but de comprendre comment ces événements influencent l'informativité du marché. L'étude analyse l'informativité de différents événements climatiques, leurs implications pour le marché boursier et la volatilité du marché, et propose des recommandations politiques pour les investisseurs et les décideurs. Pour mesurer l'informativité du marché autour des événements climatiques, une nouvelle approche diagnostique appelée analyse de régression sans biais est proposée. Des variables clés, telles que le volume des échanges, le rendement du S&P 500, la volatilité du marché représentée par l'indice VIX, et des proxies du secteur de l'énergie, sont analysées pour saisir les réponses du marché aux événements climatiques et la sensibilité du secteur de l'énergie aux occurrences environnementales. L'étude examine les changements dans R2 à partir des régressions sans biais pour différentes périodes après les événements, allant du jour de l'événement jusqu'à 30 et 63 jours de négociation après. Les résultats révèlent des effets mitigés des différents événements climatiques sur le marché boursier. Les événements de crues montrent un flux d'informations excédentaires significatif le jour de l'événement et lors de fenêtres spécifiques ultérieures, indiquant leur impact considérable sur le marché boursier. Cependant, d'autres événements tels que les cyclones tropicaux et les sécheresses ne montrent pas de flux d'informations excédentaires statistiquement significatifs, suggérant une influence immédiate limitée sur les mouvements du marché. La recherche explore également les implications du manque relatif de réaction du marché à certains événements climatiques. Les gestionnaires de portefeuille peuvent hiérarchiser leurs décisions et leurs données, en se concentrant sur d'autres risques importants à court terme, étant donné que certains événements climatiques ne fournissent pas d'informations significatives sur le marché. Cette thèse contribue à aider les investisseurs et les gestionnaires de risques à discerner les événements climatiques ayant des degrés variables d'impact sur le marché, préconise une surveillance accrue du marché et l'analyse de catégories spécifiques d'événements climatiques pour mieux comprendre leur influence sur les marchés financiers. Les décideurs peuvent utiliser les résultats pour encourager des décisions d'investissement durables et concevoir des systèmes financiers résilients face au climat.

ACKNOWLEDGMENT

This thesis is the culmination of years of dedicated study, and I am deeply grateful to all those who have supported and encouraged me throughout this journey. First and foremost, I extend my heartfelt gratitude to my supervisors, Professors *Vincent Grégoire* and *Tolga Cenesizoglu*. Their unwavering guidance, expertise, and encouragement have been instrumental in shaping this research and my academic growth. Their mentorship and support have been truly invaluable, and I am honored to have had the opportunity to work under their guidance.

I am also indebted to all my professors at HEC Montréal, with special thanks to Professors *Daniel Parent, Matteo Cacciatore, Jakub Hajda* and *Nathalie Elgrably*. Their enthusiasm for education and their dedication to fostering a passion for learning has motivated me throughout my studies in Canada.

I am deeply grateful to my brother, *Moe Hashemi*, who has been my constant source of motivation, support, and guidance since 2013. His belief in my potential and his unwavering encouragement have shaped my journey in research and academia, and I am forever grateful for his presence in my life. He is the primary source of motivation for me to be in Canada and continue my research. I also extend my appreciation to Professor *Taïeb Hafsi* of HEC Montréal, who not only involved me in a research project at HEC but also referred me for admission to this program at the most prestigious Canadian business school. His belief in my abilities has been a significant driving force behind my academic pursuits.

I am deeply appreciative of the support provided by the HEC Student Service staff, especially *Anaïs Grégoire*, *Nathalie Kubat*, *Marie-Laure Bailly, Marion Malique, Linda Ostiguy, Manon St-Michel, Julie Bilodeau, Gracia Nassar* , *Sonia Sahabun and Maud-Andrée Lemieux*. Their tireless efforts in assisting students have made my academic journey smoother and more rewarding. My heartfelt gratitude extends to HEC Montréal and the generous taxpayers in Canada who have made it possible for me to pursue my studies through the Tuition Fee Exemption Scholarship. This financial support has profoundly impacted my ability to focus on my academic pursuits, and I am genuinely thankful for this opportunity. A special thank you goes to the Career Management system at HEC Montréal, which has facilitated a strong relationship with the industry. Through their job fair, I found a life-changing job opportunity last October, and I am truly grateful for this remarkable platform.

I want to express my gratitude to my professors at the University of Tehran, whose dedication to teaching and mentoring from 2013 up to now has prepared me to excel in this program in Canada. I also extend my appreciation to my colleagues at Iran Fara bourse, who encouraged me to embark on this academic journey and the kind people of Iran who have funded all my studies there and helped me be here.

Last but not least, I am deeply thankful to my company and my managers, as well as my friends and family, who have been a constant source of support and encouragement. In particular, I would like to thank *Jean-Gabriel Émond, Marc-Antoine Jutras, Harp Brar, Ezequiel Bozzetti, Johnny Ramondino, Sébastien Massicotte, Gary Brazier, Hamed Mottaghi, Mohammad, Sahar, Amir, Omid, Shaghayegh, Sahel, Mohsen, Nassim, Maryam, Priska, Ali, Hamid, Rahim, Mohammad, Hadi, Yassi, Romina, Sabrina, Sarah and Catherine* for their unwavering support. Their encouragement and belief in me have played a pivotal role in shaping my academic and personal growth, and I am truly grateful for their presence in my life.

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Section 1: Introduction

The impact of climate events on financial markets is a topic that has gained significant attention in recent years. Its veracity has become irrefutable, underscored by the mounting repercussions of climate change-induced events on both the economy and financial markets (Tay, 2023).

In addition, there has been a notable increase in the frequency and intensity of extreme weather events worldwide, attributable to global warming. Canada, in particular, has experienced climate warming at approximately double the global average, amplifying the potential effects of weather catastrophes on the Canadian economy (U-Din et al., 2022a).

The changing climate poses new and complex risks to financial institutions and investors, as well as significantly impacting companies' stock prices. As such, it is essential to understand the relationship between climate events and the financial performance of companies, especially those listed in the S&P 500, a very well-followed index in the United States. Previous research[1] has demonstrated that climate events can have a significant impact on the stock prices of companies.

In another avenue of research, in recent years, there has been a growing interest in understanding the impact of climate events on companies' stock prices. The S&P 500 companies, which consist of 500 leading companies in various industries in the United States, are likely to be affected by climate events due to their global operations and supply chains. A large body of literature has investigated the impact of climate events on financial markets, but much of the research has focused on sector-level or index-level analysis.

However, there is limited research on climate events' impact on individual companies' stock prices. This is an essential area of study because the effects of climate events on companies can vary significantly, depending on the industry and the company's exposure to the events. For example, a company in the energy sector may experience a significant decrease in stock price due to the decrease in demand for fossil fuels because of climate change. In contrast, a company in the renewable energy sector may experience an increase in the stock price as demand for clean energy increases.

[1] (Feria-Domínguez et al., 2017; U-Din et al., 2022b; Wang & Kutan, 2013)

The efficient market hypothesis posits that changes in stock prices are driven by investors revising their evaluations of a company's prospective performance. Accordingly, under this theory, the stock price promptly reflects the impact of newly disseminated public information (Fama, 1970). In addition, considering the inherent efficiency of stock markets, the influence of natural hazards should manifest in short-term stock returns. These abnormal returns indicate the anticipated fluctuations in future profitability resulting from the incidence of such hazards. Consequently, numerous financial and behavioral studies have adopted event study methodologies to evaluate the repercussions of rare disasters on global financial markets. Notably, these investigations have unveiled that the pessimistic sentiment stemming from negative mood and anxiety significantly impacts the decision-making process of market participants (Pagnottoni et al., 2022), thereby exerting an influence on asset pricing (Capelle-Blancard & Laguna, 2010; Kaplanski & Levy, 2010).

Given the growing importance of understanding the relationship between climate events and stock prices and addressing this gap in the literature, this study aims to investigate the impact of climate events on the stock prices of S&P 500 companies. To do this, we will use a methodology like that used in the paper "Noisy FOMC Returns" by Boguth et al. (2022). This paper found that news events, such as Federal Open Market Committee (FOMC) announcements, impact the stock price. The authors used an empirical strategy to analyze the impact of news events on stock prices, the proposed method for measuring information flow and quantifying the amount of information revealed at FOMC announcements. The method involves regressing the total change in log prices over a pre-specified event window onto the change in log prices over subsets ranging from the window start date to an intermediate date t to distinguish between the more persistent price impact of information and the impact of noise. This approach builds on the concept of unbiasedness regressions across events, and the aim is to provide a new diagnostic tool for measuring information flow net of price noise. Compared to traditional event studies, the main advantage of this methodology is that it does not require all events to have the same directional impact (negative or positive) on price (Boguth et al., 2022).

In this study, we use a similar approach to investigate the impact of climate events on the stock market and use S&P 500 indices as a proxy. To make the analysis more robust, we start with S&P 500 index and later expand our model with sub-indices. Using data from various sources, including climate databases, news articles, government reports, and financial data, we use similar logic to analyze the relationship between climate events and stock prices. This allows us to quantify the impact of climate events on the stock prices of S&P 500 firms and to identify the factors that influence the relationship between climate events and stock prices to quantify information flow net of price noise.

More specifically, we aim to determine whether climate events lead to elevated returns, volatility, and trade volume due to the release of fundamental information or noise trading. To measure the information flow net of price noise around events, we propose a new diagnostic and use it to quantify the amount of information revealed during climate events. We distinguish between information and noise by analyzing the more persistent price impact of information relative to that of noise.

Our approach is based on unbiasedness regressions across events (Boguth et al., 2022), where we regress the total change in log prices (or indices level) over a pre-specified event window onto the change in log prices (or indices level) over subsets ranging from the window start date to an intermediate date t. We rely on bootstrap analysis to test the null hypothesis that climate event days reveal at least as much information as other days. We implement two bootstrap approaches: First, we resample the days within each climate event window. Second, for each climate event, we sample corresponding placebo events matched by calendar quarter and day of the week.

To account for possible differences in return informativeness across days of the week, we match the placebo events to the same days of the week as climate events.

Returns that decrease price informativeness constitute noise in the price formation process and must necessarily revert in the future. We want to investigate whether the noise arises from price pressure related to the heightened trade volume following climate events. We use aggregate daily ETF fund flows to predict price reversals following climate events as a proxy for price pressure in equity markets.

The study considers the following climate events: flooding, tropical cyclone, drought, freeze, severe storms, winter storms, and wildfires. These events were chosen because they are the most frequent and damaging climate events in the United States. They have been the subject of a large body of research and have been categorized by National Oceanic and Atmospheric Administration (NOAA) in the USA.

The data for this study is obtained from various sources, including news articles, government reports, and weather data. Climate event data be used to identify the impact of specific climate events on the stock prices of S&P 500 companies. The study uses the S&P 500 Index data from January 1, 1980, to December 31, 2022, and the climate event data from January 1, 1980, to December 31, 2022.

The general framework for our regression model would involve the following steps:

- **Data preparation:** This step involves cleaning and transforming the data to ensure that it is in a format that can be used in the analysis. For example, the stock return data may need to be transformed to ensure that it is in a consistent format, such as converting it to log returns. Additionally, the climate event data may need to be transformed to ensure that it is in a format that can be used in the analysis, such as converting it to a binary variable that indicates whether a climate event occurred on a given day.
- **Model specification:** In this step, the statistical model is specified. This would involve including variables that capture the relationship between climate events and stock prices and any confounding variables that may affect the results. For example, the model may include variables that capture the timing and intensity of climate events, as well as variables that capture the overall economic conditions, such as the interest rate and GDP.
- **Hypothesis testing:** The hypotheses developed in the theoretical framework are tested in this step. This would involve testing the relationship between climate events and stock prices and the effect of any confounding variables. Various tests, such as t-tests and F-tests, can be used to determine the statistical significance of the results.
- **Interpretation:** In this step, the analysis results are interpreted and discussed. This would involve discussing the magnitude and direction of the relationship between climate events and stock prices and the effect of any confounding variables. Additionally, the results of the hypothesis testing are discussed, and the implications of the results are explored.

This thesis contributes to the literature by providing new insights into the impact of climate events on the stock prices of individual S&P 500 companies. The study also provides valuable information for investors and policymakers, who can use this information to make informed investment and policy decisions. The results of this study could also have implications for companies, as they may be able to use the information to manage their exposure to climate events better and minimize the impact of these events on their stock prices.

Overall, this thesis provides valuable insights into the impact of climate events on the stock prices of S&P 500 indices and contributes to our understanding of the effects of climate change on financial markets. The study can account for the time-varying volatility of stock returns and provide a more accurate picture of the impact.

Section 2: Theoretical Background

2.1 Climate Change Importance in Finance

The pursuit of long-term sustainable economic development necessitates the adoption and implementation of environmentally friendly and clean technology on a wide scale, while simultaneously safeguarding our environment (Yu et al., 2022). Devastating climatic transformations, such as escalating temperatures, intensifying floods, and protracted droughts, constitute pivotal catalysts that instigate infrastructure degradation and potential disruptions to business operations. Recent investigations in climate finance have substantiated the profound risks entailed by climate change to the stability of the financial system. In response, the seminal Paris Agreement of 2015 delineated a comprehensive framework of preventive measures designed to restrict global warming to below two °C above pre-industrial levels, with further concerted endeavors aimed at containing the increase below 1.5°C by the year 2050 (Tay, 2023).

Within the context of our study, it is evident that renewable energy projects face challenges in accessing adequate financial resources. However, the emergence of digital finance presents an opportunity to bridge this gap in green finance. In the study of Yu et al. (2022), a comprehensive examination is conducted using panel data from 60 emerging and non-emerging economies spanning the period of 2010 to 2020. This research provides valuable insights into the potential of green digital finance as a catalyst for climate change mitigation.

Enhancing our comprehension of clean energy resources, fostering technological development, and cultivating adaptability in the transition toward their widespread adoption are pivotal factors for achieving sustainable growth (Lang et al., 2021). Due to growing concerns toward climate change, there is a high attention to clean energy and carbon neutral economy. In this regard, the research of (Chen et al., 2021) directly contributes to the central focus of our research. By examining the intricate relationship between climate change and its potential influence on clean energy investment, this study sheds light on a crucial link that indirectly affects the stock market.

2.2 Climate Events and Stock Market

We start by exploring the relationship between environmental, social, and governance (ESG) factors and stock prices. ESG factors have gained significant attention in recent years as they are seen as crucial determinants of a company's long-term financial performance. Climate change and its impacts are considered among the most critical ESG factors, and several studies have investigated its effect on stock prices.

Studies that have examined the relationship between climate events and stock prices have found that the impact of such events on the stock market can be both positive and negative. For instance, the literature has shown that natural disasters such as hurricanes, typhoons, and earthquakes can lead to significant decreases in stock prices. Schuh & Jaeckle (2022) found a statistically significant negative correlation between the cumulative abnormal return and the damage caused by the hurricane.

Feria-Domínguez et al. (2017) examined the impact of hurricanes on the stock prices of companies in NYSE and found that the returns were negatively affected by hurricanes. U-Din et al. (2022a) investigated the impact of extreme weather events on the Canadian stock market between 1988 and 2016. They examined the effect of these events on the Toronto Stock Exchange (TSX) composite index and its subsector indices using a combination of accounting ratios and statistical tests. They found that extreme weather events significantly negatively impact stock market returns and volatility, with the effect being noticeable the day after the event. The study also reveals that all market sub-sectors are impacted, with the I.T. and financial services sectors being the most affected and the consumer staples sector is the least. The authors conclude that the impact of global warming in Canada is higher and more widespread than in other economies.

Moreover, research has also shown that the impact of climate events on stock prices can be influenced by factors such as the event's severity, the company's location, and the sector in which the company operates. For instance, in the study of Wang & Kutan (2013), the authors examine the effect of natural disasters on the insurance sector and the composite stock market in Japan and the U.S. They assess natural disaster risk and wealth using GARCH models. The composite stock markets in the U.S. and Japan show no wealth effects, suggesting they can mitigate the effects of natural disasters on stock returns. However, the study finds significant wealth effects in the insurance sectors in the U.S. and Japan, with U.S. investors experiencing losses while Japanese investors see gains. In addition, the results show that all markets except for the composite stock market in Japan face risk effects from natural disasters.

A variety of climate-related disasters can serve as useful proxies for the risks associated with climate change. Pagnottoni et al. (2022) conducted a thorough analysis of 104 countries' worth of climate disasters across four categories: biological, climatological, geophysical, hydrological, and meteorological. The authors examined 27 global stock market indexes from February 8, 2001, through December 31, 2019, and found that financial markets' responses to shocks resulting from environmental hazards vary depending on the kind and location of the occurrence. International financial markets reacted in different ways to biological and climatological disasters. The effects of climate change on stock prices were more pronounced than those of biological factors, which had a generally favorable effect on market indexes. The research also showed that natural disasters such as floods and droughts have a relatively small impact on the value of international stock markets. Stock indexes tested showed heightened sensitivity to shocks within European countries, nevertheless.

In addition to the direct effects of climate events on specific sectors, studies have investigated the impact of climate change policies and regulations on stock prices. For instance, (Birindelli & Chiappini, 2021) examined the impact of European Union climate change policies on shareholder value from 2013 to 2018. Using the event study method, the results indicate that all sectors were affected by at least one climate policy announcement, with adverse effects being more prevalent than positive ones, especially after implementing the Paris Agreement. Positive effects were observed only in the most environmentally committed firms before the agreement. The results from data panel regressions suggest that the company's sector was a significant determinant of market reactions to climate policies rather than its environmental commitment. The study provides new insights into the relationship between environmental regulation and equity investor value. It sheds light on the role of a company's environmental commitment in mitigating the impact of regulations.

Ziegler et al. (2009) also investigated the relationship between corporate actions to address climate change and stock performance. By analyzing the U.S. and Europe stock markets over different sub-periods, the authors examine the influence of the prevailing climate policy regime. They compare the risk-adjusted returns of portfolios made up of corporations with varying levels of responses to climate change and apply both a flexible four-factor model and a one-factor model based on the Capital Asset Pricing Model. The results show negative relationships between climate change actions and stock performance over the entire observation period of 2001 to 2006. However, a trading strategy of investing in corporations with a higher level of responses to climate change led to positive abnormal returns in regions and periods with stringent climate policies.

A systematic literature review by Venturini (2022) critically examines the notion of climate change as an additional source of market risk, delving into the essential data requirements for analyzing the drivers of climate risk that shape the dynamics of the equity market. In this study, empirical evidence is presented at both the macro and micro levels, focusing on whether and to what extent the equity market incorporates climate change and its associated risks in its pricing mechanisms. Comparative analysis is conducted between top-down and bottom-up approaches to discern which climate risk factors are more likely to impact the cross-section of stock returns, both within and across sectors. Furthermore, the study highlights the significance of investors' perceptions and beliefs concerning climate change risks and investigates the implications of these factors on asset pricing. Ultimately, the article concludes by outlining potential avenues for future empirical and theoretical research within the domain of climate finance.

Another avenue of research that has investigated the impact of climate events on stock prices has focused on the role of media coverage. Several studies have found that the media can play a crucial role in shaping public opinion and investor sentiment regarding climate events and their potential impact on the stock market. The literature has shown that media coverage of climate events can lead to increased public awareness and heightened concern about the impact of such events on the financial sector, resulting in changes in stock prices. For instance, Ye (2022) examines the impact of climate news risk on uncertainties, including energy market uncertainty, economic policy uncertainty, and financial market uncertainty, using the Wall Street Journal Climate News Index. The study finds that the effect of climate news risk on uncertainties varies in the short, medium, and long terms, with the most significant impact in the short term. It also reveals that climate news risk has a positive effect on economic policy uncertainty, a negative effect on energy market uncertainty, and its effect on financial market uncertainty changed from negative to positive after 2013. The study finds that climate news risk significantly impacts economic policy uncertainty during U.N. Climate Change Conferences in Copenhagen, Doha, and Paris.

Furthermore, Ho (2022) examines the impact of climate change on the performance of mutual funds. The authors find that mutual funds with a high exposure to climate change news tend to perform better, with a risk-adjusted outperformance of 0.24% per month, compared to those with a low exposure. This is because high climate news beta funds have more investments in stocks that can hedge against climate change risk, and these stocks show higher excess returns and better financial performance.

This concern has got more attention in developing countries like China. For example, the study of Cao et al. (2015) aims to examine the effects of unexpected climatic events, both domestic and international, on the Chinese stock market, utilizing event analysis as the methodological framework. The sample consists of 21 industry-specific indices from the Shenzhen Stock Exchange in China. Specifically, the study compares the impacts of climatic events that occurred in China and the USA on the Chinese stock market. The findings reveal significant effects of meteorological disasters, such as the snowstorm in 2008 and the strong tropical storm in 2011 in China, as well as the hurricane in 2005 and the snowstorm in 2006 in the USA, on the Chinese stock market. Notably, the study identifies variations in the influence of these disasters on the Chinese stock market, with unexpected domestic climatic events exhibiting a more pronounced effect on market volatility compared to those that occurred in the USA. Furthermore, the research demonstrates that the same climatic event can yield different effects across various industries, while different climatic events can elicit diverse impacts within the same industry in China. It is worth noting that the influence of these events on industries may evolve over time.

In conclusion, previous studies have shown that climate events can significantly impact the stock market, both directly and indirectly. While some studies have found that climate events can lead to decreases in stock prices, others have shown that they can have a positive impact. The literature has also highlighted the role of media coverage in shaping public opinion and investor sentiment regarding climate events and their impact on the stock market. As such, it is crucial to consider these factors when researching climate events' impact on stock prices.

The study of Chun et al. (2022) explores the relationship between carbon-intensive fuel prices and renewable energy stock prices, incorporating the price of carbon in the EU-ETS. They use wavelet analysis to adjust time series and regression analysis to consider exogenous factors. The results show a negative impact of coal prices on renewable energy stock prices, which is explained by a negative correlation between coal and carbon prices and a positive correlation between carbon prices and renewable energy stock prices. The study provides a new perspective on the relationship between carbon-intensive fuel prices and renewable energy stock prices using filtering methods.

In their study, Kruttli et al. (2021) present a framework to understand the stock market response to uncertainty caused by extreme weather events and their economic impact. The study focuses on the stock options of firms in hurricane landfall regions and finds that implied volatility increases significantly due to the uncertainty related to these events' incidence and economic impact. Increases in idiosyncratic volatility are associated with positive expected stock returns. The authors also find that investors often underestimate this uncertainty, but after the landfall of Hurricane Sandy, this underreaction decreases.

The investigation of the effect of climate events on stock prices has received growing attention from researchers in recent years. Several studies have been conducted to examine the impact of climate events on various aspects of the financial market, including stock prices.

In addition to temperature and extreme weather events, studies have also investigated the impact of climate change on the stock market. Gillingham et al. (2015)found that companies in the carbon-intensive sectors are more vulnerable to the impacts of climate change, while companies in the renewable energy sector are likely to benefit from the transition to a low-carbon economy.

Moreover, several studies have investigated the impact of policy-related events on the stock market. For example, a study by Gillingham et al. (2018) found that the announcement of climate policies has a significant impact on the stock prices of companies in the carbon-intensive sectors. The authors found that companies in these sectors experience a decrease in stock prices following the announcement of climate policies as investors react to the increased regulatory risk associated with these policies.

Simonides et al., (2010) have explored the relationship between stock market volatility and weather-related factors, such as cloudiness, temperature, and precipitation, as well as environmental factors, such as nighttime length. The findings indicate that cloudiness and nighttime length negatively correlate with historical, implied, and realized volatility measures. The association between these factors and stock market volatility appears to differ based on the exchange's location concerning the equator. Additionally, weather deviations from seasonal norms and extreme weather conditions do not appear to impact the results significantly.

Antoniuk & Leirvik (2021) study used event study methodology to investigate the impact of unexpected political events on climate-sensitive sectors. The results showed that events related to climate change policy significantly affected returns, with the clean energy sector benefitting from increased awareness and favorable policies. In contrast, the utilities, energy-intensive, and transport sectors faced increased risks. On the other hand, events weakening climate change policy led to positive returns for the fossil energy sector. The study also found that stock market investors quickly adapted to new information related to climate change, and policymakers should be aware of these impacts on the stock market. In addition to the studies mentioned above, several other studies have investigated the impact of climate events on the stock market, including studies on the effects of floods, heat waves, and natural disasters. These studies have generally found that climate events have a significant impact on the stock market, with the effects varying depending on the type and severity of the event and the sector in which the companies are operating.

In summary, the literature on the impact of climate events on the stock market is growing and suggests that climate events have a significant impact on the stock market. However, the results of these studies are mixed, with some studies finding positive effects and others finding negative effects. This highlights the need for further research to examine the impact of climate events on the stock market, particularly considering the increasing frequency and severity of climate events.

In comparison to previous studies, our methodology provides a framework for studying the effect of the news on financial markets and allows us to examine the impact of climate events on S&P 500 indices in a more rigorous manner. The results of our study provide valuable insights into the relationship between climate events and the financial market and contribute to the existing literature in this area.

Section 3: Methodology

In this study, we aim to investigate the impact of climate events on the stock prices of S&P 500 companies. To achieve this goal, we use an event study methodology, widely used in literature, to study the effect of various events on financial markets (Brown & Warner, 1985; Fama, 1990).

In this paper, we propose a new diagnostic to measure the net information flow around climate events and use it to quantify how much information is revealed during these events.

Utilizing the method developed by Boguth et al. (2022) to measure the net information flow around climate events, we build on the unbiasedness regression approach proposed in previous research that evaluated the impact of macroeconomic information releases on stock markets. This approach regresses the total change in log prices over a pre-specified event window onto the change in log prices over subsets ranging from the window start date to an intermediate date t. This allows us to distinguish between the more persistent price impact of information and the impact of noise in price formation. Moreover, this method focuses on changes in R^2.

To test our hypothesis, we rely on bootstrap analysis. Specifically, we test the null hypothesis that climate event days reveal at least as much information as other days. We implement two bootstrap approaches: first, we resample the days within each climate event window. Second, for each climate event, we sample corresponding placebo events matched by time of year and day of the week. This sample accounts for possible differences in return informativeness across days of the week. Notably, the event days in this sample do not typically react to climate events other than by chance.

In our study, we use a similar approach to investigate the effect of climate events on the stock price of S&P 500 indices. The hypothesis is that climate events can impact stock prices. However, the effect may be limited due to the noise in the market and the difficulty in separating the information in the news from other market factors.

To test this hypothesis, we collect data on climate events and daily stock returns of S&P 500 companies. We use econometric techniques to estimate the impact of climate events on stock prices, controlling for other factors that may influence stock prices.

3.1 Theoretical Framework and Empirical Model

The first step in the empirical method would be to identify the dates of climate events and to classify them based on their intensity.

While climate events are often associated with increased information content, it is essential to consider the potential introduction of noise in observed prices as well. Such noise can either overshadow or magnify the effects of information flow on financial markets, and the dominance of either factor is contingent upon the specific event and asset under consideration.

Noise, within the context of financial markets, pertains to the discernible discrepancies observed between asset prices and their corresponding efficient counterparts or fundamental values. Additionally, in this method, we assume that all information is reflected in the price. It is important to note that at the start of the event window, the price may not yet incorporate the effects of the event. However, by the end of the window, all relevant effects are fully integrated into the price, providing a comprehensive view of the market's response to climate events (Boguth et al., 2022). This approach allows for understanding the interplay between information and market noise, shedding light on the intricate dynamics during climate events.

Identifying this noise holds significant implications for research endeavors aimed at deciphering the impact of various factors on financial markets. It is important to note that the regression analysis results only provide evidence of a relationship between climate events and stock returns and do not prove causality.

3.1.1 Unbiasedness Regression:

In this empirical approach, it is assumed that the price after the observation window corresponds to the fundamental value. Also, we should clarify that in assumptions, all information are reflected in the price before event starts. This assumption serves as a basis for assessing the impact of Climate Events on equity prices. The advantage of this approach lies in its independence from a pre-determined measure of unexpected news. Furthermore, it is essential to note that the precise influence of Climate Events on equity prices remains unknown before they occur, necessitating the measurement of their effects post-event or by examining price reactions in related markets, such as futures or derivatives.

Boguth et al. (2022) argue that this context enables a clear distinction to be made between information and noise in price dynamics. Variance ratios are employed to encapsulate the information contained within autocorrelations at various frequencies, while excess ΔR^2 is analyzed to evaluate the information content of prices. Additionally, we test the potential introduction of noise into the price process and subsequent under- or over-reaction resulting from significant information flow during Climate Events.

One significant advantage of this methodology, as opposed to traditional event studies, is its ability to measure information flow net of noise in event studies. Conventional event studies often depend on metrics related to unexpected news or assumptions regarding noise reversion over a specific time horizon. These approaches can introduce biases and limitations. In contrast, the proposed methodology utilizes a diagnostic tool that does not rely on a pre-defined measure of unexpected news. This approach offers a more comprehensive understanding of the underlying sources of price movements and the impact of events (Boguth et al., 2022).

The empirical method for this Thesis would involve testing the hypothesis that we have developed through statistical analysis of our data.

Let time be represented by the index t, and consider a climate event, such as a significant climate occurrence, taking place at the normalized event time t = 0. We establish fixed time windows $[T_1, T_2]$ surrounding the event, where $T_1 < 0$ and $T_2 > 0$ indicate periods before and after the event, respectively. Assuming a collection of events indexed by *i*, let $p_{i,t}$ denote the logarithm of the market's cum-dividend closing price on date *t*. We perform a regression analysis, examining the overall return within the entire window from T_1 to T_2, based on partial returns observed over intervals commencing at T1 and ending at dates t ∈ {T1 + 1, T1 + 2, ..., T2}.

$$p_{i,T2} - p_{i,T1} = \alpha_t + \beta_t \left(p_{i,t} - p_{i,T1}\right) + \varepsilon_{i,t} \quad (1)$$

where $p_{i,T2}$ and $p_{i,T1}$ are the log prices at the end and beginning of the window, respectively, and $p_{i,t}$ is the price at time t within the window. We assume that price at the end of the window is equal to the fundamental value, which allows them to evaluate the impact of climate events on equity prices. We use this method to evaluate the impact of climate Events on equity prices and to assess the evolution of price informativeness over time.

The coefficient β_t has garnered significant attention in previous research. Precisely, in the context where log prices follow a random walk with drift, it has been established that β_t equals 1 for all time periods, t.

Following the literature, we can conclude that when the coefficient β_t is equal to 1, the partial return from T1 to t serves as an "efficient" forecast for the complete window return from T1 to T2. This implies that no amplification or reduction of the partial return can enhance the accuracy of the forecast, as it already captures the complete information. However, when β_t is less than 1, the partial return is either attenuated or partially reversed in the total return. This phenomenon is often interpreted as a manifestation of price noise, a temporary element in prices, or an indication of "overreaction." On the contrary, when β_t is greater than 1, the partial return is magnified in the total return. This suggests the presence of "underreaction" or slow information processing. In such cases, the market appears to inadequately incorporate or respond to new information, resulting in a delayed adjustment of prices. (Barclay & Hendershott, 2003; Boguth et al., 2022; Mincer & Zarnowitz, 1969)

The interpretation of deviations from β_t = 1 as evidence of noise or underreaction relies on the assumption that short-run risk premia are adequately captured by the regression intercepts αt. This assumption is explicitly acknowledged by Biais et al. (1999). They explain that their framework allows for the inclusion of risk premia in the intercept as long as they remain constant across the sample events (Boguth et al., 2022).

In our analysis, we extend this framework by allowing the intercepts α_t to vary with event time, accommodating the possibility of different risk premia associated with specific event days, such as climate events, compared to other days. This flexible approach aligns with the modelling approach proposed by Ai et al.(2018), who consider, for instance, higher risk premia on climate event days.

It is important to emphasize that the intercepts in Equation 1 can effectively capture time-varying risk premia, provided that the variation is solely a function of event time. However, it should be noted that other forms of time-varying risk premia, such as those related to higher risk premia following low returns or vice versa, may result in estimates of β that deviate from one.

Consequently, distinguishing between such risk premia and noise becomes challenging (Boguth et al., 2022).

While previous studies have primarily focused on the beta coefficients obtained from regression (1), our analysis places a greater emphasis on the regression R^2. As our study pertains to an event study scenario where specific information is released at date t = 0, it is natural to expect that more information regarding the total return from T1 to T2 is incorporated into prices on the event date compared to other dates (Boguth et al., 2022).

The beta coefficients (β_t) do not directly capture the differences in the amount of information across days but rather reflect the persistence or reversal of price changes. On the other hand, the regression R^2 encompasses all the channels that contribute to greater price informativeness. For instance, if date t = 0 contains a significant amount of useful information about future prices, we might observe a spike in the R^2 on that date, even if there is no change in the value of β_t (Boguth et al., 2022).

We utilize the coefficient of determination (R^2) as a measure to evaluate the level of price informativeness surrounding climate events. They conduct a regression analysis, estimating a model that regresses daily stock returns on control variables, including lagged returns, market volatility, and macroeconomic indicators. By calculating the R^2 of the regression, they quantify the proportion of the variation in stock returns that these control variables can explain. The R^2 serves as a metric to gauge the degree to which stock prices convey information about future prices.

In other words, to assess the impact of climate events on price informativeness, we compare the R-squared values on climate event days to those on non-event days. This comparative analysis allows us to evaluate how climate events affect the overall level of price informativeness. Their findings indicate a decline in price informativeness on climate event days, which persists for approximately two weeks following the events. This implies that climate events dampen the overall level of price informativeness in the market.

To compute excess ΔR^2, the authors define it as the ΔR^2 from unbiasedness regressions presented in Equation (1) computed using S&P 500 returns minus 1/T, where T is the number of trading days in the full window of the unbiasedness regression. If the information flow is above normal on a given day, as expected on the event day, the corresponding ΔR^2 should exceed 1/T.

Boguth et al. (2022) conclude that the unbiasedness regression R^2 exhibits several characteristic properties. It is a function of t, where R^2_t begins at zero and reaches one when t = T2, representing the start and end points of the analyzed period. The specific trajectory of R^2_t is determined by the interplay between information flow and noise in prices.

In their scenario where there is a constant information flow without noise, such as when prices follow a random walk, R^2_t increase linearly from zero to one. This implies that as more information becomes available over time, the R^2_t value progressively captures a greater proportion of the variation in stock returns. Another scenario worth considering is when β_t is consistently equal to one, indicating that partial returns do not undergo amplification or reversal. However, heteroskedasticity in returns implies that some days contain more information than others. In such cases, the change in R^2 as t increases reflects the release of information. Higher information days are expected to exhibit more significant increases in R^2 (Boguth et al., 2022).

However, these results can be influenced when β_t deviates from one. Generally, if a day's return experiences partial reversal by T_2, the increase in R^2 may be smaller compared to the random walk case. In situations where a day's returns are fully reversed by T_2, the R^2 plot remains flat, indicating limited information content.

Therefore, the authors utilize the unbiasedness regression R^2 as a convenient summary measure of the information contained within various partial return windows. It allows for a comprehensive evaluation of the information content available at different time points, considering both the presence of noise and potential deviations of β_t from one.

3.2 Research Setting and our Event Study Steps:

3.2.1 Step 1: Data collection

The first step in our analysis is to collect the necessary data, as mentioned before.

Climate Event Data: To study the impact of climate events on stock prices, it is necessary to identify the relevant climate events. For this study, we use the National Oceanic and Atmospheric Administration (NOAA) database is widely used in literature to study the impact of climate events on various economic variables. We select the relevant climate events based on their severity and economic impact. For example, we include extreme weather events such as hurricanes, floods, and droughts that have had a significant impact on the economy.

The NOAA and the National Centers for Environmental Information (NCEI) are two primary sources of climate event data. NOAA is a scientific agency within the U.S. Department of Commerce that provides data and information on various environmental phenomena such as weather, climate, oceans, and coasts. NCEI is a division of NOAA that archives and provides access to environmental data and information. The information available from NOAA and NCEI includes the dates and intensity of various climate events such as hurricanes, floods, droughts, and heatwaves. This data can be used to quantify the impact of climate events on the stock price of the S&P 500 Index.

Stock Price Data: To study the impact of climate events on the stock prices of S&P 500 companies, we collect historical daily stock price data for each of the S&P 500 companies. The S&P 500 Index provides daily stock returns of the S&P 500 companies. It is a market-capitalization-weighted index that tracks the performance of 500 large companies listed on the stock exchange in the United States. The S&P 500 Index is a good representation of the overall U.S. stock market and is widely used as a benchmark for large-cap U.S. stocks. The stock market data for the S&P 500 Indexes are available from various financial data providers such as Yahoo Finance, Google Finance, and Bloomberg.

3.2.2 Step 2: Event definition and event window

Next, we define the climate events that we want to study. Following Boguth et al. (2022), we define the events as the occurrence of a severe weather event, such as a hurricane or drought, in a specific geographic location. We also record the date and time of the event to allow us to measure the impact on stock prices.

Defining the event window is a crucial step in conducting an analysis of the impact of climate events on the stock market. The event window refers to the period around the climate event of interest during which we expect the market to respond to the event. To determine the optimal event window, we need to consider the duration of the climate event and the potential lag between the event and its impact on the stock market.

The subsequent phase involves determining the event windows for each climate event. The event window is defined as the timeframe during which the event's impact will be assessed. In this study, the chosen event window spans 83 days, encompassing 20 days prior to the event and 63 days following the event. These 83 days represent approximately one calendar month before and one quarter after the event day.

3.2.3 Step 3: Analyze information flow.

To analyze the information flow around climate events, we propose using the diagnostic introduced by (Boguth et al., 2022). The method distinguishes between persistent price impact from information and noise using unbiased regressions across events. It involves regressing total log price change during a specified event window onto log price changes over subsets from window start to an intermediate date t.

This approach quantifies information versus noise impact at climate events. Distinguishing them is vital, as noise decreases price informativeness and requires reversion. This separation is crucial for accurate climate event impact analysis on the stock market. The diagnostic uses bootstrap analysis to test whether climate events reveal as much information as other days. Two bootstrapping methods are employed: resampling days within each event window and sampling placebo events matched by calendar quarter and day of the week. Climate event windows are defined as periods around the event (e.g., one week before and after), given their irregular scheduling.

3.2.4 Step 4: Regression analysis

In this Thesis, we will use an unbiasedness regression analysis to measure the effect of climate events on stock prices. The analysis involves regressing total log price change over an event window onto log price changes over subsets from the window's start date to an intermediate date t. This quantifies fundamental information revealed during the event.

The approach is based on the principle that fundamental info's price impact is more persistent than noise. The authors differentiate these by analyzing the relative persistence of information's price impact. The unbiased regression involves selecting an event window, collecting stock price data within it, and dividing it into subsets from start to intermediate date t. Changes in log prices (or indices) relative to each subset's beginning are calculated, and then regressed against the total change over the event window. The regression aims to identify fundamental price information revealed during the event window, considering noise. This analysis is applied across events to gauge information flow around them.

3.2.5 Step 5: Bootstrap analysis

To test the null hypothesis that climate event days reveal at least as much information as other days, we propose to use bootstrap analysis. This method utilizes unbiasedness regressions across events. It regresses the total log price change during a predefined event window onto log price changes within subsets from the window's start date to an intermediate date t. The difference between total log price change and the sum of subset changes denotes noise trading's impact during the event window.

To execute the bootstrap analysis, we adopt the methodology of Boguth et al. (2022). Firstly, we resample days within each climate event window to derive the null hypothesis's test statistic distribution. This approach estimates the test statistic's sampling distribution without assuming any specific distribution.

Secondly, we employ a stricter test using placebo events as a comparison. For each climate event, we sample matched placebo events by calendar quarter and day of the week. This accounts for potential variations in return informativeness across different days. Placebo events are assumed to react to climate events only by chance. The test statistic for the actual climate event is then compared against the distribution from placebo events. By employing these bootstrap methods, we ensure the robustness of results under different null hypotheses. Sensitivity to event window choice and intermediate period t length is also tested. Crucially, this approach distinguishes persistent price impact from information and noise, quantifying information revealed during climate events (Boguth et al., 2022). In essence, we propose using two bootstrap approaches to test the null hypothesis that climate event days reveal information equivalent to other days.

3.2.6 Step 6: Identifying the noise or information

We define noise as returns that decrease price informativeness and must necessarily revert in the future. They distinguish noise from the more persistent price impact of information by using unbiasedness regressions across events. These regressions allow us to regress the total change in log prices (or index level) over a pre-specified event window onto the change in log prices over subsets ranging from the window start date to an intermediate date. More specifically, to identify noise, we will start by analyzing the impact of climate events on stock prices and returns using unbiasedness regressions across events. The total change in log prices over a pre-specified event window could be regressed onto the change in log prices over subsets ranging from the window start date to an intermediate date.

After identifying the subsets of data that represent the price impact of fundamental information and the subsets that represent noise, we will then analyze the characteristics of the noise. For example, we examine the relationship between trade volume and noise, similar to Boguth et al. (2022). Additionally, we analyze the relationship between noise and specific climate events, such as hurricanes or wildfires, to determine if certain types of events are more likely to result in noise in the price formation process.

Section 4: Data Analysis and Findings

4.1 Climate Data Analysis

We start with providing the summary statistics which help us understand the economic impact, temporal dynamics, and relative occurrence of climate event types. This data helps policymakers, researchers, and stakeholders make informed decisions, design targeted interventions, and create effective climate change mitigation and adaptation strategies.

We examined event types of total damage from 1980 to 2022 to determine climate events' economic impact. The first graph shows the financial effects of these events in Million Dollar CPI adjusted. Figure 1 shows damage variations across event types. This information is crucial for understanding climate events' financial impacts and their potential effects on affected regions.

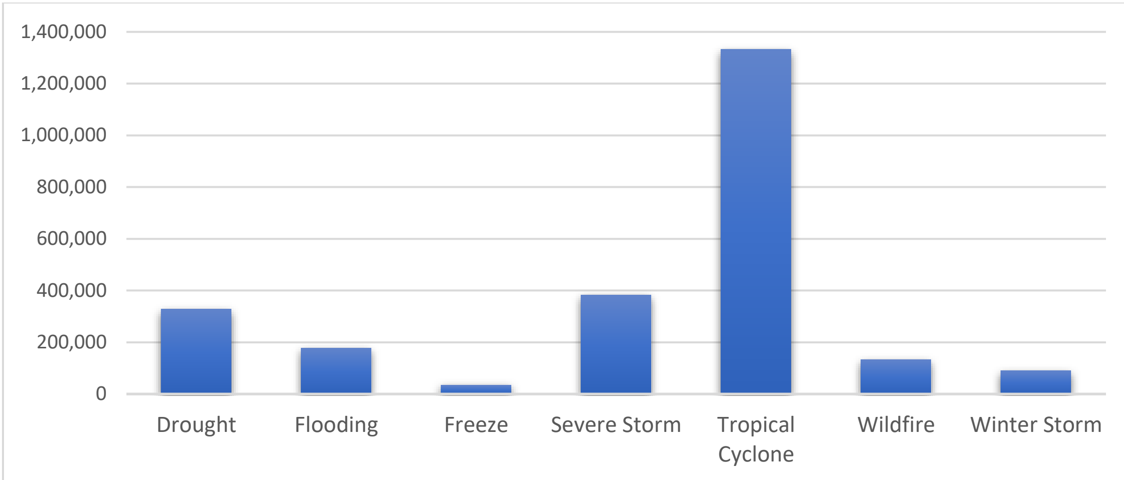


Figure 1. Total Damage of Each Event Type in Million Dollar CPI Adjusted: Economic Impact Assessment for January 1, 1980, to December 31, 2022; This figure illustrates the total financial damage incurred by various event types over the specified period. Values are measured in Million Dollar CPI adjusted.

To further characterize climate events, we analyzed their average duration over the period from January 1, 1980, to December 31, 2022. The second graph in our analysis visually represents the average duration of each event type. Understanding the average duration of these events is vital for assessing their temporal impact on affected regions. This information assists in determining the necessary response mechanisms, resource allocation, and planning for infrastructure and disaster management.

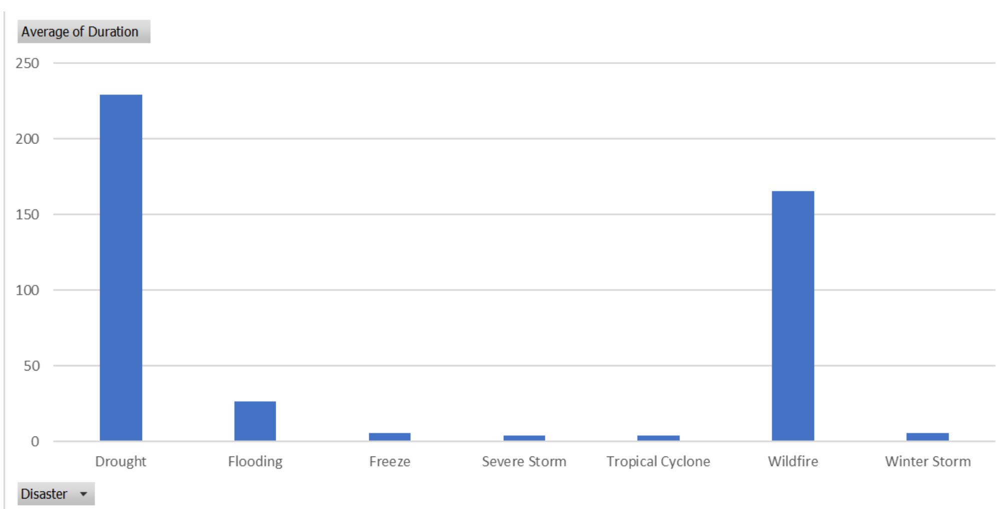


Figure 2. Average Duration of Each Event Type: Analyzing the average duration of climate events from January 1, 1980, to December 31, 2022. This graph provides insights into variations in event lengths, aiding in understanding their temporal impact on affected regions and informing response mechanisms, resource allocation, and disaster management planning.

Our third graph shows the distribution of event types relative to the 341 climate events observed during the specified period. Figure 3 shows how often different event types occur. This knowledge helps us understand climate events and identify dominant event types that require special attention and mitigation.

We have identified various types of events. To ensure robust findings when investigating the impact of different event types, we will focus on those with a substantial number of occurrences, specifically severe storms, tropical cyclones, flooding, and drought.

For events like severe storms, tropical cyclones, and flooding, which have a reasonable number of occurrences (more than 30 events), we can confidently analyze their short-term effects on the market returns. These events can offer valuable insights into how immediate market reactions may vary in response to these specific types of climate events. However, it is essential to acknowledge that drought, due to its longer average duration (more than 220 days), may present challenges in analyzing its short-term effects on market returns. Given the prolonged nature of drought events, the impact on financial markets may span over an extended period, making it more suitable for studying longer-term effects and trends rather than immediate short-term reactions.

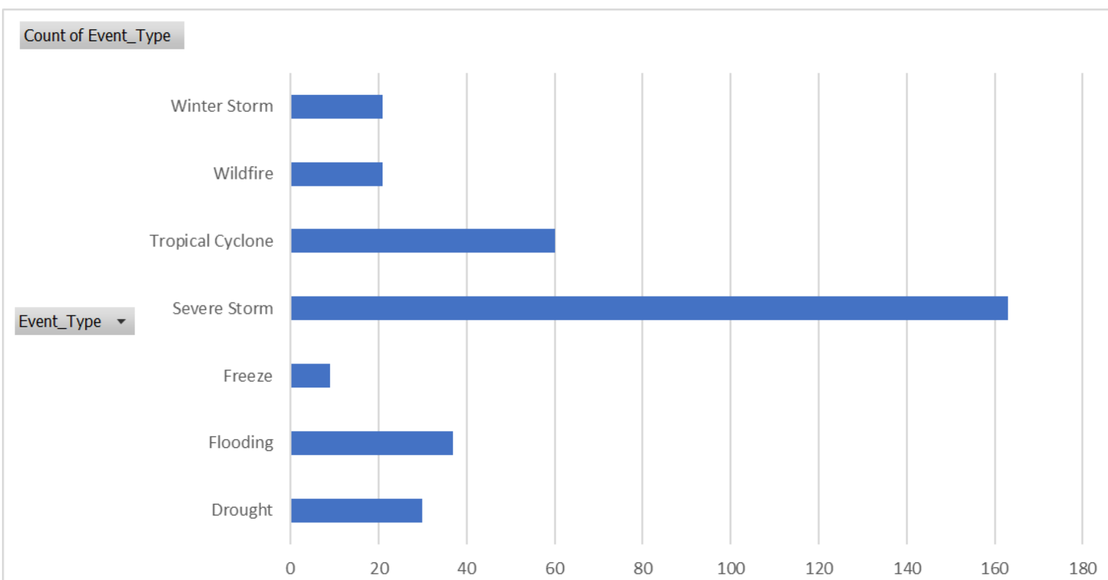


Figure 3. Share of Each Event Type in Climate Events: This figure displays the relative frequency and occurrence of different climate events observed between January 1, 1980, and December 31, 2022. Each event type's proportion is depicted in relation to the total number of 341 climate events during this period.

Therefore, when examining the effects of different types of events on market returns, we will concentrate on severe storms, tropical cyclones, flooding, and other events with a considerable number of occurrences. We will carefully consider the duration and scale of each event type to tailor our analysis and draw meaningful conclusions from short-term effects where applicable.

4.2 Market Reaction to Climate Events

In the context of this thesis, our primary objective is to examine whether the observed increased returns, volatility, and trade volume during these climate events are a consequence of the dissemination of new and fundamental information or if they are driven by noise trading. Traditional models of price formation, including (Kyle, 1985) and (Glosten & Milgrom, 1985) suggest that trade volume reflects the flow of information as investors interpret public signals. Likewise, according to various models like (Ross, 1989), volatility signifies the rapid adjustment of prices to new information in efficient markets. By investigating these aspects, we aim to shed light on the underlying factors influencing market dynamics during climate events and determine whether they are driven by genuine information or merely noise trading.

4.2.1 Climate events and trade volume

To investigate the effect of climate events impact on equity prices, we start by analyzing Trade volume. In our study, abnormal log trade volume is defined as the residuals obtained from the regression model as follows:

$$Log\,Volume_t \;=\; \alpha + \;+ Year\;FE \;+\; Month\;FE \;+\; Day\;FE \;+ \varepsilon_t \;(2)$$

Where $Log\,Volume_t$ represents the log of the total daily trade volume. The terms $Year\;FE, Month\;FE\;and\;Day\;FE$ refer to the fixed effects for the year, month, and day-of-the-week, respectively. The parameter α is the intercept term, and ε_t represents the error term or residuals of the model.

The figure below displays the average abnormal trade volume of the SPDR S&P 500 ETF (SPY) around Climate Events. Abnormal trade volume is determined using the residuals obtained from a regression model, as described earlier. To assess the uncertainty around our estimates, we use the shaded area in the graphs to represent the 95% confidence intervals. The confidence intervals provide a measure of the precision of our estimates and allow us to make statistical inferences about the significance of the observed effects.

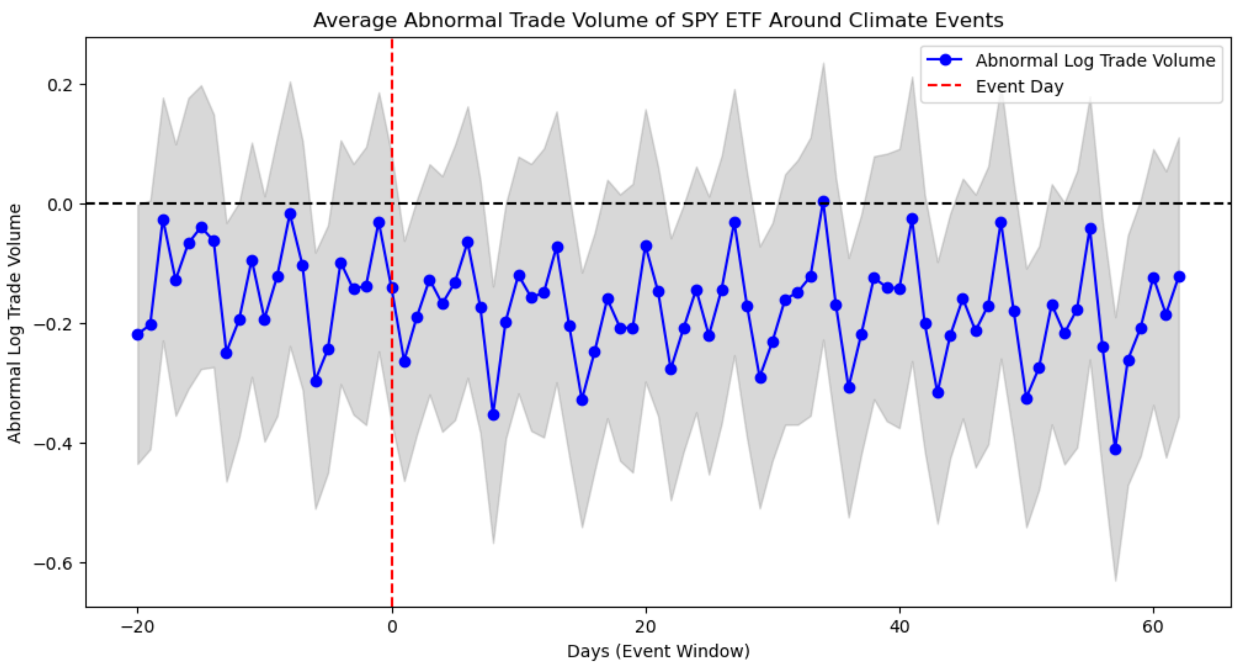


Figure 4. The average abnormal trade volume of the SPDR S&P 500 ETF (SPY) around Climate Events. Abnormal trade volume is calculated as residuals from the regression model (Equation 3) with Year, Month, and Day fixed effects. Shaded areas represent 95% confidence intervals.

We observed no discernible trend in the graph but noticed a prominent seasonality pattern, which could be linked to the timing of Climate Events. This seasonality could be a sign of having no significant effect of Climate events on Trading Volume in the stock market. The seasonality in abnormal trading volume can be attributed to some factors. A significant 37% of events occur during the time that the market is closed (Saturday and Sunday), in addition to events occurring on Monday; the effects of all events occurring during these three days will impact trades occurring on Monday.

4.2.2 Climate events and return of market

To investigate the effect of climate events on market returns, we begin by analyzing the log of returns of the S&P 500 index. In our study, the log return of the S&P 500 index is defined as follows while keeping the other settings and fixed effects unchanged. Let R_t represent the daily return of the S&P 500 index.

$$Log\ R_t \ = \alpha + \ + Year\ FE \ + \ Month\ FE \ + \ Day\ FE \ + \varepsilon_t \ (3)$$

In this model, $Log\ R_t$ denotes the logarithm of the daily return of the S&P 500 index. The terms $Year\ FE, Month\ FE\ and\ Day\ FE$ correspond to the fixed effects for the year, month, and day of the week, respectively. The parameter α represents the intercept term, and ε_t signifies the error term or residuals of the model.

The log return is a common way to measure the percentage change in stock prices over a specific period, and using the logarithm helps normalize the return distribution and provides a more meaningful representation of percentage changes.

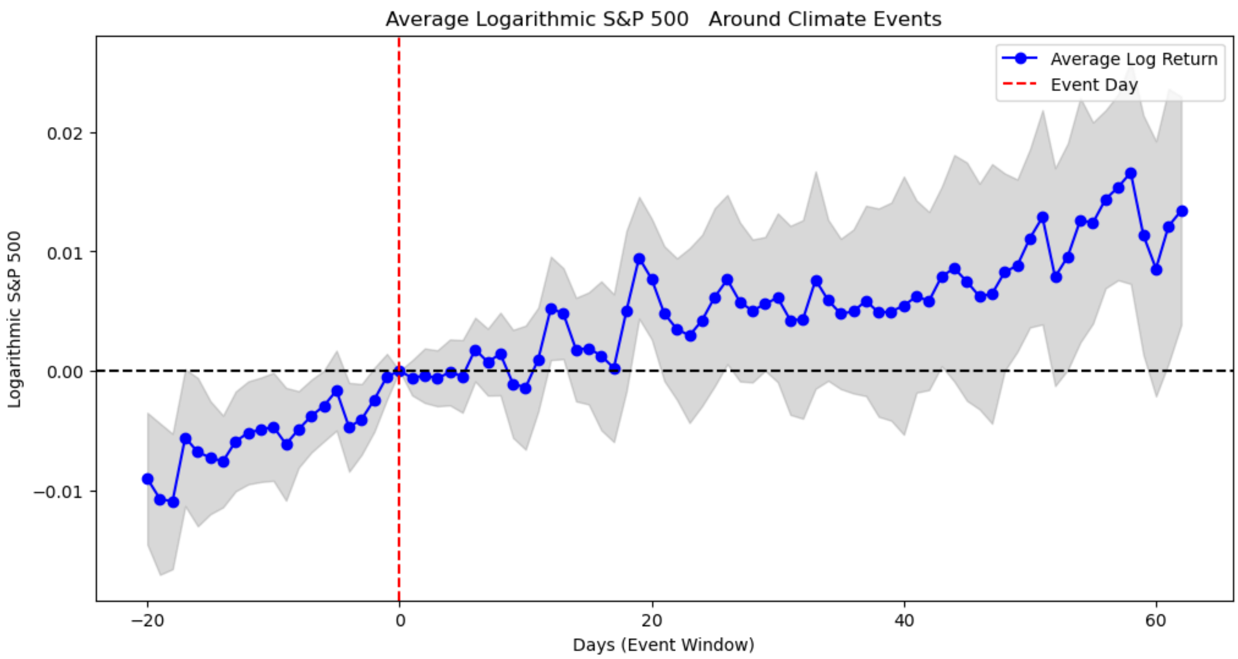


Figure 5.Market Return Analysis - Log Returns of S&P 500 Index around Climate Events. This figure presents the analysis of log-returns of the S&P 500 index around various climate events with fixed effects for year, month, and day of the week included. The graph illustrates a positive overall trend in market returns over an 83-day period, with notable increases before and after the events. Pre-event, the market exhibits an approximate 1% increase in return, indicating a positive trend before the events. Post-event, there is a gradual but slight positive return, extending up to 63 days (equivalent to a quarter) after the events, suggesting continued positive market sentiment or potential sustained positive effects from the events on the market.

In this graph, we observe a positive trend over the entire time window, indicating an overall increase in the market's return. Specifically, we note that the return of the market experiences a notable 2 percent increase over the course of 83 trading days, which can be approximately 6% annually. Before the events, which we consider as the 20 trading days (equivalent to 1 month) leading up to the events, there is an approximate 1% increase in the market return. This could indicate a pre-event positive trend in the market's performance, could suggesting some anticipation or optimism before the occurrence of these events or it could be attributed to total market return.
Following the events in the five trading days (1 week) immediately after the events, the market's return remains relatively constant, hovering around 0%. This stability, in return, may reflect a

period of market digestion and adjustment to the event's impact. Continuing from the week after the events, we observe a gradual but slight positive return, extending up to 63 days (equivalent to a quarter) after the events.

Since the event window length event windows are more than one-quarter long, and to ensure the validity of our findings, we propose implementing a placebo event analysis by selecting 100 random dates within our sample and treating them as placebo events.

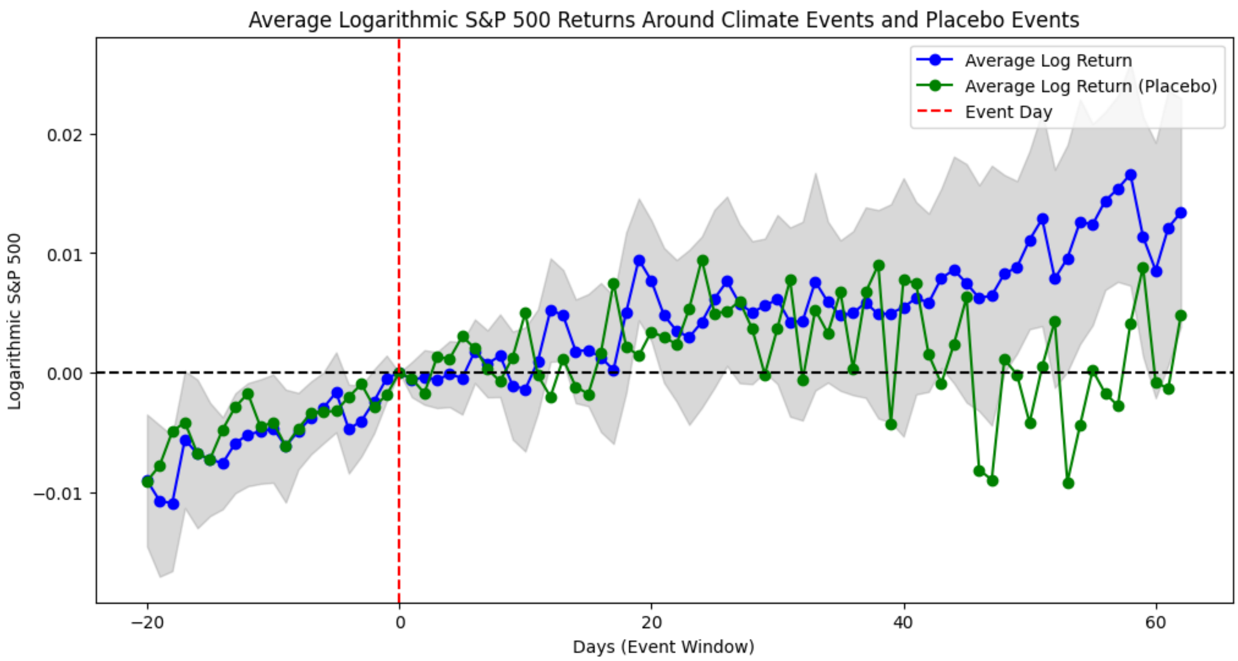


Figure 6. Comparison of Logarithmic S&P 500 Returns Around Actual Climate Events and Placebo Events. This figure illustrates the average logarithmic returns of the S&P 500 index around both actual climate events and placebo events. The blue line represents the average log returns observed around actual climate events, while the green line indicates the trend in average log returns for placebo events. The event day is marked by a red dashed vertical line. The shaded gray area represents the 95% confidence interval for the average log returns around actual climate events. The comparison between the two trends provides insights into whether the observed impact on market returns during actual climate events is distinguishable from what might be expected due to random fluctuations.

These placebo events would allow us to examine whether the observed trend in market returns around actual climate events is distinct from what we might expect due to random fluctuations. Upon comparing the average log returns around actual climate events with the average log returns observed around placebo events, a similarity is evident in the returns observed before events and up to 30 days following events. Both sets of average log returns exhibit a gradual and slight increase of up to approximately 2% during this period. We need to investigate more to understand whether this shared trend in the early stages can be attributed to the initial response of the market, both to actual climate events and placebo events or the total positive return of market explains this trend.

However, a significant divergence between the two trends emerges beyond the 30-day post-event window. During this phase, the average log return around actual climate events maintains a steady, albeit slight, upward trajectory. This suggests that the market's positive sentiment persists over the long term, potentially indicating that the climate events have had lasting effects on market sentiment, economic conditions, or investor behavior. In contrast, the average log return (Placebo) exhibits greater swings and fluctuations beyond the 30-day mark. These pronounced fluctuations imply that the observed trend is more erratic, likely influenced by random market variations rather than a distinct pattern or underlying factor.

On the other hand, this trend could be attributed to the average increase in S&P500. To understand whether the observed 2% increase in average log returns around climate events is primarily attributed to the events themselves or if it is related to the average increase in the S&P 500 over the years, we conduct a comparative analysis. We compare the average log return increase attributed to events and the average annual increase in the S&P 500 over the years.

The average log return increase around climate events is negative (-21.327143), while the average annual increase in the S&P 500 over the years is positive (21.330237). The negativity indicates that, on average, the market experiences a decrease in returns in the immediate vicinity of climate events. This short-term impact could be due to heightened uncertainty, sentiment shifts, or reactionary market behavior triggered by the events. Given these values, it is reasonable to conclude that the observed increase in average log returns around climate events could be primarily attributed to the average annual increase in the S&P 500 over the years rather than the events themselves. This conclusion considers the dynamics of short-term event-driven behavior (as indicated by the negative average log return increase) and the long-term growth trend in the S&P 500 (as indicated by the positive average annual increase).

It suggests that the observed increase in average log returns might be influenced by the broader market trends and annualized growth rather than driven by the specific impact of climate events on market returns. This conclusion is also generalizable for the future graphs for different events.

Given that different types of events are considered in this analysis, researchers have calculated the average return of the S&P 500 index around these different events. The intention is to explore whether the impact on the market varies depending on the nature or category of the event. In the following figures, we have captured the reaction of the market in terms of market return to different climate events.

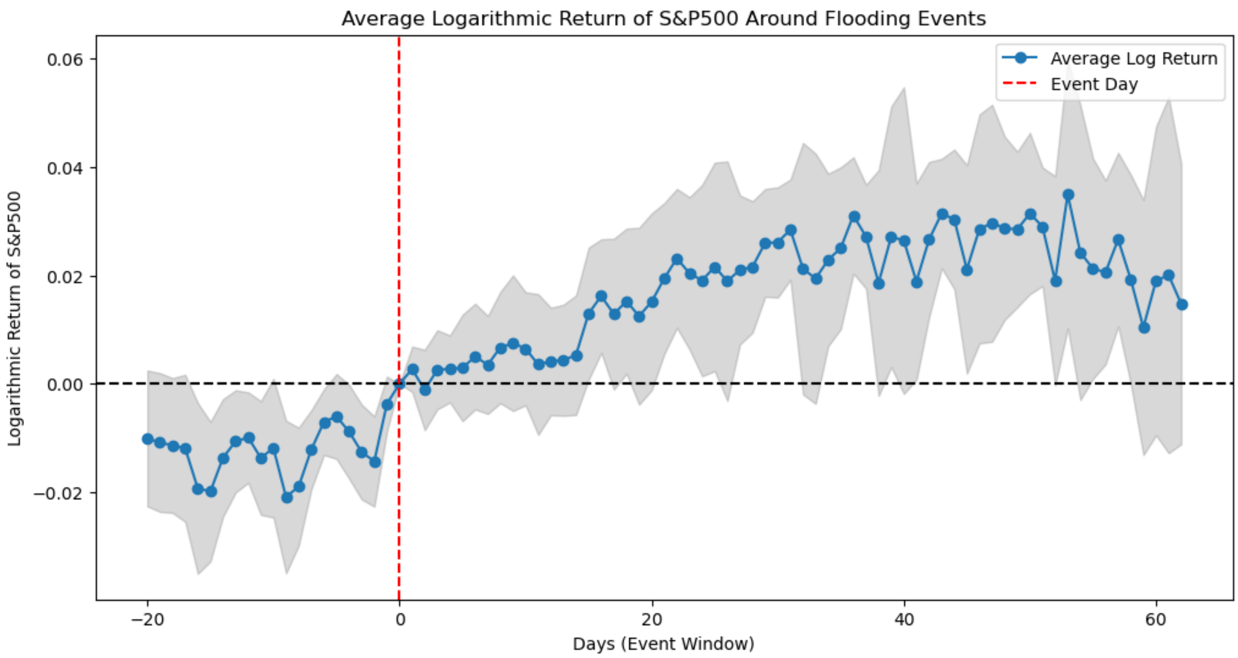


Figure 7. The average return of the S&P 500 index around Flooding. This figure presents the average return of the S&P 500 index in the context of flooding events. The log return of the S&P 500 index is utilized as defined in Equation (4), with fixed effects for year, month, and day of the week included. The positive trend observed in market returns around flooding events aligns with the overall pattern observed across all events. Before flooding events, there is a consistent pattern of negative log returns, indicating a downward movement in market performance leading up to the events. However, after the flooding events, the market returns turn positive, suggesting a potential recovery or optimistic sentiment following the events.

Flooding events exhibit a positive trend in market returns, which aligns with the overall trend observed across all events and was attributed to the market return. Before flooding events, there is a pattern of negative log returns, indicating a downward movement in market performance leading up to the events. However, after the flooding events, the market returns turn positive, suggesting a potential recovery or optimistic sentiment following the events.

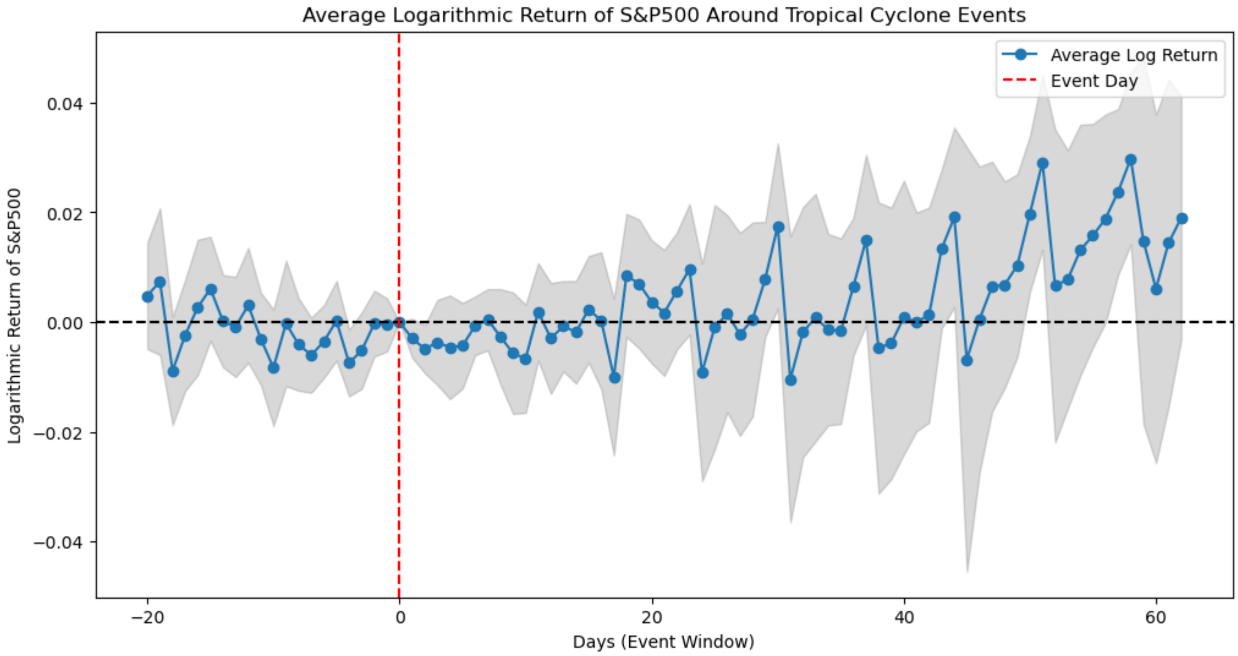


Figure 8. The average return of the S&P 500 index around Tropical Cyclone. The figure shows the daily natural logarithmic return of the S&P 500 index. Before the events, a seasonality pattern with lower volatility is evident. The figure includes Year, Month, and Day fixed effects in the model (Equation 3).

For tropical cyclone events, there is no prominent deterministic trend in market returns. Instead, a seasonality pattern is evident, with less volatility observed before the events. Before the occurrence of tropical cyclone events, discernible seasonality patterns emerge, characterized by lower volatility. The figure showcases a trend where market returns exhibit lower fluctuations and a more stable environment leading up to the events. The inclusion of fixed effects in the model aids in capturing these seasonality patterns, providing insights into market behavior. The figure implies that investors may adopt a cautious approach in anticipation of potential market impacts resulting from the impending cyclone.

After the occurrence of the events, the figure indicates a marginally negative return over the initial five trading days (equivalent to a week). However, this short-lived downturn is followed by a rapid recovery, as returns swiftly rebound to a neutral point around 0. During this post-event phase, a seasonality pattern emerges once again, marked by a subtle upward trend.

It is noteworthy that approximately 20 days after the events, the figure reveals a striking phenomenon characterized by significant and sizeable fluctuations. This recurring pattern is characterized by pronounced ups and downs in market returns. This trend demands closer scrutiny and interpretation.

The observed pattern of dramatic swings after the 20-day mark suggests the presence of external influences or factors beyond the event window. It could be attributed to a myriad of factors, such as changing market sentiment, economic indicators, or unforeseen events. A comprehensive analysis of these fluctuations is crucial to understanding their underlying drivers.

The analysis of drought events shows a slightly positive trend in market returns during the event window. Given the longer average duration of droughts, the short-term effects on market returns might not be as pronounced as observed in other event types.

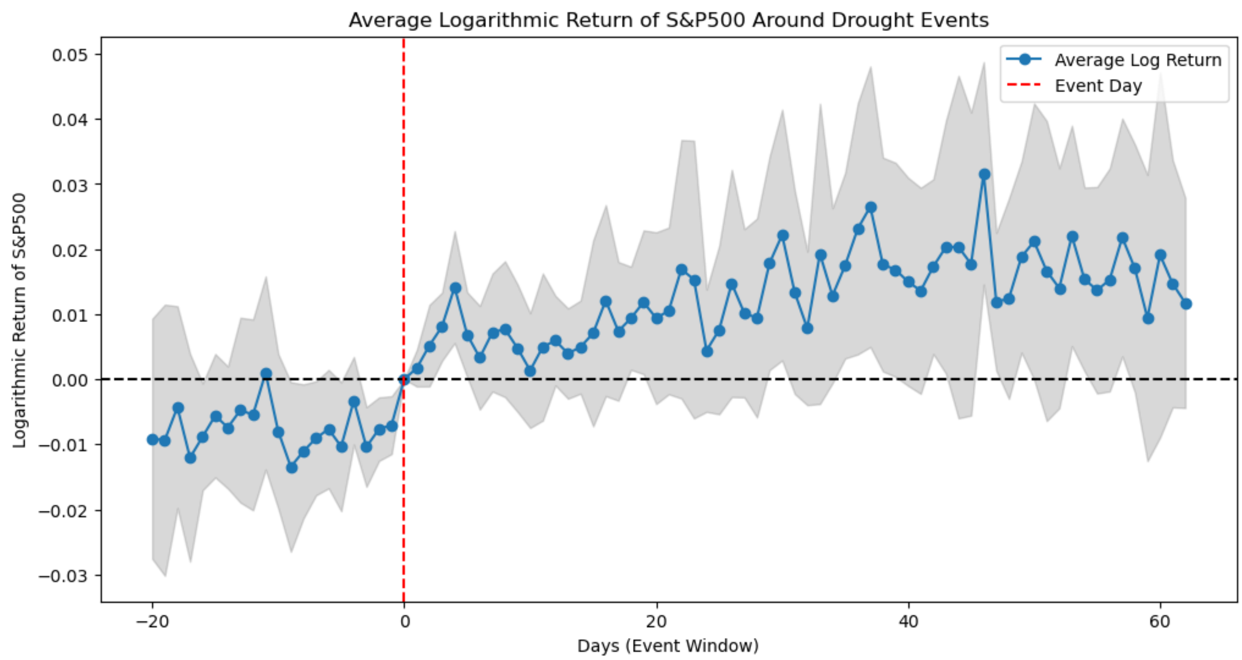


Figure 9. Average return of the S&P 500 index around Drought. The figure presents the daily natural logarithmic return of the S&P 500 index during drought events. A slightly positive trend in market returns is observed during the event window. Due to the longer average duration of droughts, the short-term effects on market returns may not be as pronounced as in other event types. The analysis includes Year, Month, and Day fixed effects in the model (Equation 3).

Like drought events, severe storm events demonstrate a slightly positive trend in market returns during the event window. This pattern aligns with the overall positive trend observed across all events and market.

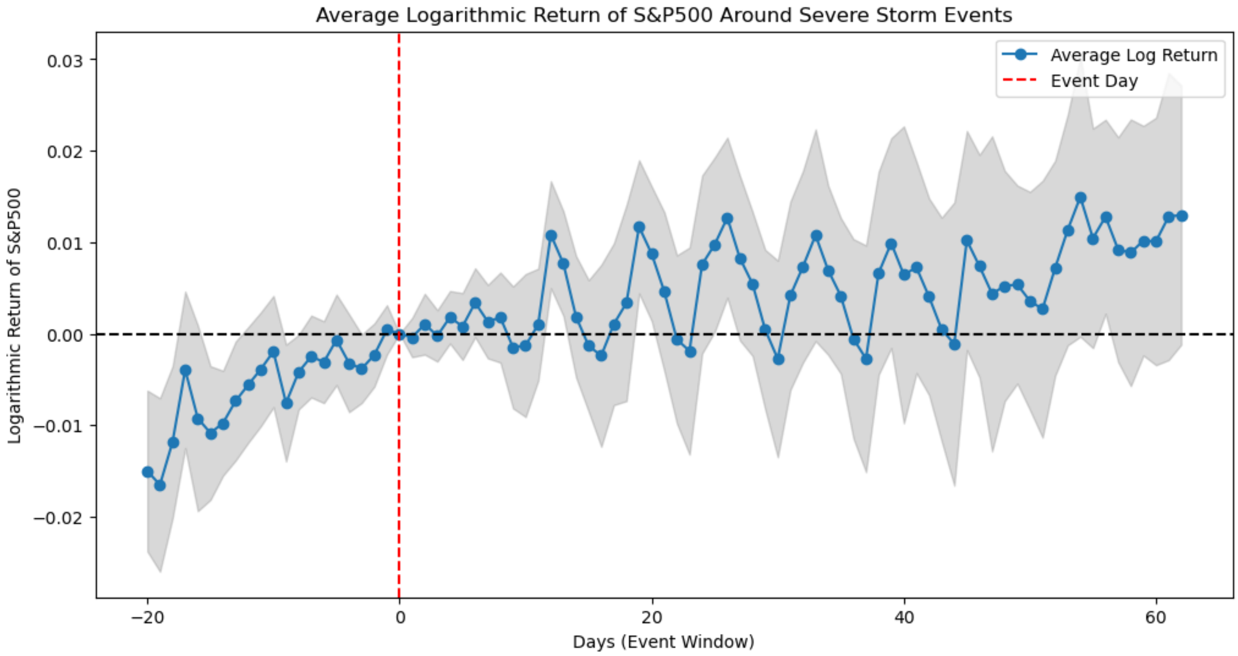


Figure 10. The average return of the S&P 500 index around Severe Storm Events. The figure illustrates the daily natural logarithmic return of the S&P 500 index during severe storm events. Similar to drought events, a slightly positive trend in market returns is evident during the event window, aligning with the overall positive trend observed across all events. The analysis incorporates Year, Month, and Day fixed effects in the model (Equation 4)

However, it is pertinent to address the intriguing observation of significant swings in the average returns approximately ten days after the event. This post-event period is characterized by pronounced fluctuations that warrant closer examination and explanation.

For Wildfire events, we observe a slightly constant return in the short term, one month before and after the events.

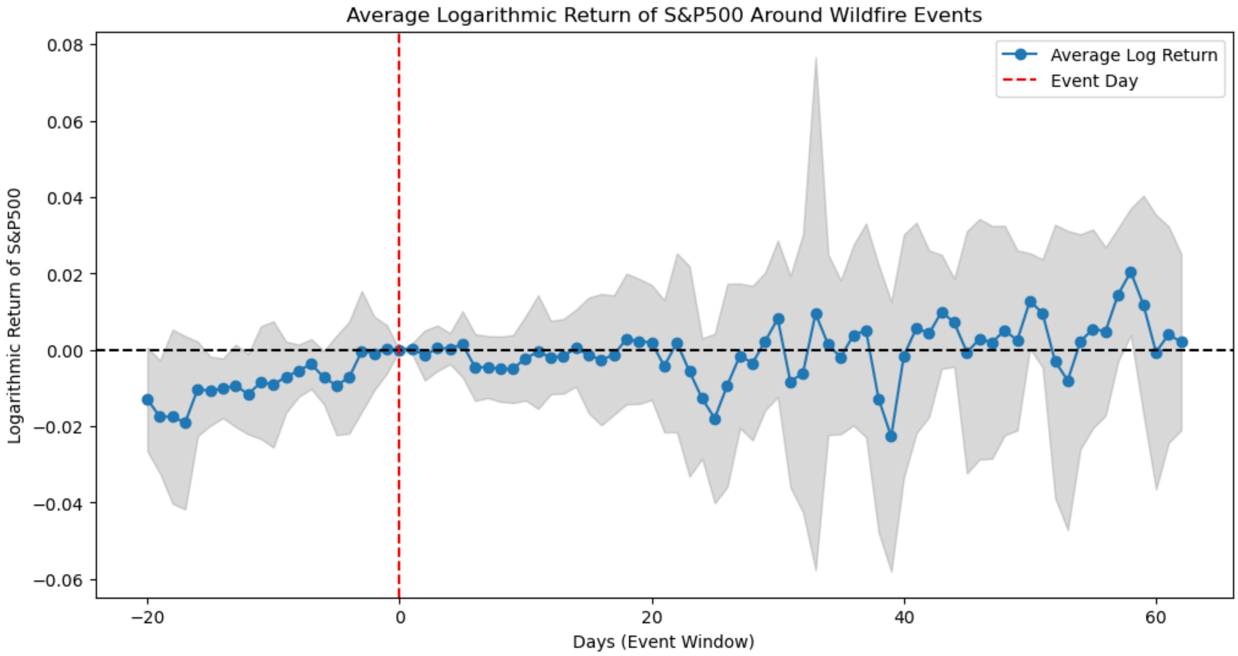


Figure 11. The average return of the S&P 500 index around Wildfire Events. The figure displays the daily natural logarithmic return of the S&P 500 index during wildfire events. We observe a slightly constant return in the short term, one month before and after the events. The analysis includes Year, Month, and Day fixed effects in the model (Equation 3).

Considering these specific patterns for different event types, it becomes evident that each type of climate event can influence market returns differently.

4.2.3 Climate events and volatility of market

To examine better the impact of climate events on equity prices, we continue our investigation by analyzing the close price of the VIX index, which serves as a proxy for market volatility. The VIX index, often referred to as the "fear gauge," is a widely recognized measure of market volatility and investor sentiment. It represents the market's expectation of near-term volatility conveyed through S&P 500 index options. When the VIX index is higher, it indicates that investors anticipate increased market volatility, signifying higher levels of fear or uncertainty (Jiang & Tian, 2007).

In our research, we define the abnormal log close price of the VIX index as the residuals obtained from the following regression model:

$$Log\ VIX_t\ =\ \alpha + \ + Year\ FE\ +\ Month\ FE\ +\ Day\ FE\ + \varepsilon_t\ (4)$$

Same as the previous Model, $Log\ VIX_t$ represents the daily log of the VIX index's closing price. The rest of the variables are the same. The figure below illustrates the average logarithmic close price of the VIX index around Climate Events.

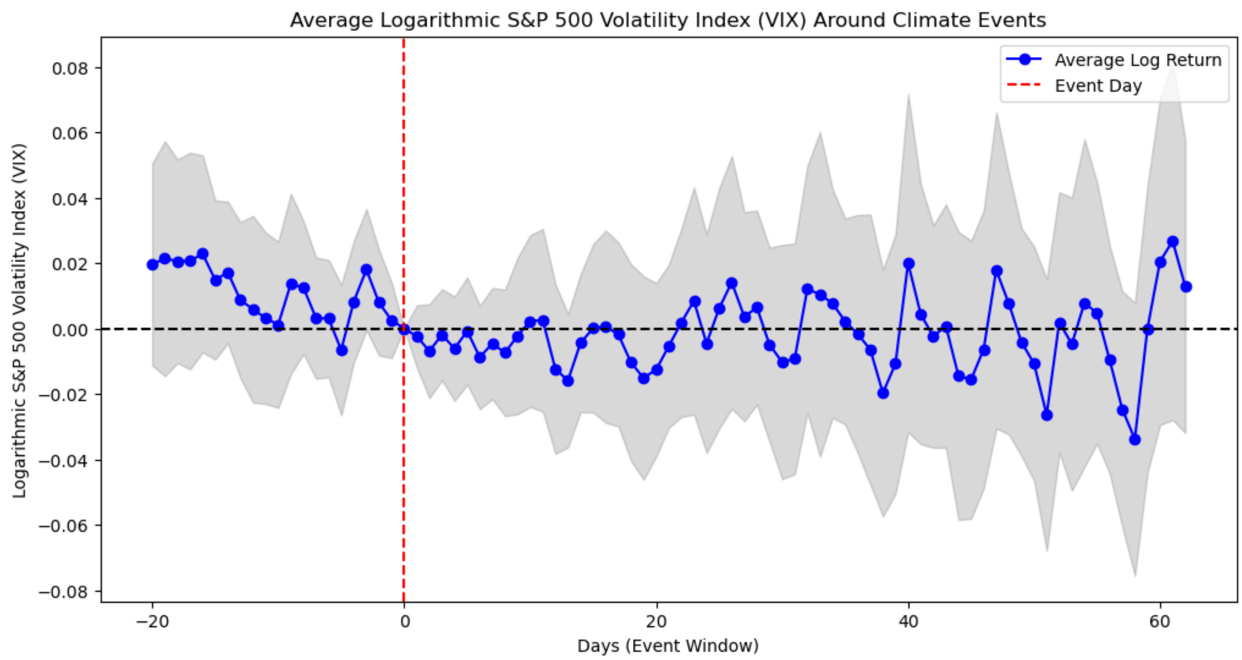


Figure 12. Caption: "Figure 11. Average logarithmic close price of the VIX index around Climate Events. The figure presents the daily log of the VIX index's closing price during climate events. The analysis includes Year, Month, and Day fixed effects in the model (Equation 4). The observed pattern of the VIX index suggests exciting dynamics related to market volatility in response to these events, with a slightly negative trend before the event, fluctuations around zero for approximately three weeks, and seasonality in fluctuations within the event window.

The observed pattern of the VIX index suggests interesting dynamics related to market volatility in response to these events. Let us summarize the findings:

Slightly Negative trend before the Event: Before the climate events, there was a slight negative trend in the volatility index, with a reduction of approximately 2%.

Fluctuations around zero for almost three weeks: Following the initial negative trend, the volatility index experiences fluctuations around the zero level for about two weeks surrounding the climate events. These fluctuations could be interpreted as a relatively calm or less volatile market environment during this period.

Seasonality in Fluctuations within the Event Window: Within the event windows, the observed fluctuations around zero represent a seasonality pattern in the VIX index. This suggests that specific times or durations within the event window may exhibit recurring patterns of market volatility, possibly linked to the timing of climate events or other factors influencing market sentiment.

The subsequent fluctuations around zero indicate a period of stability or low volatility, potentially influenced by market participants' response to the events or external factors that mitigate uncertainty. The presence of seasonality within the event windows suggests that specific periods within the event's time frame consistently demonstrate specific volatility patterns.

Similarly, to the analysis conducted for market returns, we have explored the behavior of the volatility index (VIX) for each type of climate event. However, during our investigation, we did not identify significantly different patterns in the VIX index for each type of event. Across different event types, we observed consistent trends in the VIX index, with the index showing a slightly negative trend before the events, fluctuations around zero during the event windows, and evidence of seasonality within those windows. These observed patterns were consistent across all types of climate events, suggesting that market volatility responded in a relatively uniform manner to the occurrences of various environmental events.

The lack of significant differences in the VIX index patterns among different event types indicates that, from a market volatility perspective, climate events are generally perceived and responded to in a similar manner by market participants. The overall behavior of the VIX index around climate events seems to be influenced by broader market dynamics, macroeconomic factors, and investor sentiment rather than specific characteristics of each event type.

4.2.4 Climate events and reaction of the NYSE energy sector

Using the same methodology in subsection 4.2 of this thesis, we intend to investigate the impact of climate events on the energy sector. We analyze the Average Logarithmic Return of the NYSE Energy Index around climate events. The NYSE Energy Index represents a basket of energy-related stocks listed on the New York Stock Exchange, making it a suitable choice for studying the effects of climate events on the energy sector. Like the previous analysis, we will examine the Average Logarithmic Return around climate events to identify any significant trends, patterns, or seasonality.

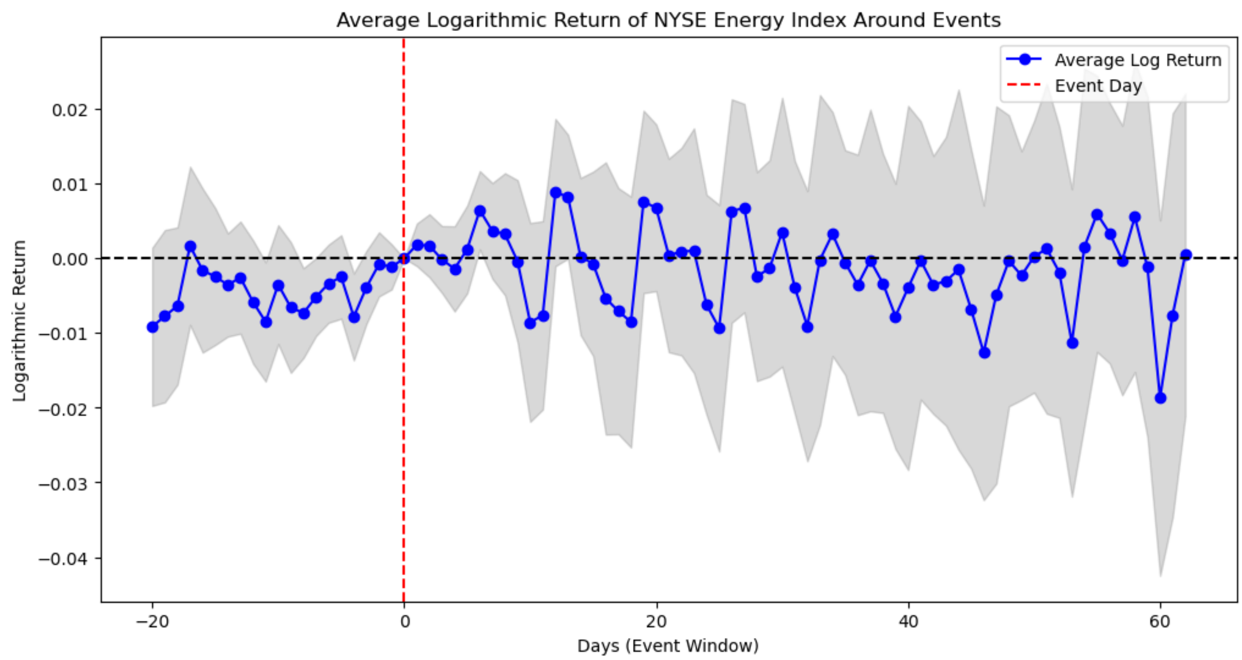


Figure 13. Average Logarithmic Return of NYSE Energy Index Around Events. This figure presents the results of our analysis on the Average Logarithmic Return of the NYSE Energy Index around climate events. The NYSE Energy Index, representing a basket of energy-related stocks listed on the New York Stock Exchange, offers valuable insights into the impact of climate events on the energy sector. By examining the Average Logarithmic Return before, during, and after climate events, we aim to understand the sector's responsiveness to climate-related occurrences.

In our analysis, we have observed that there is insufficient evidence to conclude any significant effect of climate events on the energy sector or market volatility.

The lack of a significant relationship between climate events and the NYSE Energy Index suggests that short-term impacts may not substantially affect energy companies, or these effects may not be consistently observable. Similarly, the absence of a clear relationship with the VIX index implies that market participants' perception of volatility and risk in response to these events does not follow a consistent pattern. Several factors could contribute to these findings. First, the effects of climate events on the energy sector and market volatility might be more pronounced over longer time horizons, with short-term analyses unable to capture the cumulative impact of climate-related factors. Second, market movements and the energy sector's performance are influenced by a wide array of factors beyond climate events, including geopolitical developments, macroeconomic indicators, and regulatory changes. Lastly, the heterogeneity of climate events, each with unique characteristics and impacts, could lead to mixed and inconsistent effects across different events, making it difficult to discern a uniform relationship.

4.3 Informativeness of Climate Events

Initially, we performed an analysis on several key variables, including Trade volume of the SPDR S&P 500 ETF (SPY), S&P 500 Return, and market volatility represented by the VIX index. Additionally, we specifically analyzed the NYSE Energy Index, which provides valuable insights into the energy sector's response to climate events.

As previous analysis does not show a significant impact of climate events, we continue with the aim to quantify the information flow net of price noise around climate events and assess how much information is revealed during these events. To achieve this, we use a novel diagnostic approach by Boguth et al. (2022) that differentiates between the persistent price impact of information and that of noise. To quantify information flow net of price noise, we implemented unbiasedness regressions across climate events. In this approach, we regressed the total change in log prices over a predetermined event window onto changes in log prices over various subsets within the window, ranging from the window's start date to an intermediate date, denoted as "t."

Unbiasedness regression allows us to distinguish between the persistent price impact attributable to the release of information related to climate events and the shorter-term price fluctuations resulting from noise or liquidity trades. By isolating the persistent price impact, we can accurately measure the informational content revealed during climate events.

The use of unbiasedness regression helps address the challenge of analyzing the informativeness of prices, given that the "fair" price and precise information content of these climate events remain unobservable. Through this methodology, we aim to gain a deeper understanding of the underlying factors influencing market dynamics during climate events and assess the informational efficiency of financial markets in response to environmental occurrences (Boguth et al., 2022).

4.3.1 Regression settings and hypothesis shaping

In this study, we have conducted a comprehensive investigation into the impact of climate events on the stock market by employing an unbiasedness regression analysis. To ensure a well-rounded assessment of market dynamics in response to environmental occurrences, we have strategically chosen a set of key indexes and Exchange-Traded Funds (ETFs). These include the widely recognized S&P 500 index, which serves as a broad representation of the U.S. stock market, capturing the overall market sentiment and investor behavior. Additionally, we have focused on the NYSE Energy index and specific energy-related ETFs, such as the Energy Select Sector SPDR Fund (XLE), SPDR Oil & Gas Exploration & Production ETF (XOP), and United States Oil Fund, LP (USO). These selections allow us to delve into the energy sector's specific response to climate events, given its sensitivity to environmental factors and regulatory changes. Furthermore, we have included the Financial Select Sector SPDR Fund (XLF) to explore the financial sector's behavior alongside climate events for a holistic understanding of sectoral interactions. By analyzing these indexes and ETFs, we aim to uncover valuable insights into the impact of climate events on the stock market, inform risk management strategies, and guide sustainable investment decisions amidst the challenges posed by environmental factors. There are some more justifications for our choice as follows:

1. **Representation of the Stock Market:** The S&P 500 index is widely regarded as a broad representation of the U.S. stock market, encompassing 500 large-cap companies from various sectors. By using the S&P 500 index as a benchmark, the regression analysis gains insights into the overall market performance, reflecting the general market sentiment and investor behavior.
2. **Sector-Specific Focus:** The NYSE Energy index and the selected ETFs (XLE, XOP, USO) offer a focused examination of the energy sector's response to climate events. These indexes and ETFs include energy-related companies, providing a comprehensive view of how climate events impact energy stocks' performance and the sector's overall stability.
3. **Market Sensitivity:** The energy sector is notably sensitive to climate-related factors, such as extreme weather events, regulatory changes, and shifts in energy demand patterns. Analyzing the NYSE Energy index and energy-focused ETFs allows researchers to understand how climate events influence energy companies' stock returns and their resilience to environmental challenges (Liu et al., 2021).
4. **Liquidity and Trading Volume:** The S&P 500 index and widely traded ETFs (such as XLE, XOP, USO) are characterized by high liquidity and significant trading volumes. These characteristics ensure that the data used in the unbiasedness regressions accurately reflect market sentiment and provide robust results.
5. **Diversification:** The S&P 500 index and the selected ETFs represent diverse portfolios of companies, reducing individual stock-specific risks. This diversification is crucial in controlling for potential confounding factors and ensuring a more comprehensive analysis of the stock market's response to climate events.
6. **Data Availability:** The S&P 500 index and ETFs are widely tracked and publicly available, providing ample data points for the regression analysis. Access to reliable and comprehensive data enhances the accuracy and robustness of the findings.
7. **Comparability:** By including the NYSE Energy index and selected ETFs alongside the S&P 500 index, the regression analysis enables comparisons between the overall market

performance and the performance of specific sectors (e.g., energy and financial sectors). This comparison offers valuable insights into how climate events impact different sectors within the stock market.

In our methodology, we focus on changes in the coefficient of determination (R^2) from unbiasedness regressions using S&P 500 returns and other selected Indexes and ETFS. The objective is to gauge the level of information flow on specific days or within certain periods concerning climate events. To address the question of whether there is an excess of information on particular days or windows relative to what is expected under the null hypothesis, we employ a comparative approach.

Under the **null hypothesis, which considers no excess information on a given day or period,** we anticipate that R^2 should increase by 1/T, where T = T2 - T1 + 1 represents the number of trading days in the full window of the unbiasedness regression.

If there is above-normal information flow on a specific day, as anticipated on event days, the corresponding ΔR^2 should exceed 1/T. To ensure comparability across estimates from different window lengths, we define the Excess ΔR^2 as ΔR^2 relative to the one implied by the null hypothesis:

$$\text{Excess } \Delta R_t^2 = \frac{T}{K} \Delta R_t^2 - 1 \quad (5)$$

The variable "K" represents the number of days under consideration for analyzing changes in "R^2." When K is set to 1, the metric " Excess ΔR_t^2" quantifies the additional information available on a specific day compared to a typical day. A positive value indicates an abnormal surge in information, while a negative value suggests a below-average increase in price informativeness. A value below -1 signals a significant drop in price informativeness, where noise dominates over valuable information. On the other hand, when K exceeds 1, it measures the average excess information content per day within the specified timeframe (Boguth et al., 2022).

Considering our previous analysis, which did not reveal a significant impact of climate events on S&P 500 returns, the energy sector, and market volatility, the alternative hypothesis considered is that there is an excess of information on a given day or within specific windows. By examining the changes in R^2, we seek to identify any abnormal information flow on climate event days, leading to a better understanding of the informational efficiency of the stock market concerning environmental occurrences.

4.3.2 Climate event informativeness for S&P 500

Table 1 presents the values of ΔR^2 and excess ΔR^2 for various time periods, including the day of the Climate Events (t = 0) and three subsequent periods (t = 0, t = [-5, 5], t = [-5, 10]). The unbiasedness regression analysis is performed over different windows, which range from 20 trading days before the announcement date to 30 and 63 trading days after the event. These windows are utilized to assess the impact of Climate Events on the data without any bias.

Table 1. Unbiasedness Regressions For S&P500 – All Events (Adjusted P-Values). This table presents the values of ΔR^2 and excess ΔR^2 for various time periods surrounding Climate Events, including the event day (t = 0) and three subsequent periods (t = [-5, 5], t = [-5, 10]). The unbiasedness regression analysis is performed over different windows, ranging from 20 trading days before the announcement date to 30 and 63 trading days after the event. The purpose of this analysis is to assess the impact of Climate Events on price informativeness while considering the effect of noise and random variation. ΔR^2 represents the change in price informativeness, while excess ΔR^2 accounts for changes in price informativeness that are specifically related to Climate Events. P-values have been obtained through bootstrapping and have been adjusted according to our hypothesis.

Event TYPE	No. Observation	Period/ Windows	S&P 500			
			[−20,30]		[−20,63]	
			ΔR2	Excess ΔR^2	ΔR^2	Excess ΔR^2
All Events	341	t=0	0.019	-0.027 0.473	-0.002	-1.193 0.767
		t=[-5,5]	0.194	-0.098 0.607	0.113	-0.140 0.607
		t=[-5,10]	0.243	-0.225 0.813	0.157	-0.175 0.667

We present the p-values to test the null hypothesis that abnormal information flow during the event does not result in larger increases in price informativeness compared to a scenario with constant information flow. The initial set of p-values is obtained through bootstrapping, where we simulate 150 climate events (Number of Bootstrap) windows by randomly rearranging the sequence of trading days within a specific window around the events. For example, we shuffle the ordering of trading days within the 20 days before the event to the 63 days after the event.

The purpose of bootstrapping is to assess whether any observed increases in price informativeness during the events are statistically significant and not merely due to chance. By comparing the actual data to the distribution obtained from these bootstrapped samples, we can ascertain the likelihood of observing such increases by random variation alone, thereby validating the significance of the results.

The first two columns in the table represent ΔR^2 and Excess ΔR^2 for the Climate Event Day (t = 0). For the windows ending 30 days after the announcement (Row1), our analysis does not support rejecting the null hypothesis that excess ΔR^2 provides no information about the climate event. Additionally, the point estimates suggest a decrease in price informativeness on those days due to the event. For instance, the point estimate for the [−20, 63] window is −1.193, indicating that the change in price informativeness corresponds to a decrease equivalent to one day's worth of information related to the climate event. This observation remains consistent regardless of the starting point of the window. However, we notice that as we shorten the ending point of the window, the magnitude of the effect increases, and the statistical significance diminishes for the windows ending 63 trading days after the event.

One potential explanation for this trend involves the interplay between information incorporation and data variability. It is possible that prices on the event day do not instantaneously fully absorb all relevant information associated with the climate event. As we extend the observation period further from the event, the availability of pertinent information becomes scarcer, potentially leading to an increase in data noise. Consequently, this combination of limited available information and heightened data noise could contribute to the observed patterns in the results. Most calculated p-values are notably greater than 0.05, a finding that implies we lack statistical grounds to reject the null hypothesis stating that no additional information inflow occurs on those specific days.

In the second Row of Table 1, we examine the results for the t = [-5, 5] period. For the two windows ending 30 and 63 days after the Events, the findings align with what we observed for t = 0, indicating that excess ΔR^2 remains negative during these periods as well. To maintain consistency with other tables, we continue to present the p-values for a one-tailed test, testing that excess ΔR^2 is positive. However, the actual focus here is to detect positive excess ΔR^2, so our null hypothesis is the reverse, seeking evidence that excess ΔR^2 is not positive. Therefore, the p-values for this test are obtained by subtracting one from the original p-values from regression, as reflected in the adjusted numbers in the table.

Moving to the following row, which covers ΔR^2 for the t = [-5, 10] windows, the results are not statistically significant, with p-values ranging from 0.607 to 0.813 for both periods. The point estimates indicate that these days do not exhibit an excess information flow concerning price in response to events. In summary, our analysis shows that when the excess information content is negative on Event days, it implies positive excess ΔR^2 on other days. However, the significance of these results varies depending on the specific periods being examined. While certain windows exhibit statistically significant results consistent with negative excess ΔR^2, others do not demonstrate significant excess information flow related to price changes in response to the events.

Considering our non-significant findings concerning climate events' informativeness or noisiness, we acknowledge the need to gain a deeper understanding of their impact on the stock market. To achieve this, we undertake a decomposition of events into different types, aiming to discern and analyze the effect of each specific type of climate event on the stock market. This approach allows us to explore potential variations in market responses and uncover any distinct patterns or trends associated with types of climate events. By delving into these individual event categories, we aim to shed further light on the relationship between climate events and the stock market, enabling a more comprehensive and nuanced assessment of their influence on financial markets. Table 2 presents the results of regression on each type of events.

Table 2. Unbiasedness Regressions For S&P500 – (Adjusted P-Values). This table presents the values of ΔR2 and excess ΔR2 for various time periods surrounding Climate Events, including the event day (t = 0) and three subsequent periods (t = [-5, 5], t = [-5, 10]). The unbiasedness regression analysis is performed over different windows, ranging from 20 trading days before the announcement date to 30 and 63 trading days after the event. The purpose of this analysis is to assess the impact of Climate Events on price informativeness while considering the effect of noise and random variation. ΔR^2 represents the change in price informativeness, while excess ΔR^2 accounts for changes in price informativeness that are specifically related to Climate Events.

Event TYPE	No. Observation	Period/ Windows	S&P 500			
			[−20,30]		[−20,63]	
			ΔR^2	Excess ΔR^2	ΔR^2	Excess ΔR^2
Flooding	**37**	**t=0**	0.143	6.310	-0.001	-1.066
				0.053		0.533
		t=[-5,5]	0.638	1.960	0.292	1.231
				0.080		*0.420*
		t=[-5,10]	0.613	0.953	0.426	1.234
				0.139		*0.353*
Tropical Cyclone	**60**	**t=0**	0.043	1.192	-0.030	-3.500
				0.293		0.827
		t=[-5,5]	0.055	-0.745	-0.159	-2.217
				0.827		0.993
		t=[-5,10]	0.137	-0.562	-0.070	-1.365
				0.893		0.980
Drought	**30**	**t=0**	-0.061	-4.124	-0.068	-6.700
				0.873		0.933
		t=[-5,5]	0.206	-0.047	0.268	1.046
				0.598		0.307
		t=[-5,10]	-0.003	-1.009	0.107	-0.436
				0.940		0.693

Event TYPE	No. Observation	Period/ Windows	S&P 500 [−20,30]		S&P 500 [−20,63]	
			ΔR^2	Excess ΔR^2	ΔR^2	Excess ΔR^2
Freeze	**9**	**t=0**	0.145	6.390	0.213	16.915
				0.353		0.153
		t=[-5,5]	0.270	0.253	0.394	2.005
				0.607		0.347
		t=[-5,10]	0.507	0.617	0.036	-0.813
				0.539		0.653
Severe Storm	**163**	**t=0**	-0.006	-1.327	-0.001	-1.095
				0.753		0.607
		t=[-5,5]	0.185	-0.143	0.150	0.142
				0.697		0.459
		t=[-5,10]	0.234	-0.255	0.184	-0.034
				0.779		0.540
Winter Storm	**21**	**t=0**	0.041	1.106	0.052	3.371
				0.479		0.193
		t=[-5,5]	0.208	-0.037	0.093	-0.287
				0.687		0.733
		t=[-5,10]	0.424	0.351	0.274	0.439
				0.501		0.519
Wildfire	**21**	**t=0**	0.041	1.106	0.052	3.371
				0.479		0.193
		t=[-5,5]	0.208	-0.037	0.093	-0.287
				0.687		0.733
		t=[-5,10]	0.424	0.351	0.274	0.439
				0.502		0.519

Based on the table 2, flooding triggers significant excess information flow on the event day (t=0) and persists during 11-day (t=[-5, 5]) and 16-day (t=[-5, 10]) periods, indicating an active market response. In contrast, tropical cyclones result in limited excess information and stable markets across these periods. Droughts show subdued market reactions with limited excess information. Freeze, severe storm, winter storm, and wildfire events yield variable and inconsistent excess information flow, leading to unpredictable market responses. Overall, floods prompt heightened market activity, while other events evoke less significant market reactions.

Overall, Table 2 reveals varying effects of different climate events on the S&P 500. For some events, we find significant excess information flow, while for others, the excess information flow is not statistically significant. These results highlight the complex and nuanced relationship between climate events and the stock market's behavior, indicating that certain events may have a more pronounced impact on market movements while others may be less influential or more challenging to identify.

In our analysis of flooding events, we have observed significant results for the first two rows with a 90% confidence interval and the third line with an 85% confidence interval. Specifically, for flooding events within the 30-day window after the event (t = 0), we find that the information flow is approximately 6.31 times greater compared to a normal day, as predicted by the Random Walk model. Similarly, for the t = [-5, 5] window, we observe that in those 11 days, we receive nearly twice as much information as we would typically receive in 22 normal days.

For the remaining events, we have not obtained statistically significant results, meaning that we cannot confidently reject the Null Hypothesis. Nevertheless, from an economic standpoint, it is essential to note that the numbers we have received are substantial and carry significant significance. Although statistical significance might not have been established, these large figures indicate noteworthy effects and warrant further investigation into their economic implications.

In other words, our examination of flooding events has revealed compelling evidence for increased information flow on the event day and within specific windows after the event, suggesting that flooding events have significant impacts on the stock market.

4.3.3 Climate event informativeness for volatility of market

Given the current evidence about the impact of climate events on the stock market's information flow, we now aim to extend our investigation to understand their effect on market volatility. To do so, we will employ the VIX index, a well-known measure of market volatility and investor sentiment. We can discern the informativeness of climate events in predicting market volatility. This analysis will enable us to explore whether climate events serve as significant indicators of heightened market uncertainty and risk.

Table 3. Unbiasedness Regressions for VIX index – (Adjusted P-Values). This table presents the values of ΔR2 and excess ΔR2 for various time periods surrounding Climate Events, including the event day (t = 0) and three subsequent periods (t = [-5, 5], t = [-5, 10]). The unbiasedness regression analysis is performed over different windows, ranging from 20 trading days before the announcement date to 30 and 63 trading days after the event. The purpose of this analysis is to assess the impact of Climate Events on price informativeness while considering the effect of noise and random variation. ΔR^2 represents the change in price informativeness, while excess ΔR^2 accounts for changes in price informativeness that are specifically related to Climate Events.

Event TYPE	No. Observation	Period/ Windows	VIX index [−20,30]		VIX index [−20,63]	
			ΔR^2	Excess ΔR^2	ΔR^2	Excess ΔR^2
Flooding	37	t=0	-0.118	-7.001	-0.029	-3.429
				0.873		0.867
		t=[-5,5]	0.197	-0.088	0.077	-0.409
				0.653		0.707

Event TYPE	No. Observation	Period/ Windows	VIX index [−20,30] ΔR²	VIX index [−20,30] Excess ΔR²	VIX index [−20,63] ΔR²	VIX index [−20,63] Excess ΔR²
		t=[-5,10]	0.176	-0.438 0.813	0.034	-0.821 0.820
Tropical Cyclone	**60**	t=0	0.076	2.892 0.100	0.069	4.814 0.100
		t=[-5,5]	0.082	-0.620 0.960	0.067	-0.488 0.780
		t=[-5,10]	0.174	-0.447 0.953	0.134	-0.299 0.720
Drought	**30**	t=0	0.060	2.043 0.240	-0.012	-1.983 0.733
		t=[-5,5]	0.115	-0.466 0.847	-0.011	-1.086 0.827
		t=[-5,10]	0.693	1.210 0.020	0.034	-0.822 0.673
Freeze	**9**	t=0	0.115	4.858 0.587	0.029	1.428 0.399
		t=[-5,5]	-0.08	-1.370 1.000	-0.145	-2.109 1.000
		t=[-5,10]	0.103	-0.671 1.000	-0.081	-1.425 1.000
Severe Storm	**163**	t=0	0.028	0.444 0.473	0.017	0.420 0.493
		t=[-5,5]	0.105	-0.512 0.919	-0.004	-1.031 0.987
		t=[-5,10]	0.274	-0.128 0.720	0.063	-0.669 0.920
Winter Storm	**21**	t=0	-0.104	-6.327 0.920	0.031	1.630 0.480
		t=[-5,5]	-0.133	-1.616 1.000	-0.079	-1.602 0.967
		t=[-5,10]	0.038	-0.879 0.913	0.172	-0.097 0.547
Wildfire	**21**	t=0	-0.022	-2.100 0.747	0.010	-0.123 0.433
		t=[-5,5]	0.055	-0.746 0.893	0.252	0.928 0.240
		t=[-5,10]	0.182	-0.420 0.747	0.091	-0.522 0.780

Based on the provided table, flooding events exhibit consistently negative ΔR^2 and excess ΔR^2 values on the event day (t=0) and during the subsequent 10 days (t=[-5, 10]), indicating no significant excess information flow and implying market stability. Similarly, tropical cyclones show minor, non-significant excess information on the event day (t=0) but turn negative during the 10-day window (t=[-5, 10]), signifying a lack of substantial influence on the VIX index. Drought events result in limited and non-significant excess information, with mixed patterns over the 10-day period (t=[-5, 10]), suggesting a muted impact. Across various events like freeze, severe storm, winter storm, and wildfire, there is no consistent significant excess information detected, highlighting market resilience to these occurrences.

Our analysis of the VIX index does not reveal sufficient evidence to reject the null hypothesis that climate events have excess information. Consequently, we must consider these events as noise rather than informative signals. The lack of statistically significant results in several cases suggests that the relationship between climate events and market volatility might not be as pronounced as initially anticipated. In other words, our analysis suggests that climate events do not significantly contribute to predicting or explaining fluctuations in market volatility, and they may be regarded as noise rather than informative signals. This outcome highlights the need for further investigation and analysis to uncover additional factors and influences that impact market sentiment and volatility dynamics.

4.3.4 Climate Event informativeness for energy sector

Continuing our research in the same context, we now aim to investigate the effect of climate events on specific sectors of the market, particularly in the energy sector. As discussed earlier, the energy sector is particularly susceptible to climate events, making it a relevant area of study to understand the impact of such occurrences on financial markets.

To analyze the relationship between climate events and the energy sector's performance, we have chosen three Exchange-Traded Funds (ETFs) as representative indicators of this sector. These ETFs are Energy Select Sector SPDR Fund (XLE); SPDR Oil & Gas Exploration & Production ETF (XOP) and United States Oil Fund, LP (USO).

Through this analysis, we will assess the potential influence of climate events on the energy sector's performance and explore how these events may impact investor sentiment, stock prices, and overall market dynamics in the energy domain. Our findings will be presented in the following tables, detailing the effects of climate events on the selected ETFs.

Table 4. Unbiasedness Regressions for Energy Select Sector SPDR Fund – (Adjusted P-Values). This table presents the values of ΔR2 and excess ΔR2 for various time periods surrounding Climate Events, including the event day (t = 0) and three subsequent periods (t = [-5, 5], t = [-5, 10]). The unbiasedness regression analysis is performed over different windows, ranging from 20 trading days before the announcement date to 30 and 63 trading days after the event. The purpose of this analysis is to assess the impact of Climate Events on price informativeness while considering the effect of noise and random variation. ΔR^2 represents the

change in price informativeness, while excess ΔR² accounts for changes in price informativeness that are specifically related to Climate Events.

Event TYPE	No. Observation	Period/ Windows	XLE			
			[−20,30]		[−20,63]	
			ΔR^2	Excess ΔR^2	ΔR^2	Excess ΔR^2
Flooding	**37**	**t=0**	*0.143*	*6.310*	*-0.001*	*-1.066*
				0.053		*0.533*
		t=[-5,5]	*0.638*	*1.960*	*0.292*	*1.231*
				0.080		*0.420*
		t=[-5,10]	*0.613*	*0.953*	*0.426*	*1.234*
				0.140		*0.353*
Tropical Cyclone	**60**	**t=0**	*-0.020*	*-2.029*	*0.013*	*0.071*
				0.767		*0.493*
		t=[-5,5]	*0.081*	*-0.626*	*-0.005*	*-1.037*
				0.873		*0.993*
		t=[-5,10]	*0.382*	*0.218*	*0.141*	*-0.260*
				0.280		*0.687*
Drought	**30**	**t=0**	*0.033*	*0.699*	*0.005*	*-0.561*
				0.310		*0.640*
		t=[-5,5]	*-0.144*	*-1.668*	*0.065*	*-0.507*
				0.798		*0.613*
		t=[-5,10]	*0.231*	*-0.264*	*0.214*	*0.124*
				0.713		*0.547*
Freeze	**9**	**t=0**	*0.036*	*0.854*	*0.044*	*2.720*
				0.787		*0.787*
		t=[-5,5]	*0.216*	*0.001*	*0.299*	*1.284*
				0.787		*0.787*
		t=[-5,10]	*0.227*	*-0.277*	*0.320*	*0.682*
				0.999		*0.787*
Severe Storm	**163**	**t=0**	*-0.027*	*-2.394*	*-0.011*	*-1.952*
				0.847		*0.767*
		t=[-5,5]	*0.238*	*0.105*	*0.137*	*0.048*
				0.433		*0.553*
		t=[-5,10]	*0.267*	*-0.149*	*0.186*	*-0.022*
				0.647		*0.587*
Winter Storm	**21**	**t=0**	*0.044*	*1.251*	*-0.072*	*-7.012*
				0.28		*0.967*
		t=[-5,5]	*0.506*	*1.345*	*0.219*	*0.672*
				0.113		*0.339*
		t=[-5,10]	*0.700*	*1.232*	*0.222*	*0.168*
				0.147		*0.399*
Wildfire	**21**	**t=0**	*0.010*	*-0.513*	*0.054*	*3.523*
				0.620		*0.307*
		t=[-5,5]	*0.131*	*-0.391*	*0.264*	*1.017*
				0.699		*0.193*
		t=[-5,10]	*0.192*	*-0.388*	*0.230*	*0.206*
				0.839		*0.447*

The provided table offers insights into the impact of different climate events on information flow in financial markets. During flooding events, the event day (t=0) and subsequent 16-day period exhibit significant positive ΔR^2 and excess ΔR^2 values, indicating a substantial excess information flow. In contrast, tropical cyclones show limited information flow on the event day and during the 16-day period, with fluctuating ΔR^2 and excess ΔR^2 values, suggesting a less consistent impact. Drought events present mixed results, with potential excess information on the event day and varying significance levels in the 16-day window. Freeze, severe storm, winter storm, and wildfire events demonstrate inconsistent and non-significant excess information flow across all time frames. Overall, flooding events strongly influence information flow, while other climate events exhibit varying and less significant impacts on financial markets.

This analysis reveals varying effects of different climate events on this sector. Some events demonstrate significant excess information flow, while others do not show statistically significant excess information. This suggests that certain climate events may have more pronounced impacts on the Energy sector, influencing market movements, while others may be less influential or more challenging to identify.

The following table will analyze SPDR Oil & Gas Exploration & Production ETF (XOP) :

Table 5. Unbiasedness Regressions for SPDR Oil & Gas Exploration & Production ETF. This table presents the values of ΔR2 and excess ΔR2 for various time periods surrounding Climate Events, including the event day (t = 0) and three subsequent periods (t = [-5, 5], t = [-5, 10]). The unbiasedness regression analysis is performed over different windows, ranging from 20 trading days before the announcement date to 30 and 63 trading days after the event. The purpose of this analysis is to assess the impact of Climate Events on price informativeness while considering the effect of noise and random variation. ΔR2 represents the change in price informativeness, while excess ΔR2 accounts for changes in price informativeness that are specifically related to Climate Events.

Event TYPE	No. Observation	Period/ Windows	XOP [−20,30]		XOP [−20,63]	
			ΔR^2	Excess ΔR^2	ΔR^2	Excess ΔR^2
Flooding	**37**	**t=0**	-0.067	-4.404	-0.105	-9.789
				0.747		0.713
		t=[-5,5]	0.495	1.296	0.349	1.667
				0.147		0.247
		t=[-5,10]	0.697	1.221	0.383	1.010
				0.047		0.293
Tropical Cyclone	**60**	**t=0**	-0.039	-2.996	-0.012	-2.033
				0.867		0.773
		t=[-5,5]	0.064	-0.704	-0.008	-1.065
				0.913		0.980
		t=[-5,10]	0.404	0.287	0.159	-0.167
				0.28		0.673
Drought	**30**	**t=0**	0.09	3.571	-0.061	-6.091
				0.847		0.233
		t=[-5,5]	-0.835	-4.869	0.045	-0.655
				0.967		0.620
		t=[-5,10]	-0.673	-3.145	0.222	0.165

Event TYPE	No. Observation	Period/ Windows	XOP [−20,30] ΔR^2	XOP [−20,30] Excess ΔR^2	XOP [−20,63] ΔR^2	XOP [−20,63] Excess ΔR^2
				0.987		0.613
Freeze	9	t=0	0.032	0.639	0.040	2.360
				0.747		0.747
		t=[-5,5]	0.285	0.320	0.379	1.896
				0.747		0.747
		t=[-5,10]	0.303	-0.035	0.418	1.196
				1.000		0.747
Severe Storm	163	t=0	-0.008	-1.410	-0.002	-1.127
				0.707		0.640
		t=[-5,5]	0.251	0.166	0.139	0.061
				0.38		0.533
		t=[-5,10]	0.326	0.039	0.270	0.418
				0.533		0.253
Winter Storm	21	t=0	0.009	-0.517	-0.017	-2.462
				0.687		0.773
		t=[-5,5]	0.397	0.841	0.339	1.586
				0.400		0.213
		t=[-5,10]	0.494	0.575	0.427	1.243
				0.433		0.280
Wildfire	21	t=0	-0.061	-4.098	-0.058	-5.902
				0.987		0.887
		t=[-5,5]	0.057	-0.738	0.136	0.038
				0.920		0.573
		t=[-5,10]	0.087	-0.723	0.035	-0.814
				0.987		0.953

During flooding events, the event day (t=0) demonstrates a significant lack of excess information, contrasting the Random Walk model predictions. However, during both the 11-day (t=[-5, 5]) and 16-day (t=[-5, 10]) periods, there is a substantial excess information flow, indicating active market dynamics. Tropical cyclones exhibit a lack of excess information on the event day and an absence of significant excess information during the subsequent 16-day window, highlighting market stability. Drought events, although showing some potential excess information on the event day and during the 16-day period, indicate a significant lack of excess information flow within the 5-day window (t=[-5, 5]). Across various other events like freeze, severe storm, winter storm, and wildfire, mixed and non-significant excess information flow patterns are observed, emphasizing the complexity of XOP's response to these climate events.

In summary, the varying effects of different climate events on this specific sector. Some events exhibit a significant lack of excess information, while others indicate statistically significant excess information flow. This suggests that certain climate events may have more pronounced impacts on the Oil & Gas Exploration & Production sector, influencing market movements, while others may be less influential or more challenging to identify.

The table below presents the results of the United States Oil Fund, LP (USO):

Table 6. Unbiasedness Regressions for United States Oil Fund, LP. This table presents the values of ΔR2 and excess ΔR2 for various time periods surrounding Climate Events, including the event day (t = 0) and three subsequent periods (t = [-5, 5], t = [-5, 10]). The unbiasedness regression analysis is performed over different windows, ranging from 20 trading days before the announcement date to 30 and 63 trading days after the event. The purpose of this analysis is to assess the impact of Climate Events on price informativeness while considering the effect of noise and random variation. ΔR^2 represents the change in price informativeness, while excess ΔR^2 accounts for changes in price informativeness that are specifically related to Climate Events.

Event TYPE	**No. Observation**	**Period/ Windows**	**USO**			
			[−20,30]		**[−20,63]**	
			ΔR^2	**Excess ΔR^2**	**ΔR^2**	**Excess ΔR^2**
Flooding	**37**	**t=0**	0.0180	-0.085	-0.037	-4.100
				0.567		0.853
		t=[-5,5]	0.315	0.463	0.072	-0.447
				0.327		0.633
		t=[-5,10]	0.560	0.784	0.330	0.731
				0.100		0.213
Tropical Cyclone	**60**	**t=0**	0.043	1.206	0.052	3.345
				0.427		0.307
		t=[-5,5]	0.291	0.347	0.201	0.532
				0.373		0.420
		t=[-5,10]	0.336	0.069	0.183	-0.037
				0.453		0.550
Drought	**30**	**t=0**	0.025	0.265	-0.007	-1.580
				0.540		0.698
		t=[-5,5]	0.126	-0.414	0.072	-0.452
				0.707		0.653
		t=[-5,10]	0.143	-0.545	0.134	-0.298
				0.760		0.667
Freeze	**9**	**t=0**	-0.039	-3.000	-0.040	-4.376
				0.998		0.998
		t=[-5,5]	0.306	0.417	0.328	1.504
				0.780		0.780
		t=[-5,10]	0.425	0.355	0.449	1.355
				0.780		0.780
Severe Storm	**163**	**t=0**	-0.097	-5.972	-0.147	-13.363
				0.953		0.998
		t=[-5,5]	-0.232	-2.074	-0.235	-2.791
				0.980		0.973
		t=[-5,10]	-0.118	-1.375	-0.178	-1.932
				0.993		0.907
Winter Storm	**21**	**t=0**	-0.097	-5.972	-0.147	-13.363
				0.953		1.000
		t=[-5,5]	-0.232	-2.074	-0.235	-2.791
				0.980		0.973
		t=[-5,10]	-0.118	-1.375	-0.178	-1.932
				0.993		0.907
Wildfire	**21**	**t=0**	0.029	0.462	-0.001	-1.051

Event TYPE	No. Observation	Period/ Windows	USO [−20,30] ΔR^2	USO [−20,30] Excess ΔR^2	USO [−20,63] ΔR^2	USO [−20,63] Excess ΔR^2
				0.447		0.719
		t=[-5,5]	-0.048	-1.222	0.038	-0.710
				0.859		0.687
		t=[-5,10]	0.120	-0.617	0.105	-0.450
				0.859		0.739

The analysis of various climate events' impact on information flow yields nuanced insights. During flooding events, there's no clear evidence of excess information flow on the event day (t=0). However, positive, and statistically significant ΔR^2 and excess ΔR^2 values emerge during the subsequent 16-day period (t=[-5, 10]), indicating significant information flow. Tropical cyclones exhibit significant excess information on the event day (t=0) and potential excess information without strong confidence during the 16-day period. Droughts present potential excess information during the event day and the 16-day period, albeit with varying levels of statistical significance. For freeze, severe storm, winter storm, and wildfire events, mixed and non-consistent patterns are observed, lacking clear evidence of significant excess information flow across all time frames.

Our analysis of the USO fund reveals varying impacts of different climate events. Some events lead to significant excess information flow, while others do not show statistical significance. This suggests that certain climate events strongly influence the fund, while others have less impact. Statistically insignificant results highlight the need for further research on climate events' interactions with the USO fund. Overall, the nature of different climate events plays a significant role in their impact on excess information flow in financial markets. For example, flooding causes market fluctuations, tropical cyclones have consistent effects, drought's impact depends on intensity and duration, and events like freezes and storms show less consistent impacts, possibly due to regional or sector-specific effects.

Conclusion of events informativeness for the energy sector:

In examining the association between different climate events and Energy sector ETFs, notable patterns emerge. Flooding events disrupt supply chains and production for oil and gas companies, resulting in diverse effects within ETFs like XOP. For USO, flooding impacts regions with oil infrastructure, leading to distinct price shifts. Similarly, XLE's varied composition results in differing impacts on renewable and non-renewable energy firms. Tropical cyclones significantly affect oil and gas operations, impacting excess information flow and prices in XOP, USO, and XLE. Drought affects energy companies' water-intensive operations, influencing production and supply chain dynamics, thereby impacting excess information flow differently across the three ETFs. Freeze events prompt varied responses, contingent on the specific regions impacted and the extent of energy operations affected by extreme cold. Severe storms, winter storms, and wildfires disrupt energy infrastructure, leading to varying excess information flow and price informativeness based on the specific companies and regions affected within each ETF. These observations underscore the intricate relationship between climate events and the Energy sector, shaping market dynamics in multifaceted ways.

4.3.5 Climate event informativeness for financial sector

In continuation, we have chosen to investigate the effect of climate events on the Financial Select Sector SPDR Fund (XLF). The motivation behind selecting XLF is driven by the significance of the financial sector's role in the broader economy and its sensitivity to various external factors, including climate events. As climate-related risks and the impact of climate change continue to gain attention and recognition in the financial industry, it becomes crucial to understand how climate events influence the performance and informativeness of financial sector assets.

As the financial sector is a crucial driver of economic growth and stability, this research can offer valuable knowledge that can inform policy decisions and contribute to building a more sustainable and resilient financial system.

Table 7. Unbiasedness Regressions for Financial Select Sector SPDR Fund. This table presents the values of ΔR2 and excess ΔR2 for various time periods surrounding Climate Events, including the event day (t = 0) and three subsequent periods (t = [-5, 5], t = [-5, 10]). The unbiasedness regression analysis is performed over different windows, ranging from 20 trading days before the announcement date to 30 and 63 trading days after the event. The purpose of this analysis is to assess the impact of Climate Events on price informativeness while considering the effect of noise and random variation. ΔR^2 represents the change in price informativeness, while excess ΔR^2 accounts for changes in price informativeness that are specifically related to Climate Events. P-values have been obtained through bootstrapping to assess the statistical significance of the results and validate the impact of the events on price movements.

Event TYPE	No. Observation	Period/ Windows	XLF [−20,30]		XLF [−20,63]	
			ΔR^2	Excess ΔR^2	ΔR^2	Excess ΔR^2
Flooding	37	t=0	0.038	0.939	-0.180	-16.105
				0.500		0.600
		t=[-5,5]	0.354	0.641	-0.018	-1.136
				0.400		0.760
		t=[-5,10]	0.357	0.137	0.106	-0.443
				0.413		0.207
	60	t=0	0.049	1.520	0.040	2.344

Event TYPE	No. Observation	Period/ Windows	XLF [−20,30] ΔR^2	XLF [−20,30] Excess ΔR^2	XLF [−20,63] ΔR^2	XLF [−20,63] Excess ΔR^2
				0.267		0.233
Tropical Cyclone		t=[-5,5]	-0.041	-1.191	-0.195	-2.492
				0.887		0.967
		t=[-5,10]	0.06	-0.809	-0.111	-1.585
				0.913		0.953
Drought	30	t=0	-0.063	-4.207	0.006	-0.480
				0.820		0.480
		t=[-5,5]	-0.429	-2.989	-0.023	-1.175
				0.700		0.573
		t=[-5,10]	-0.428	-2.364	0.090	-0.53
				0.707		0.513
Freeze	9	t=0	0.13	5.655	-0.109	-10.135
				0.793		1.000
		t=[-5,5]	-0.907	-5.206	0.940	6.176
				1.000		0.793
		t=[-5,10]	0.071	-0.773	-0.051	-1.269
				1.000		1.000
Severe Storm	163	t=0	0.033	0.679	0.008	-0.346
				0.373		0.460
		t=[-5,5]	0.236	0.095	0.188	0.435
				0.387		0.187
		t=[-5,10]	0.26	-0.170	0.239	0.257
				0.773		0.233
Winter Storm	21	t=0	0.044	1.263	-0.042	-4.502
				0.373		0.720
		t=[-5,5]	0.090	-0.583	0.107	-0.179
				0.807		0.647
		t=[-5,10]	0.243	-0.225	0.109	-0.427
				0.713		0.727
Wildfire	21	t=0	0.074	2.798	0.071	4.982
				0.413		0.407
		t=[-5,5]	0.084	-0.612	0.191	0.458
				0.820		0.467
		t=[-5,10]	0.299	-0.045	0.359	0.885
				0.700		0.373

The analysis of XLF provides insights into climate events' impact on the financial sector. For the event window from -20 to +30 days around these events:

Flooding and tropical cyclones show slight positive ΔR^2 on the event day, implying increased price informativeness and excess information flow. The impact, while small compared to other sectors, modestly affects XLF. Drought events exhibit negative ΔR^2 on the event day, indicating reduced price informativeness due to potential noise domination. This trend persists in surrounding days. Freezing events have notable positive ΔR^2 on the event day, suggesting brief price informativeness increase, diminishing in subsequent windows. Severe storms and winter storms show limited excess ΔR^2, implying minor impact on XLF's price informativeness. Wildfires have positive ΔR^2 on the event day, with diminishing impact in following windows.

The financial sector's response depends on climate event nature. Flooding and tropical cyclones, with specific industry impacts, modestly influence XLF. Droughts, affecting agriculture, significantly and consistently affect the financial sector due to broader economic implications. These outcomes align with climate event characteristics and their potential financial industry impacts. Here are some reasons that can help justify the observed results:

Flooding and Tropical Cyclones: These events can have significant localized impacts, affecting industries like insurance, real estate, and construction. However, the financial sector, as a whole, may not be as directly influenced by these events, leading to relatively modest effects on XLF. The financial sector's diversification and ability to spread risks across various industries may mitigate the impact of these events on the overall sector.

Drought: Drought events can have far-reaching implications for the economy, particularly affecting agricultural industries. As the financial sector is closely tied to the overall health of the economy, drought-related challenges faced by agricultural sectors can translate into reduced economic activities and investments. Consequently, this can lead to decreased price informativeness and higher noise levels in the financial markets during drought periods, explaining the observed negative ΔR^2 values.

Freezing events: Freezing events can disrupt transportation and energy sectors, but they may also boost specific industries like energy and utilities. The positive ΔR^2 values on the event day may reflect increased price informativeness in these specific sectors. However, the subsequent windows show diminishing effects, possibly due to the transient nature of freezing events and their limited long-term impact on the broader financial industry.

Severe Storms and Winter Storms: These events may not directly impact major financial activities or specific industries within the financial sector, leading to relatively small or insignificant excess ΔR^2 values. The impact of severe storms and winter storms may be more localized, affecting specific geographic regions rather than the broader financial market.

Wildfires: Wildfires can have devastating effects on the environment and localized economies, particularly in regions heavily reliant on tourism and agriculture. The observed positive $\Delta R2$ value on the event day may indicate increased price informativeness in sectors directly impacted by wildfires, but the subsequent windows show diminishing effects. This may suggest that the broader financial sector is less affected by wildfires compared to specific industries within regions directly affected by these events.

Section 5: Discussion

5.1 Market reaction to climate events

In this study, we delved into the impact of climate events on the stock market, focusing on the Energy sector. Our analysis covered trade volume, market returns, and market volatility. We discovered a notable seasonality pattern in trade volume during climate events, indicating specific times when stock market trading is affected. Market returns displayed positive trends pre-event, stabilizing post-event, implying market reaction and effects. Different event types influenced market returns uniquely, underscoring the need for event-specific understanding.

Examining the VIX index, we observed fluctuations around zero during climate events, suggesting varying market reactions and volatility patterns. Notably, event types showed similar responses in market volatility, indicating consistent market perceptions. Surprisingly, climate events had no significant impact on the NYSE Energy Index and VIX index, suggesting inconsistent short-term effects.

Our study emphasizes the significance of event heterogeneity and the need for tailored investment and risk management strategies. Continuous monitoring and long-term analysis of climate events' implications on financial markets and the energy sector are essential for developing sustainable investment approaches.

5.2 Informativeness of climate events

While direct impacts on trade volume, market returns, and volatility were not evident, our method of filtering out price noise offered valuable insights into market behavior during these events. We used unbiasedness regression to distinguish persistent price impacts from short-term fluctuations caused by noise or liquidity trades.

Flooding events notably influenced the S&P 500 index, leading to excess information flow on the event day and subsequent windows, impacting the stock market. In contrast, tropical cyclones, droughts, freezes, severe storms, winter storms, and wildfires did not exhibit significant information flow, highlighting the varying influence of different events on market movements.

The analysis of Energy sector ETFs (XLE, XOP, and USO) further illuminated diverse patterns in excess information flow and price informativeness. XLE showed limited excess information during flooding events but significant flow afterward. XOP displayed consistent excess information, particularly during flooding and tropical cyclones, reflecting the sensitivity of its constituent companies. USO, tied to crude oil prices, exhibited less consistent excess information flow, affected by disruptions caused by climate events impacting oil supply and demand dynamics. These variations underscore the importance of considering ETF composition and the interplay of geopolitical, demand, and macroeconomic factors in shaping market responses to climate events. Further research is essential for a comprehensive understanding of these complex interactions.

5.3 Contributions and Innovations

One key revelation is the limited immediate impact of many climate events on financial markets, challenging traditional assumptions and decision-making processes for managers. The findings underscore the importance of strategic resource allocation, suggesting that focusing on strategic factors other than immediate climate events might be more beneficial for portfolio managers and investors.

Furthermore, the study's sector-specific focus, particularly on energy and financial sectors, provides a unique lens into how different industries respond to environmental challenges. This targeted approach enriches our understanding of sector-specific vulnerabilities and resilience in the face of climate-related disruptions. Additionally, the research's meticulous categorization of climate events and analysis of their informativeness offer valuable insights into market behavior. By identifying climate events with significant impacts, the study aids risk assessment and management, guiding investors and policymakers in more effective resource allocation to mitigate financial risks.

5.4 Implications and Policy Recommendations

The study emphasizes the impact of specific climate events, like flooding, on the stock market's information flow, urging investors to monitor these events closely for informed decisions and risk management. Additionally, sector-specific responses, especially in the energy sector, underline the need for tailored industry insights to guide sustainable investments. The study highlights the complexity of market responses to climate events, cautioning against direct correlations between events and heightened market uncertainty. Each event's unique attributes require nuanced evaluation, shaping market behavior differently.

To bridge the gap in market awareness, policymakers can develop climate financial literacy programs, educating stakeholders on climate event implications and strategies for integrating climate factors into investments. Collaborations with climate scientists can enhance the accessibility and accuracy of relevant climate data, facilitating informed decision-making. Integrating climate considerations into financial regulations, disclosures, and stress testing frameworks ensures a climate-aware financial sector, enabling effective risk management.

5.5 Limitations

The Results of this thesis may have some limitations that should be acknowledged. Firstly, data constraints, particularly in historical climate data, may impact the analysis's robustness. Secondly, the complex nature of market behavior, influenced by various factors beyond climate events, poses challenges in isolating their specific impact. Thirdly, individual investors and institutions may respond diversely due to differences in risk appetite and awareness levels, a complexity not fully captured. Additionally, the study's chosen event window might not comprehensively encompass short-term and long-term market responses. Lastly, the study's focus on the U.S. stock market limits generalizability; extending findings globally necessitates considering regional variations and considering the location of events. These constraints underscore the importance of cautious interpretation.

5.6 Recommendations for Future Research

Based on the limitations, several recommendations for future research can be made to enhance further our understanding of the relationship between climate events and financial markets:

1. **Expand Data Sources:** Future research could benefit from incorporating additional and more comprehensive datasets, including more extensive historical climate data and high-frequency financial market data. Using multiple data sources can improve the accuracy and reliability of the analysis.
2. **Geographical Analysis:** Expanding the analysis to include global markets and regional stock exchanges can help identify region-specific variations in market responses to climate events. Different regions may be affected differently by climate events, and understanding these variations can provide valuable insights for investors and policymakers.
3. **Market Segment Analysis:** Investigate how different market segments, such as renewable energy companies or insurance providers, react to climate events. Focusing on specific sectors or industries that are more directly influenced by climate factors may reveal different patterns of market response.
4. **Long-Term Effects:** Examine the long-term impact of climate events on financial markets beyond the immediate event window. Understanding how markets react and recover over extended periods can provide a more comprehensive assessment of the market's resilience to climate risks.
5. **Climate Policy Analysis:** Investigate the interaction between climate policy developments and financial market behavior. Assess how changes in climate regulations and government policies influence market responses to climate events.

By addressing these recommendations, future research can provide more robust and nuanced insights into the impact of climate events on financial markets.

Section 6: Conclusion

In conclusion, this thesis has delved into the complex relationship between climate events and financial market dynamics, aiming to unravel the extent to which these events influence market informativeness. Climate change is a critical global concern, and understanding its impact on financial markets is of paramount importance for effective risk management and sustainable investment decisions. The research has provided valuable insights into the informativeness of various climate events, their implications for the stock market and market volatility, and derived policy recommendations for investors and policymakers.

The findings of this study have shed light on the mixed effects of different climate events on the stock market. While flooding events exhibit significant excess information flow, indicating their considerable impacts on the market, other events, such as tropical cyclones and droughts, do not provide statistically significant results, suggesting a limited immediate influence on market movements. Additionally, the analysis of the VIX index has indicated that climate events might not significantly contribute to predicting or explaining market volatility fluctuations.

The research has also addressed the implications of the market's relative lack of reaction to certain climate events. The complexity of decision-making for portfolio managers, when overloaded with data, has been highlighted, emphasizing the need to prioritize decisions and data focus on other critical risks in the short term.

References

Ai, H., & Bansal, R. (2018). Risk preferences and the macroeconomic announcement premium. *Econometrica*, *86*(4), 1383–1430.

Barclay, M. J., & Hendershott, T. (2003). Price discovery and trading after hours. *The Review of Financial Studies*, *16*(4), 1041–1073.

Biais, B., Hillion, P., & Spatt, C. (1999). Price discovery and learning during the preopening period in the Paris Bourse. *Journal of Political Economy*, *107*(6), 1218–1248.

Birindelli, G., & Chiappini, H. (2021). Climate change policies: Good news or bad news for firms in the European Union? *Corporate Social Responsibility and Environmental Management*, *28*(2), 831–848.

Boguth, O., Grégoire, V., & Martineau, C. (2022). Noisy FOMC Returns. *Available at SSRN*.

Brown, S. J., & Warner, J. B. (1985). Using daily stock returns: The case of event studies. *Journal of Financial Economics*, *14*(1), 3–31.

Cao, G., Xu, W., & Guo, Y. (2015). Effects of climatic events on the Chinese stock market: applying event analysis. *Natural Hazards*, *77*(3), 1979–1992. https://doi.org/10.1007/s11069-015-1687-9

Capelle-Blancard, G., & Laguna, M.-A. (2010). How does the stock market respond to chemical disasters? *Journal of Environmental Economics and Management*, *59*(2), 192–205. https://doi.org/https://doi.org/10.1016/j.jeem.2009.11.002

Chen, X., Fu, Q., & Chang, C.-P. (2021). What are the shocks of climate change on clean energy investment: A diversified exploration. *Energy Economics*, *95*, 105136. https://doi.org/https://doi.org/10.1016/j.eneco.2021.105136

Chun, D., Cho, H., & Kim, J. (2022). The relationship between carbon-intensive fuel and renewable energy stock prices under the emissions trading system. *Energy Economics*, *114*, 106257. https://doi.org/https://doi.org/10.1016/j.eneco.2022.106257

Fama, E. F. (1970). Efficient capital markets: A review of theory and empirical work. *The Journal of Finance*, *25*(2), 383–417.

Fama, E. F. (1990). Stock returns, expected returns, and real activity. *The Journal of Finance*, *45*(4), 1089–1108.

Feria-Domínguez, J. M., Paneque, P., & Gil-Hurtado, M. (2017). Risk perceptions on hurricanes: Evidence from the US stock market. *International Journal of Environmental Research and Public Health*, *14*(6), 600.

Gillingham, K., Nordhaus, W. D., Anthoff, D., Blanford, G., Bosetti, V., Christensen, P., McJeon, H., Reilly, J., & Sztorc, P. (2015). *Modeling uncertainty in climate change: A multi-model comparison*. National Bureau of Economic Research.

Gillingham, K., & Stock, J. H. (2018). The cost of reducing greenhouse gas emissions. *Journal of Economic Perspectives*, *32*(4), 53–72.

Glosten, L. R., & Milgrom, P. R. (1985). Bid, ask and transaction prices in a specialist market with heterogeneously informed traders. *Journal of Financial Economics*, *14*(1), 71–100.

Ho, T. (2022). Climate change news sensitivity and mutual fund performance. *International Review of Financial Analysis*, *83*, 102331. https://doi.org/https://doi.org/10.1016/j.irfa.2022.102331

Jiang, G. J., & Tian, Y. S. (2007). Extracting model-free volatility from option prices: An examination of the VIX index. *Journal of Derivatives*, *14*(3).

Kaplanski, G., & Levy, H. (2010). Sentiment and stock prices: The case of aviation disasters. *Journal of Financial Economics*, *95*(2), 174–201. https://doi.org/https://doi.org/10.1016/j.jfineco.2009.10.002

Kruttli, M. S., Roth Tran, B., & Watugala, S. W. (2021). *Pricing Poseidon: Extreme weather uncertainty and firm return dynamics*.

Kyle, A. S. (1985). Continuous auctions and insider trading. *Econometrica: Journal of the Econometric Society*, 1315–1335.

Lang, M., Lane, R., Zhao, K., Tham, S., Woolfe, K., & Raven, R. (2021). Systematic review: Landlords' willingness to retrofit energy efficiency improvements. *Journal of Cleaner Production*, *303*, 127041. https://doi.org/https://doi.org/10.1016/j.jclepro.2021.127041

Liu, H., Ferreira, S., & Karali, B. (2021). Hurricanes as news? Assessing the impact of hurricanes on the stock market returns of energy companies. *International Journal of Disaster Risk Reduction*, *66*, 102572. https://doi.org/https://doi.org/10.1016/j.ijdrr.2021.102572

Mincer, J. A., & Zarnowitz, V. (1969). The evaluation of economic forecasts. In *Economic forecasts and expectations: Analysis of forecasting behavior and performance* (pp. 3–46). NBER.

Pagnottoni, P., Spelta, A., Flori, A., & Pammolli, F. (2022). Climate change and financial stability: Natural disaster impacts on global stock markets. *Physica A: Statistical Mechanics and Its Applications*, *599*, 127514.

Ross, S. A. (1989). Information and volatility: The no-arbitrage martingale approach to timing and resolution irrelevancy. *The Journal of Finance*, *44*(1), 1–17.

Schuh, F., & Jaeckle, T. (2022). Impact of hurricanes on US insurance stocks. *Risk Management and Insurance Review*.

Symeonidis, L., Daskalakis, G., & Markellos, R. N. (2010). Does the weather affect stock market volatility? *Finance Research Letters*, *7*(4), 214–223. https://doi.org/https://doi.org/10.1016/j.frl.2010.05.004

Tay, B.-H. (2023). Climate change and stock market: a review. *IOP Conference Series: Earth and Environmental Science*, *1151*(1), 012021.

U-Din, S., Nazir, M. S., & Sarfraz, M. (2022a). The climate change and stock market: catastrophes of the Canadian weather. *Environmental Science and Pollution Research*, *29*(29), 44806–44818.

U-Din, S., Nazir, M. S., & Sarfraz, M. (2022b). The climate change and stock market: catastrophes of the Canadian weather. *Environmental Science and Pollution Research*, *29*(29), 44806–44818. https://doi.org/10.1007/s11356-022-19059-4

Venturini, A. (2022). Climate change, risk factors and stock returns: A review of the literature. *International Review of Financial Analysis*, *79*, 101934. https://doi.org/https://doi.org/10.1016/j.irfa.2021.101934

Wang, L., & Kutan, A. M. (2013). The impact of natural disasters on stock markets: Evidence from Japan and the US. *Comparative Economic Studies*, *55*, 672–686.

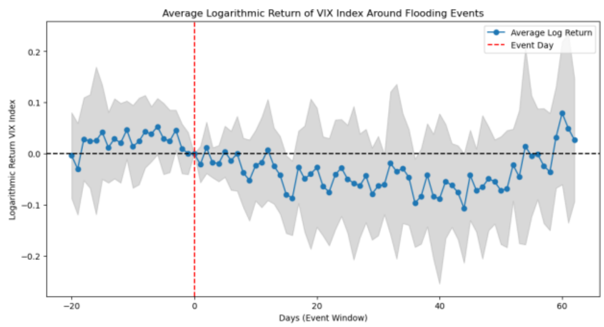
Ye, L. (2022). The effect of climate news risk on uncertainties. *Technological Forecasting and Social Change*, *178*, 121586. https://doi.org/https://doi.org/10.1016/j.techfore.2022.121586

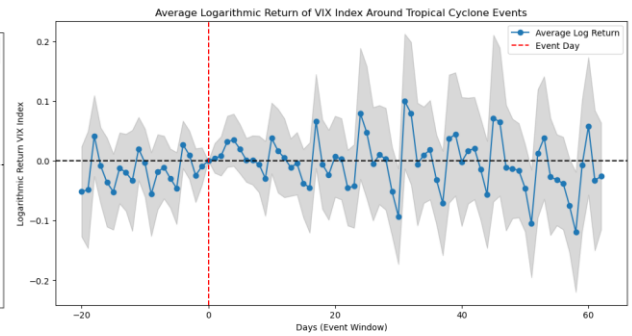
Yu, H., Wei, W., Li, J., & Li, Y. (2022). The impact of green digital finance on energy resources and climate change mitigation in carbon neutrality: Case of 60 economies. *Resources Policy*, *79*, 103116. https://doi.org/https://doi.org/10.1016/j.resourpol.2022.103116

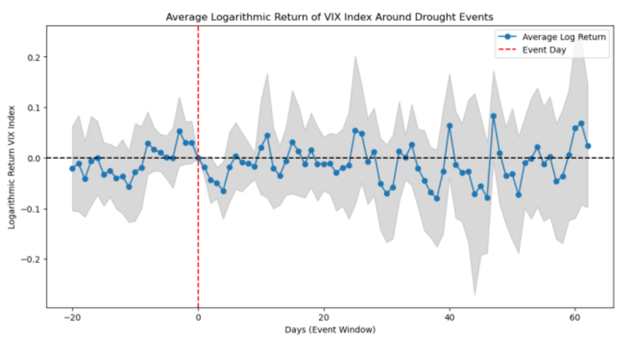
Ziegler, A., Busch, T., & Hoffmann, V. H. (2009). Corporate responses to climate change and financial performance: The impact of climate policy. *CER-ETH-Center of Economic Research at ETH Zurich, Working Paper*, *09/105*.

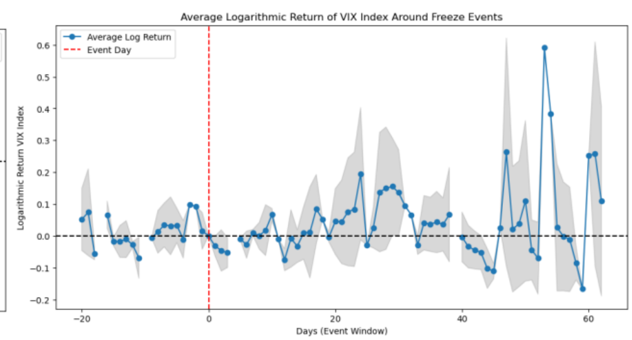
Appendixes

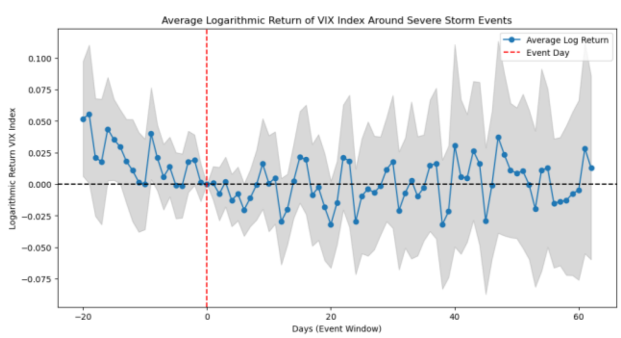
8.1 Average Log Return of VIX Index around Events

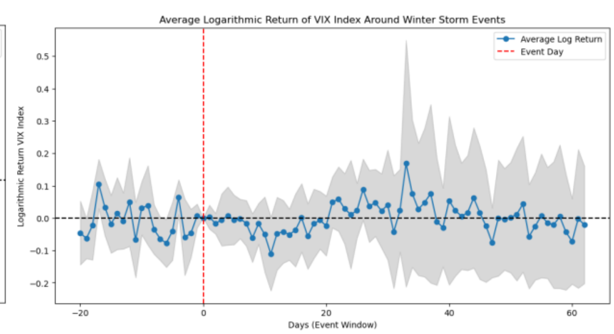


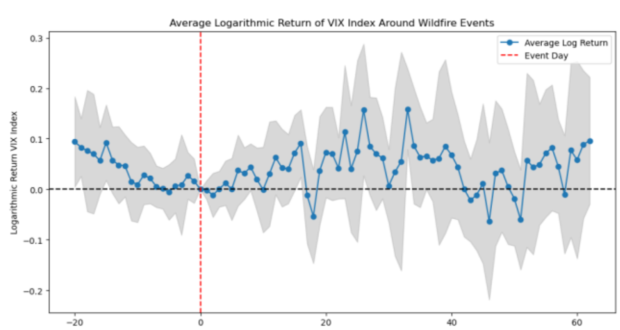












8.2 Average Log Return of NYSE Energy Index Around Events