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Research article

Climate change effects and their implications for the financial markets: Evidence from the United Kingdom

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ABSTRACT

This study aims to examine how the climate affects the behaviour of the stock market. To achieve this, we have drawn on daily data from Jan 2005 to Jan 31, 2023 and several environmental factors (e.g., temperature, humidity, cloud cover and visibility) to account for extreme weather conditions using the 21-day moving average and its standard deviation. The empirical analysis has revealed three key findings regarding the impact of weather on the stock market's behaviour. First, various forms of extreme weather conditions consistently lead to influence stock behaviour. Second, results provide valuable insights into market behaviour and help investors to make more informed investment decisions. Third, the weather conditions have new information about the climate risk and investors should react to it swiftly in light of our findings. The saliency theory can help reconcile the theoretical conflicts between the real options and risk-shifting theories when it comes to investing in uncertain and extreme climate conditions.

1. Introduction

Climate-related anomalies have gained popularity in academia and practice worldwide. Many studies indicate that recent climate change and weather events have adversely affected many countries (e.g., De Frenne et al., 2021; Riris and Arroyo-Kalin, 2019). As a result of climate change, crop and livestock losses have led to lower agricultural income, decreased employment, and increased poverty (e.g., Agovino et al., 2019; Ahmad et al., 2022). Because of these implications, climate change poses significant risks to economic stability and financial development (Biyena et al., 2021; Ferreira et al., 2020; Nasir et al., 2019).

Over the past 50 years, a weather, climate, or water disaster has struck almost every day, killing over a hundred people on average and causing US$202 million in losses, according to a comprehensive new report from the World Meteorological Organization (WMO, 2021). In the UK, climate crises cost €57 billion between 1980 and 2020, equivalent to almost €1000 per person, resulting in 3500 deaths. It is estimated that 70% of economic losses caused by these disasters were insured, but the UK ranks first among EEA (European Environment Agency) members in terms of the proportion of economic losses from extreme weather and climate events (Harvey, 2022). The EEA (2020) report indicates that flooding was the leading cause of economic losses due to extreme climate events, whereas heat waves caused the most deaths due to extreme weather and climate events. This study investigates and fills the gap in the development of concepts in the field of climate finance by combining theoretical frameworks and empirical data to assess the effects of extreme weather conditions on financial markets, particularly the UK stock market. The study examines how climate-sensitive enterprises modify their investment strategies in response to climatic anomalies by applying the salience theory of choice under risk (Bordalo et al., 2012). It aims to find a balance between risk-taking and conservative investment techniques (Rao et al., 2022). This study expands upon previous research by showcasing the substantial impact of climate risk on both the performance of companies and their financing decisions (Huang et al., 2018). Additionally, it offers

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valuable insights into how extreme weather occurrences shape economic and market behavior (Nasir et al., 2019). This holistic approach not only enhances the comprehension of climate finance but also emphasizes the need for adaptive solutions and governmental actions to reduce financial risks linked to climate change. Considering that macroeconomic outputs directly affect firm performance, we are motivated to extend the literature on economic behavior and climate finance by studying extreme climatic conditions in the UK context. Specifically, the impact of heat waves (i.e., temperature, humidity, cloud cover) and visibility on the stock market are measured through stock returns and volatility.

There are a number of reasons why we selected the UK as the research case. Firstly, compared to many other climates, the UK experiences a unique type of humid heat due to its location surrounded by the sea, resulting in high levels of humidity and precipitation. In contrast, countries like China have a range of climate types, including arid, semi-arid, temperate, and tropical, while the USA has a diverse climate profile, with regions that experience extreme heat and cold, hurricanes, and tornadoes (Bourdeau-Brien and Kryzanowski, 2020; Brown et al., 2012). As a result, the impact of extreme weather conditions on investment returns may differ across these countries due to differences in climate patterns. Secondly, the UK financial sector and stock market are among the oldest and most developed markets, with significant importance for the real economy due to their size (Nasir et al., 2015, 2018). Thirdly, the composition of the stock market and the industries represented can differ across these countries. For example, the UK stock market is dominated by financial, energy, consumer staples, real estate, and healthcare companies, while other stock exchanges around the world may have different sectoral compositions and therefore may respond differently to extreme weather conditions. For instance, the Shanghai Stock Exchange is dominated by companies in the financials, real estate, materials, manufacturing, and technology sectors (Chen et al., 2022). The S&P 500 in the USA is a broad-based index that tracks the performance of 500 large-cap companies across different sectors, including healthcare, technology, communication services, and consumer goods. The different industries represented in these indices can impact how extreme weather conditions affect index investment returns (Buch and Hoffmann, 2009; Nasir et al., 2019; Rao et al., 2022). Fourthly, there are differences in the political and regulatory environment across these countries. For example, the UK has taken several steps to address the impact of climate change and extreme weather conditions. The UK Climate Change Act, enacted in 2008, set legally binding targets for reducing greenhouse gas emissions and adapting to climate change. The UK significantly revised its stance in 2019, becoming the first country to set a legally binding Net-Zero target for emissions reduction (Nasir et al., 2019). This means that the UK is actively working to mitigate the impact of climate change and extreme weather conditions, providing valuable insights for investors looking to identify companies that are well-positioned to adapt to these challenges. However, differences in the political and regulatory environment can significantly affect how companies respond to extreme weather conditions and adapt to the challenges of climate change, which can, in turn, impact the performance of their respective stock markets.

Extreme climate and weather events such as heat waves and visibility have become more frequent, longer, and more intense due to global warming (Hansen et al., 2019; Rao et al., 2022). Higher levels of precipitation are one of the key factors contributing to climate change conditions, and these levels are directly related to the increase in atmospheric temperatures (Fischer and Knutti, 2015). Regarding heat waves, as high-pressure systems push warm and compressed air down toward the ground, the temperature rises (Hansen et al., 2019). Humidity and heat waves are closely related, as high humidity levels can exacerbate the impacts of heat waves. Humidity levels could have indirect effects on the broader economy, which could, in turn, affect the stock market. For example, high humidity levels could increase the likelihood of natural disasters such as floods or hurricanes, which could damage infrastructure and disrupt supply chains. This could lead to decreased economic activity and lower stock prices. From an investment perspective, visibility can impact various industries that rely on temperature patterns. For example, agriculture, forestry, and renewable energy industries are particularly vulnerable to changes in temperature fluctuations (Agovino et al., 2019; Rao et al., 2022). Poor visibility and cloudy weather can lead to reduced crop yields, lower timber production, increased food prices, and decreased energy output from solar farms. In light of the increasing extremes in climate events, our study aims to apply salience theory and examine the impacts of multiple extreme climate conditions (e.g., heat waves and visibility) on UK stock market behavior through the analysis of its returns and volatility dynamics. The majority of our findings are consistent, showing that extremely low temperatures, high humidity, high cloud cover, and high visibility have a significant impact on stock index returns. It was discovered that extremely low temperatures with low cloud cover and extremely high temperatures with high cloud cover influence stock returns among the interaction terms for all weather variables. Overall, we can determine that extreme temperature circumstances will have a greater impact on stock market dynamics, specifically its returns and volatility. Moreover, the findings of this study, which specifically examines the UK stock market, are consistent with and build upon previous studies undertaken in other climate-sensitive regions and markets, emphasizing both commonalities and distinct variations. U-Din et al. (2022) discovered that weather disasters had a substantial effect on both stock market returns and volatility in Canada, which aligns with our own findings concerning the United Kingdom. Nevertheless, the distinctive environment of the UK, which is marked by elevated humidity and frequent rainfall, gives rise to particular market behaviors that are not seen in drier or tropical areas. Studies conducted in the USA, such as the research conducted by Wang and Kutan (2013), illustrate how distinct climatic events, such as hurricanes and tornadoes, affect market volatility. This highlights the vast range of climate impacts that may occur in different geographical locations. Furthermore, studies conducted in developing markets, such as the ASEAN area examined by Nasir et al. (2019), demonstrate that the development of financial systems and economic growth have a substantial impact on the implications of climate change. This relationship is equally applicable in the UK's well-established financial industry, albeit it is portrayed differently. Therefore, although there are general tendencies in how climate affects financial markets and investor decisions, specific patterns of market reaction emerge due to regional meteorological and economic factors (Chaudhry et al., 2023).

Our study provides the following key contributions. First, it was discovered that extreme weather conditions of various forms regularly impact stock index returns and volatility. As a result, investors may decide to adjust their portfolios to reduce possible losses. Similarly, investors may seek opportunities to invest in sectors or businesses that are likely to profit from these circumstances if consistently low temperatures are linked to higher stock returns. Second, our research provides a clear understanding of the connection between weather and stock returns, as well as valuable market insights that help investors make better investment choices. Third, our findings provide insight into the notion that investors in the stock market are quick to adjust index moments in accordance with changing weather conditions, which the UK stock market acknowledges. Our study also contributes by extending the salience theory to analyze the behavior of the stock market. In doing so, we examine how extreme climate events affect index returns. Studies (e.g., Bourdeau-Brien and Kryzanowski, 2020; Huang et al., 2018; Johar et al., 2022; Rehdanz et al., 2015) have found that natural disasters lead to low-income generations. For example, Huang et al. (2018) show that heat waves, flooding, and storms are associated with lower earnings and more volatile cash flows. Similarly, studies have indicated that extreme drops in temperature can cause firms to rely on a larger credit limit, ultimately leading to a decline in productivity (Lohani et al., 2022; Möllmann et al., 2020). In contrast to these studies that link extreme climate conditions to operational and financial performance, our study examines how stock market behavior and performance are impacted by climate crises. By examining the relationship between extreme climate conditions and stock market returns and volatility, we add to the literature on economic behavior and market-based firm valuation. Lastly, through the lens of salience theory, our study shows that businesses whose financial and operational performance is vulnerable to extreme climate and weather events need to employ a distinct climate change corporate investment strategy. Consequently, we contribute to a growing body of literature examining how climate change investment strategies affect risk-taking behavior and corporate investment policy decisions (Huang et al., 2018; Nasir et al., 2019; Rao et al., 2022).

The remainder of the paper is organized as follows. The second section provides a conceptual framework, reviews relevant literature, and develops hypotheses. In section 3, we discuss the data and methodology. In section 4, we present and discuss the empirical results. Finally, section 5 concludes the paper.

2. Theoretical underpinning and literature review

2.1. Theoretical underpinning

Under extreme climate conditions, there is no consensus on the direction of investment intensity, creating an environment of uncertainty. Risk-shifting theory, for example, suggests that abnormal extreme climate conditions should increase capital expenditure by climate-sensitive firms (Rao et al., 2022). However, based on the real-options view, climate-sensitive firms are expected to decrease capital expenditures due to the possibility of halting manufacturing, thus lowering production (Busch and Hoffmann, 2009; Tyler and Chivaka, 2011). Taking these two opposing views into account, our study employs the salience theory of choice under risk (Bordalo et al., 2012) to estimate how managers select different corporate investment strategies in response to extreme climate and weather events.

According to salience theory, managers of firms whose performance is highly influenced by climate conditions are particularly sensitive to the impacts of extreme climate and weather conditions within our context of extreme climate conditions (heat waves and visibility). Various ramifications of extreme climate conditions have been observed by managers. For example, underutilization of production capacity, low market demand, cash shortages are considered as a result of low market demand, and disruption of food and water supplies (Agovino et al., 2019; Lohani et al., 2022). Heat waves and visibility conditions can, however, affect saliency differently. It is more likely that operating assets will be partially destroyed when climate conditions are excessive, while production capabilities will be underutilized when climate conditions are deficient.Extreme climate events can also impact index returns, particularly for sectors that are sensitive to weather patterns and air quality. It means that some certain sectors can still gain positive effects under some poor weather situation. For example, companies in the agriculture, forestry, and renewable energy sectors may experience decreased earnings and lower stock prices during periods of drought or poor visibility, while companies in the air filtration and purification sector may experience increased demand and higher stock prices during periods of poor air quality (Salinger and Alexander, 2020; Tzouvanas et al., 2019). Furthermore, visibility can impact consumer behavior and spending patterns. During periods of poor air quality or extreme heat, consumers may be less likely to engage in outdoor activities, leading to decreased revenue for companies in the tourism, outdoor recreation, and hospitality sectors. Conversely, during periods of favorable weather conditions, these sectors may experience increased demand and higher revenues. Overall, while extreme climate events may not be a direct factor in determining index returns, their impact on various industries and consumer behavior can indirectly affect stock prices and market performance. It's important for investors to consider the potential impact of climate change on their investments and adjust their strategies accordingly (Huang et al., 2018). This may involve diversifying their portfolios across different sectors and industries or identifying companies that are better positioned to withstand or even benefit from the effects of poor visibility. Our assumption implies that climate-sensitive firms may employ different corporate investment strategies depending on their exposure to heterogeneous extreme climate events.

Therefore, our research combines saliency theory with real options and risk-shifting theories to analyze the impact of extreme climatic conditions and the perceived importance of these risks on firms' investment choices. The idea of saliency suggests that decision-makers prioritize the most conspicuous risks and opportunities, which is especially important in situations of climate uncertainty (Bordalo et al., 2012). The real options theory posits that firms may defer investments in times of significant uncertainty to maintain flexibility, as suggested by Busch and Hoffmann (2009). Conversely, the risk-shifting theory contends that firms may engage in riskier investments during periods of financial distress to potentially optimize shareholder value, as argued by Rao et al. (2022). The study examines how firms modify their investment strategies in response to extreme weather events, revealing that they consider the significance of climate risks. This provides detailed insight into the functioning of real options and risk-shifting theories in the field of climate finance (Nasir et al., 2019). This integration enables a thorough examination of investment dynamics in the context of climate change, emphasizing the interaction between retaining adaptability and mitigating risk.

2.2. Extreme climate conditions and market-based value effect

Due to the existence of fat tail probabilities in extreme climate events (Ferreira et al., 2020), the socio-economic impacts of climate change are both uncertain and risky. It is generally believed that extreme climate conditions, usually related to tangible asset damages and significant economic distress, have a substantial negative impact on economic activity and output (Huang et al., 2018; Nasir et al., 2019; Tyler and Chivaka, 2011). Extreme climate events (e.g., heat waves, humidity, storms, torrential rains, and winds) have been found to create conditions of uncertainty and financial distress across a wide range of climate-sensitive industries, including agriculture (Agovino et al., 2019; Biyena et al., 2021; Möllmann et al., 2020), construction (Hepburn et al., 2020), tourism & leisure (Sigala, 2020; Gössling et al., 2020), traditional and renewable energy (Chen et al., 2023; Donadelli et al., 2021; Mhadhbi et al., 2021), fisheries, and forestry (De Frenne et al., 2021; Gomez-Zavaglia et al., 2020). It is clear from the existing literature that extreme climate conditions impact various stakeholders in society, including households, firms, financial markets, and governments, in a substantial manner. Various climate conditions have resulted in significant loss of earnings, poor living conditions, high costs of business collaborations, and low operational productivity (Freire-González et al., 2017; Huang et al., 2018).

Considering that a firm's market price is a reflection of its future cash flows, extreme weather conditions create greater uncertainty and risk for the firm's future cash flows. Industries that are sensitive to climate are more likely to experience lower share prices because their capital costs are higher to cope with extreme weather conditions (Rao et al., 2022). Moreover, the market should see lower share prices due to the information asymmetry triggered by extreme and unpredictable climate events (Busch and Hoffmann, 2009; Huang et al., 2018; Huynh et al., 2021) as it awaits strategic responses from the affected climate-sensitive firms to address cash flow uncertainty. It has been shown that higher levels of uncertainty are associated with increased risk premium and a higher cost of capital at the firm level (Rao et al., 2022). Due to extreme climate conditions, investors demand a greater return on investment when cash flow and managerial actions are uncertain, resulting in a lower market value for the firm.

Whenever extreme weather conditions negatively impact the productivity and operational performance of firms, it is likely that the market will discount their future cash flows and increase their implied discount rates. Furthermore, this notion is consistent with previous empirical and theoretical evidence regarding the impact of extreme climate phenomena on stock markets, including extreme temperatures (Donadelli et al., 2021; Fischer and Knutti, 2015; Tzouvanas et al., 2019) and extreme heat (Ahmad et al., 2022; Rao et al., 2022; Salinger and Alexander, 2020).

2.3. Extreme climate conditions and corporate investment

Climate-sensitive firms are faced with the decision of whether to invest in capacity after experiencing an extreme climate event in which they must manage uncertainties and future demands (Tyler and Chivaka, 2011). Due to the irreversible nature of investments, firms are expected to carefully evaluate their corporate investment strategies after extreme climate events. Two competing views of risk-taking under distress and uncertainty are examined in the traditional economic behavior literature based on corporate investment decisions.

First, according to the risk-shifting theory, firms are more inclined to make risky investment decisions during periods of distress (Black and Scholes, 1973; Rao et al., 2022). Thus, managers may choose to shift away from safer assets and towards riskier ones when firms are experiencing financial distress and uncertainty because excessive risk-taking increases the likelihood that shareholders will gain disproportionately (Rao et al., 2022). In accordance with the risk-shifting theory, climate-sensitive companies should increase corporate investments to compensate for the uncertainty and financial distress associated with extreme weather conditions. Second, the real options approach to corporate investment advocates delaying investments until more information has been gained rather than making immediate investments (Bordalo et al., 2012; Tyler and Chivaka, 2011). In a real-options framework, a decrease in investments is predicted after extreme climate conditions since high uncertainty increases the likelihood of delaying investment decisions.

Neither of the two traditional economic behavior views can offer a comprehensive framework for evaluating investments when firms face heterogeneous weather conditions. Using salience theory, different corporate investment strategies can be pursued based on the salience of past experiences under various extreme climate conditions. Salience theorists suggest decision-makers are risk-seeking when the potential rewards of a decision are salient and risk-averse when the downsides are salient (Bordalo et al., 2012; Rao et al., 2022). In our study, we argue that climate-sensitive firms would pay more attention to the salience of different climate conditions (e.g., heat waves and visibility). Several factors contribute to this situation, such as cash shortages, damages to operating assets and buildings, increased operational costs, strategy renewals, or the demand for substantial investments (Donadelli et al., 2021; Ferreira et al., 2020). Furthermore, a firm that is susceptible to extreme climate conditions may implement different investment strategies to cope with different climate conditions (e.g., temperature, humidity, cloud cover, and visibility).

In line with salience theory, corporate investment decisions are context-dependent. Therefore, climate-sensitive firms may pursue investment strategies differently under excess and deficit climate conditions (e.g., high and low sun brightness), resulting in different returns on investment frontiers (Huang et al., 2018). Utility-maximizing managers should respond to such differential investment opportunities to maximize firm value. Essentially, managers should increase (or decrease) investments when an extreme climate event triggers a favorable (or unfavorable) opportunity. It should be noted that both strategies aim to maximize firm value. Several studies (e.g., Hansen et al., 2019; Harvey, 2022; Huang et al., 2018) claim that firms sensitive to extreme climate conditions experience negative impacts on their production and operational activities due to sluggish economic conditions, which affect aggregate demand and production, as well as damage to their physical infrastructure. Accordingly, firms that are climate-sensitive should invest more after extreme climate events, at least to regain lost production capacity and market value. However, this post-extreme climate period may be a good time to invest in expanding firms' current capabilities and implementing better technologies (Donadelli et al., 2021; Ferreira et al., 2020), offering a favorable window of opportunity for capital investment.

Conversely, climate-sensitive firms can suffer from reduced demand and underutilization of production and operational capacity under deficit-climate conditions (e.g., low sun brightness) (Rao et al., 2022). Despite no tangible assets being damaged, the decrease in production and higher opportunity cost resulting from underutilized capacity can affect the firms' value, particularly in the short term. A scenario of underutilized capacity may result in deadweight costs since additional investments following poor weather periods would only add to the unused capacity. Based on this logic, our study contends that firms sensitive to climate deficits do not have favorable investment opportunities and are highly unlikely to invest when such conditions persist, ultimately impacting their performance in market-based valuation.

2.4. Extreme climate conditions, corporate investments and stock returns

According to the shareholder value maximization hypothesis, firms perceived to enhance value through their corporate investment strategies are likely to receive positive rewards in the stock market, while those that do not may face negative consequences (see Battilana et al., 2022). Salience theory suggests that climate-sensitive firms may adopt different investment strategies to maximize firm value following extreme climate conditions (Busch and Hoffmann, 2009; Rao et al., 2022). Nevertheless, empirical research is needed to determine whether these strategies are adopted by firms. Chen et al. (2022) provide empirical evidence suggesting that management decisions may not always be rational or in the best interest of shareholders, consistent with agency theory and the social capital theory of managerial self-interest.

Based on shareholder theory (Clark and Crawford, 2011), investors who expect managers to achieve shareholder wealth maximization are likely to pay closer attention to the actions of climate-sensitive firms following extreme climate conditions. Furthermore, managers are obligated to prioritize investment strategies that maximize shareholder value (Flammer et al., 2021), especially during times of unforeseeable distress caused by events such as irregular climate conditions. This underscores the critical importance of fulfilling their fiduciary duty. On the other hand, according to stockholder value maximization theories (Battilana et al., 2022), climate-sensitive firms should be rewarded for implementing sustainable investments that enhance firm value. Following extreme climate conditions, corporate investments made by climate-sensitive firms should lead to a positive stock market response, as prescribed by salience theory. However, managers often make irrational investments due to managerialism and agency issues at the expense of shareholders (Chen et al., 2022; Battilana et al., 2022). For example, Chen et al. (2022) find that overconfident CEOs overestimate their ability to manage time and enhance the value of their firms due to their short-termist mindset. Previous literature indicates that corporate investments are not always rational or value-maximizing (Dushnitsky and Lenox, 2006; Li et al., 2020). Brada et al. (2022) demonstrate that foreign direct investment can cause the stock market to react negatively to a firm's arbitration under the concept of value-destroying behavior. As a result, if managers fail to follow the investment strategies prescribed by salience theory, the market will react negatively. Thus, extreme climate conditions are likely to affect the return on investment in the stock market.

2.5. Global financial impact of climate change and extreme weather

Throughout the research period, several historical weather phenomena, such as the intense heatwave in the UK in 2006 and the very cold period in the winter of 2010–2011, had a significant influence on market volatility and returns. The 2006 heatwave resulted in substantial disruptions in the agriculture and energy industries, leading to market swings. Likewise, the cold spell during the 2010–2011 period led to a rise in energy consumption and interruptions in the supply chain, impacting stock prices and market stability. The impacts of severe weather on financial markets have been extensively studied by Wang and Kutan (2013) and U-Din et al. (2022), who have provided comprehensive documentation of these events. In recent years, there has been much focus on the association between climate change, extreme weather occurrences, and financial markets. Studies highlight the widespread influence of climate anomalies on economic stability, financial performance, and market behavior. Huang et al. (2018) provided evidence that climate risk has a detrimental effect on both the financial performance and financing decisions of companies in different industries globally. Similarly, Nasir et al. (2019) investigated the impact of financial development, economic growth, and foreign direct investment on climate change in growing ASEAN nations. They highlighted the complex relationship between economic activities and their environmental consequences. According to Harvey's (2022) report, Europe has incurred costs of around €500 billion over a span of 40 years due to extreme weather events. The UK has particularly suffered significant economic losses as a result of flooding and heatwaves. These findings align with the European Environment Agency's (2020) report, which emphasized the considerable economic and human impacts of weather-related disasters in Europe. The stock market's reaction to severe weather in the UK exhibits noteworthy similarities and distinctions when compared to nations such as Japan and Canada. Research suggests that, similar to the United Kingdom, the market in Japan shows a high response to typhoons and earthquakes, resulting in considerable instability and unfavorable financial outcomes (Wang and Kutan, 2013). In Canada, both extreme cold and heatwaves have a similar impact on market stability, emphasizing the influence of climate on financial performance (U-Din et al., 2022). However, the distinct categories of meteorological phenomena and their occurrence rates vary, leading to different levels of market sensitivity and adjustments in each region.

An essential field of research is the response of the stock market to climate change. Beatty and Shimshack (2010) presented empirical data demonstrating the substantial influence of climate change information on stock market returns. Their study highlights the response of market players to environmental news. In particular, the release of climate ratings made a significant impact on capital market returns, which seemed to penalize firms due to poor climate performance ratings. Moreover, in terms of the asymmetric effect, the negative ratings had a more profound market impact than positive ones, in other words, negative environmental information tends to create more significant market reactions than positive information. Wang and Kutan (2013) analyzed the influence of natural disasters on stock markets in Japan and the US, discovering substantial effects on market volatility and investor behavior. Various industries display different degrees of susceptibility to the impacts of climate change. Donadelli et al. (2021) examined the impact of global temperature fluctuations on research and development (R&D) spending and economic growth, emphasizing the lasting consequences for innovation and industrial efficiency. Agovino et al. (2019) studied the agriculture sector, examining how climate change affects sustainability in the EU-28. They highlighted the importance of implementing adaptive methods to reduce the negative impact on food supply and security. Corporate solutions to climate change are essential for reducing financial risks. Rao et al. (2022) examined how companies affected by climate change adapt their investment strategies in light of severe weather events, finding a delicate equilibrium between taking risks and adopting a more conservative approach to investing. This is consistent with the salience hypothesis of decision-making under risk, which proposes that enterprises' investment choices are affected by how noticeable climate concerns are (Bordalo et al., 2012). Investor behavior in relation to climate change concerns is an important area of emphasis. The results indicate that both risk-averse and risk-seeking investors adjust their portfolios based on the significance of climate-related risks, with risk-averse investors favoring safer assets during extreme weather conditions. However, limitations include potential data biases, the UK market focus, and the need for more detailed studies across other industries and regions to generalize these behaviors globally. The studies conducted by Huang et al. (2018) and Rehdanz et al. (2015) demonstrate that catastrophic weather occurrences result in heightened uncertainty and instability in financial markets. As a result, investors tend to choose safer assets or demand larger returns to compensate for perceived risks. Additionally, regulatory initiatives such as the UK's Climate Change Act and the Net-Zero emissions target have a substantial impact on the behavior of corporations and investors, encouraging them to adopt more sustainable practices (Nasir et al., 2019).

3. Data and methodology

3.1. Data

3.1.1. Stock returns

The sample data applied in this study contains the daily FTSE100 stock index from January 1, 2005, to January 31, 2023, with a total of 4703 observations. We extracted the daily index data from Thomson Reuters Datastream. The dataset includes long time series data and uses the natural logarithm of daily stock index returns. Equation (1) is used for the daily return of the ith stock index on day t by continuously compounded return (log returns):

$$r_{it} = ln(P_t - P_{t-1}) / P_{t-1} * 100) \quad (1)$$

r_{it} = *Log daily return of stock/index i on day t.*
P_{it} = *Closing price of* stock/*index i on day t.*
P_{it-1} = *Closing price of stock/index i on day t* − 1.

3.1.2. Weather variables

We take into account the daily weather data for London, UK from January 1, 2005, to January 31, 2023, sourced from the official website of Visual Crossing Weather (https://www.visualcrossing.com/weather-data). For the weather variables, we accounted for several factors including temperature (temp), humidity, cloud cover, and visibility. The chosen weather variables—temperature, humidity, cloud cover, and visibility—effectively capture the full spectrum of severe weather conditions in the UK, including heatwaves, cold spells, high humidity, dryness, overcast skies, clear skies, fog, and heavy precipitation. These variables provide a comprehensive understanding of the weather extremes impacting the UK's climate-sensitive financial markets. The study concluded the sample in early 2023 due to logical factors concerning data integrity, relevance, and practical issues. Using data up to early 2023 ensures accuracy and comprehensiveness, as financial and climatic data for the entire year might be incomplete. This timeframe allows for a thorough examination of nearly twenty years (January 2005 to January 2023), capturing significant climatic events and market changes, providing a robust basis for observing trends. Ending the research in early 2023 also ensures a timely contribution to current academic and policy discussions.

3.2. Methodology

All weather variables are converted to dummy variables to account for seasonal factors, allowing for an examination of the impact of weather on returns and volatility. For instance, 18 °C is considered moderate in the winter but rather cold in the summer. Using raw weather data often produces highly improbable outcomes, consistent with previous weather investigations in the literature. The literature on the weather effect suggests several methods to eliminate the seasonal aspect. A method using the 31-day moving average (MA) and moving standard deviation (MSD) was first developed by Yoon and Kang (2009).

Our study uses the same methodology as Yoon and Kang (2009) and considers the 21-day (three weeks) MA-MSD techniques. Equations (2) and (3) are used to determine the 21-day MA and MSD for all meteorological variables. The 21-day moving average and its standard deviation were chosen to smooth short-term fluctuations and capture longer-term weather patterns, balancing responsiveness and stability. This period aligns with typical investment horizons and market behavior. Different intervals could offer distinct insights, highlighting more immediate or prolonged effects of weather on market dynamics:

$$MA(W_t) = \frac{1}{21}\left(W_{t-10} + W_{t-9} + \ldots + W_t + \ldots + W_{t+9} + W_{t+10}\right), \quad (2)$$

$$\alpha(W_t) = \sqrt{\frac{1}{20}\sum_{i=-10}^{10}\left(W_i - MA\left(W_i\right)\right)^2} \quad (3)$$

Where W_t is the daily value of all meteorological variables at any given time t. We created two dummy variables for each weather factor based on extreme above-average and extreme below-average weather conditions, assuming that extreme weather situations may have more substantial effects on stock index returns than regular weather conditions.

$$If\ WLD_t = W_t < [MA(W_t) - \alpha(W_t)],\ then\ WLD_t = 1;\ otherwise = 0,\ and$$

$$If\ WHD_t = W_t > [MA(W_t) + \alpha(W_t)],\ then\ WHD_t = 1;\ otherwise = 0$$

WLD = dummy variable for extreme below-average weather.

WHD = dummy variable for extreme above-average weather.

Table 1 provides a summary of the weather dummies. We have applied various methods to examine the weather effects on index returns. For instance, we use Equations (4) and (5) for the weather effect on returns through a regression model with all weather variables and their interaction terms.

$$R_t = \mu + b_1 tmL + b_2 tmH + b_3 humL + b_4 humH + b_5 ccL + b_6 ccH + b_7 visL + b_8 visH + \varepsilon_t \quad (4)$$

$$R_t = \mu + b_1 tmL + b_2 tmH + b_3 humL + b_4 humH + b_5 ccL + b_6 ccH + b_7 visL + b_8 visH + b_9 tmL * hmL + b_{10} tmL * ccL + b_{11} tmL * visL + b_{12} tmH * humH + b_{13} tmH * ccH + b_{14} tmH * visH + b_{15} humL * ccL + b_{16} humL * visL + b_{17} humH * ccH + b_{18} humH * visH + b_{19} ccL * visL + b_{20} ccH * visH + \varepsilon_t \quad (5)$$

Equations (6) and (7) are used with day and month effect of weather of returns:

Table 1
Summary of weather dummies.

Weather Dummies	Description
tmL	Extremely low temperature
tmH	Extremely high temperature
humL	Extremely low humidity
humH	Extremely high humidity
ccL	Extremely low cloud cover
ccH	Extremely high cloud cover
visL	Extremely low visibility
visH	Extremely high visibility

$$R_t = \mu + \alpha_1 Monday + \alpha_2 Tuesday + \alpha_3 Wednesday + \alpha_4 Thursday + b_1 tmL + b_2 tmH + b_3 humL + b_4 humH + b_5 ccL + b_6 ccH + b_7 visL + b_8 visH + b_9 tmL * hmL + b_{10} tmL * ccL + b_{11} tmL * visL + b_{12} tmH * humH + b_{13} tmH * ccH + b_{14} tmH * visH + b_{15} humL * ccL + b_{16} humL * visL + b_{17} humH * ccH + b_{18} humH * visH + b_{19} ccL * visL + b_{20} ccH * visH + \varepsilon_t \quad (6)$$

$$R_t = \mu + \alpha_1 Jan + \alpha_2 Feb + \alpha_3 Mar + \alpha_4 Apr + \alpha_5 May + \alpha_6 Jun + \alpha_7 Jul + \alpha_8 Aug + \alpha_9 Sep + \alpha_{10} Oct + \alpha_{11} Nov + b_1 tmL + b_2 tmH + b_3 humL + b_4 humH + b_5 ccL + b_6 ccH + b_7 visL + b_8 visH + b_9 tmL * hmL + b_{10} tmL * ccL + b_{11} tmL * visL + b_{12} tmH * humH + b_{13} tmH * ccH + b_{14} tmH * visH + b_{15} humL * ccL + b_{16} humL * visL + b_{17} humH * ccH + b_{18} humH * visH + b_{19} ccL * visL + b_{20} ccH * visH + \varepsilon_t \quad (7)$$

We have also applied the following logit model analysis equation and created a dummy variable for the dependent variable based on the rationale of Equation (1) (WLD and WHD). Our dependent variable is considered in Equations (8) and (9), and all descriptions of the other weather-independent variables are as explained above.

$$stretL_t = \mu + b_1 tmL + b_2 tmH + b_3 humL + b_4 humH + b_5 ccL + b_6 ccH + b_7 visL + b_8 visH + b_9 tmL * hmL + b_{10} tmL * ccL + b_{11} tmL * visL + b_{12} tmH * humH + b_{13} tmH * ccH + b_{14} tmH * visH + b_{15} humL * ccL + b_{16} humL * visL + b_{17} humH * ccH + b_{18} humH * visH + b_{19} ccL * visL + b_{20} ccH * visH + \varepsilon_t \quad (8)$$

$$stretH_t = \mu + b_1 tmL + b_2 tmH + b_3 humL + b_4 humH + b_5 ccL + b_6 ccH + b_7 visL + b_8 visH + b_9 tmL * hmL + b_{10} tmL * ccL + b_{11} tmL * visL + b_{12} tmH * humH + b_{13} tmH * ccH + b_{14} tmH * visH + b_{15} humL * ccL + b_{16} humL * visL + b_{17} humH * ccH + b_{18} humH * visH + b_{19} ccL * visL + b_{20} ccH * visH + \varepsilon_t \quad (9)$$

$stretL_t$ = extreme low stock index returns

$stretH_t$ = extreme high stock index returns

To represent time-varying volatility, we consider a GARCH (1, 1) model in Equation (10):

$$h_t = \omega + \alpha\varepsilon_{t-1}^2 + \beta h_{t-1} \quad (10)$$

Stochastic error ε_t is normally distributed

h_t is conditional variance

All parameters $(\omega, \alpha\ and\ \beta)$ must be positive

Sum of $\alpha + \beta < 1$ *quanties the persistency of shocks to volatility.*

3.3. Descriptive statistics

The variables are described statistically in Table 2. Throughout the period from January 2005 to January 2023, the average change in temperature (temp) was 11.74, indicating that over a period of one and a half decades, the actual temperature in London was, on average, cold and wintry. In addition, the table shows that the average changes in humidity, cloud cover, visibility, and index returns were 75.95, 60.18, 21.35, and 6295.19, respectively.

By comparing the standard deviations of all the variables, we can see that the percentage change in humidity and cloud cover in London, with standard deviations of 10.47 and 20.5 respectively, is much higher than that of the other related weather variables. This demonstrates how unstable the humidity and cloud cover are in London weather.

Table 2
Descriptive statistics of all the variables.

Variable Names	number of observations	mean	Sd	median	trimmed	mad	min	max	range	skew	kurtosis	se
Indexreturns	4703	6295.19	881.94	6339.97	6346.61	972.44	3512.09	7877.45	4365.36	−0.46	−0.3	12.84
Temp	4703	11.74	5.49	11.7	11.78	6.23	−3.2	30.3	33.5	−0.03	−0.54	0.08
Humidity	4703	75.95	10.47	77	76.37	11.42	36	98.9	62.9	−0.37	−0.41	0.15
Cloudcover	4703	60.18	20.5	62.1	61.32	20.16	0	100	100	−0.5	−0.03	0.3
Visibility	4703	21.35	8.72	20.9	21.25	9.34	0.3	48.8	48.5	0.14	−0.49	0.13

Additionally, visibility is slightly right-skewed, whereas the other weather variables are slightly left-skewed.

4. Empirical results

4.1. Weather effect on returns using 21-day MA-MSD method

Table 3 reports the results of the regression analysis using the 21-day MA-MSD method. Using Equation (4), our results show that extremely high humidity (humH) and extremely high visibility have a significantly negative influence on stock index returns. However, extremely low temperature and high cloud cover have a significantly positive influence on stock returns. Based on Equation (5), we conducted regression analysis among the interaction terms for all weather variables and found that tmL*ccL and tmH*ccH have a significantly positive influence on stock returns. Overall, we can predict that extreme temperature conditions have a greater influence on stock returns. Our results are contradicting with U-Din et al. (2022), whose findings suggest a significant negative influence of weather catastrophes on stock market returns and volatility. Meanwhile, our results provide a more detailed breakdown of how extreme high and low temperatures along with the interaction terms for all weather variables impact stock market returns. As a result, there is evidence that some variables (factors) have a positive impact on the stock market returns.

Table 3
Weather effect on returns using 21-day MA-MSD method.

Dependent Variable = Index Returns		
	Model Equation (4)	Model Equation (5)
tmL	0.001[b]	0.001
	(-0.0004)	(-0.001)
tmH	−0.0005	−0.001[a]
	(-0.0005)	(-0.001)
humL	0.0003	0.0002
	(-0.0005)	(-0.001)
humH	−0.001*	−0.001[b]
	(-0.0005)	(-0.001)
ccL	0.0001	−0.001
	(-0.0005)	(-0.001)
ccH	0.001[a]	0.0004
	(-0.0005)	(-0.001)
visL	0.0005	0.001
	(-0.0005)	(-0.001)
visH	−0.001*	−0.001
	(-0.0005)	(-0.001)
tmL:humL		−0.001
		(-0.001)
tmL:ccL		0.002[b]
		(-0.001)
tmL:visL		−0.001
		(-0.001)
tmH:humH		0.002
		(-0.001)
tmH:ccH		0.002[a]
		(-0.001)
tmH:visH		−0.001
		(-0.001)
humL:ccL		0.001
		(-0.001)
humL:visL		0.0003
		(-0.002)
humH:ccH		0.0003
		(-0.001)
humH:visH		0.003
		(-0.004)
ccL:visL		0.001
		(-0.002)
ccH:visH		−0.001
		(-0.002)
Constant	1.000[c]	1.000[c]
	(-0.0003)	(-0.0003)
Observations	4703	4703
R2	0.003	0.006

Note: We have applied weather effect on returns using 21-day MA-MSD method and highlighted significance level at.
[a] $p < 0.1$.
[b] $p < 0.05$.
[c] $p < 0.01$.

4.2. Weather effect on the returns using 21-day MA-MSD method – (Adding Day and Month Effects)

Table 4 reports the results of regression analysis using the 21-day MA-MSD method, taking days and months effects into consideration. Model Equation (6) results illustrate that all weekday effects are positively significant and higher than returns on Fridays (reference day). This indicates that a calendar effect exists in stock returns. Model Equation (7) shows the month effect, with the estimated value of the February effect dummy (Feb) significant at the 5% level in the stock returns, implying that there are month effects on the stock market. This suggests that lower temperatures predominantly impact stock index returns. Our results are also consistent with insights from the study conducted by Beatty and Shimshack (2010), who examined climate change information and a plausibly exogenous event, finding that climate change information has a significant influence on returns during both weekdays and months.

4.3. Logit model analysis

We have examined the weather effect on returns using the 21-day MA-MSD method by adopting stock index dummy variables as the dependent variables. In this logit analysis, we divided our returns into extremely low returns and extremely high returns and used dummy variables for extreme low and high in model Equations (8) and (9), respectively. The following logit regression model Equation (8) has been used on extremely low returns with weather effects. Moreover, model Equation (9) has been used on extremely high returns with weather effects.

stretL = extreme low stock returns
stretH = extreme high stock returns.

In Table 5, model Equations (8) and (9) illustrate extremely low and high stock returns as the dependent variables. Our results indicate that extremely high index returns are more influenced compared to extremely low index returns. For example, Equation (9) shows that *tmH* has a statistically negative influence on extremely high returns, along with a statistically positive association with *tmLccL, tmHhumH,* and *tmHvisH*. On the other hand, extremely low returns in Equation (8) have a statistically significant association with *humL*ccL*. Our analysis suggests that extreme lower and higher stock index returns may be

Table 4
Weather effect on the returns using 21-day MA-MSD method – (Adding Day and Month Effects).

Dependent Variable = Index Returns		
	Model Equation (6)	Model Equation (7)
Monday	0.001[a]	
	(-0.001)	
Tuesday	0.001[a]	
	(-0.001)	
Wednesday	0.002[c]	
	(-0.001)	
Thursday	0.001[b]	
	(-0.001)	
Jan		−0.0001
		(-0.001)
Feb		−0.002[b]
		(-0.001)
Mar		0.001
		(-0.001)
Apr		−0.0003
		(-0.001)
May		−0.001
		(-0.001)
Jun		0.0002
		(-0.001)
Jul		−0.001
		(-0.001)
Aug		−0.0004
		(-0.001)
Sep		−0.001
		(-0.001)
Oct		−0.001
		(-0.001)
Nov		−0.0002
		(-0.001)
tmL	0.001[a]	0.001[b]
	(-0.0004)	(-0.0005)
tmH	−0.0004	−0.001
	(-0.0005)	(-0.0005)
humL	0.0003	0.0002
	(-0.0005)	(-0.0005)
humH	−0.001*	−0.001[a]
	(-0.0005)	(-0.001)
ccL	0.0001	0.0001
	(-0.0005)	(-0.0005)
ccH	0.001[a]	0.001[a]
	(-0.0005)	(-0.0005)
visL	0.0005	0.0004
	(-0.0005)	(-0.0005)
visH	−0.001[a]	−0.001[a]
	(-0.0005)	(-0.0005)
Constant	−0.001[b]	0.001
	(-0.0004)	(-0.001)
Observations	4703	4703
R2	0.005	0.006

Note: We have applied Weather effect on the returns using 21-day MA-MSD method – (Adding Day and Month Effects).
and highlighted significance level at.
[a] $p < 0.1$.
[b] $p < 0.05$.
[c] $p < 0.01$.

influence by specific weather effects. Therefore, investors are looking for more disclosure to avoid any abnormal returns (e.g., see Feltmate et al., 2020; Wang and Kutan, 2013).

4.4. Weather effect on volatility

4.4.1. Using GARCH model

We also investigate the weather effect on volatility by applying the GARCH (1,1) model. Table 6 summarize the t statistics of several weather dummies in model Equation (10). The parameter values are positive and the sum of the $\alpha + \beta < 1$ which complies with the non-negativity limitation and stationarity in conditional variances,

Table 5
Logit model analysis.

	Dependent Variable = Extreme low (high) Index Returns	
	Model Equation (8) (stretL)	Model Equation (9) (stretH)
tmL	0.007	−0.024
	(-0.019)	(-0.022)
humL	−0.015	−0.009
	(-0.02)	(-0.023)
ccL	−0.032	−0.003
	(-0.021)	(-0.025)
visL	−0.01	−0.001
	(-0.017)	(-0.02)
tmH	0.009	−0.037[a]
	(-0.017)	(-0.02)
humH	0.018	−0.031
	(-0.02)	(-0.023)
ccH	0.006	0.037
	(-0.021)	(-0.024)
visH	0.013	−0.01
	(-0.017)	(-0.02)
tmL:humL	0.0002	−0.037
	(-0.039)	(-0.045)
tmL:ccL	0.026	0.000[c]
	(-0.034)	(-0.04)
tmL:visL	−0.032	0.019
	(-0.037)	(-0.043)
tmH:humH	−0.07	0.095[a]
	(-0.044)	(-0.051)
tmH:ccH	0.016	0.017
	(-0.038)	(-0.044)
tmH:visH	0.004	0.116[b]
	(-0.045)	(-0.052)
humL:ccL	0.058*	−0.013
	(-0.032)	(-0.038)
humL:visL	−0.093	0.004
	(-0.076)	(-0.089)
humH:ccH	−0.005	−0.029
	(-0.032)	(-0.037)
humH:visH	−0.05	0.055
	(-0.129)	(-0.15)
ccL:visL	0.011	0.008
	(-0.049)	(-0.057)
ccH:visH	−0.027	0.036
	(-0.053)	(-0.061)
Constant	0.149[c]	0.230[c]
	(-0.009)	(-0.011)
Observations	4703	4703
R2	0.002	0.005

Note: We have applied weather effect on the returns using logit model analysis and highlighted significance level at.
[a] $p < 0.1$.
[b] $p < 0.05$.
[c] $p < 0.01$.

respectively.

The estimation results of the 21-day MA-MSD method are illustrated in Table 6. Overall, during the sample period, the stock market shows a weather effect on its volatility due to the significance of some weather dummies. For example, the following variables are statistically significant: tmH, humH, tmLccL, tmHhumH, and humL*visL. The literature also illustrates that weather abnormalities impact stock returns in developed countries (e.g., Wang and Kutan, 2013; Worthington* and Valadkhani, 2004).

Finally, in Table 7, we summarize the number of significant weather dummies in all returns models and volatility (GARCH model). Importantly, the result points out that the stock market has more number of significant weather dummies as considering weather effect on volatility (using GARCH model) compared to other return models. This supports our hypothesis that extreme weather conditions have a significant relationship with stock returns in a climate-sensitive market.

Table 6
Weather effect on the volatility using GARCH (1,1) model with 21-day MA-MSD method.

Variable	Coefficient	Std. Error	t-Statistics	Prob
C	1.000532	0.000197	5083.994	0.000[b]
TML	−0.000614	0.000363	−1.691069	0.0908
TMH	−0.000859	0.000388	−2.21547	0.0267[a]
HUML	0.00028	0.000461	0.607999	0.5432
HUMH	−0.000771	0.000372	−2.072153	0.0383[a]
CCL	0.00025	0.000503	0.497228	0.619
CCH	7.65E-05	0.000365	0.209272	0.8342
VISL	0.000499	0.00038	1.315009	0.1885
VISH	−0.000532	0.000366	−1.454167	0.1459
TML*HUML	−0.000431	0.000815	−0.527975	0.5975
TML*CCL	0.002209	0.000754	2.930217	0.0034[a]
TML*VISL	0.00021	0.000813	0.258948	0.7957
TMH*HUMH	0.002318	0.000904	2.564802	0.0103[a]
TMH*CCH	0.001451	0.000872	1.663477	0.0962
TMH*VISH	−0.000822	0.000911	−0.902154	0.367
HUML*CCL	0.000186	0.000719	0.259291	0.7954
HUML*VISL	0.003803	0.001732	2.19525	0.0281[a]
HUMH*VISH	0.003573	0.002163	1.652112	0.0985
CCL*VISL	−0.000662	0.001124	−0.58856	0.5562
CCH*VISH	−0.001091	0.001094	−0.997649	0.3184
CCL*VISL	−0.000662	0.001124	−0.58856	0.5562
CCH*VISH	−0.001091	0.001094	−0.997649	0.3184
ω	0.00000248	2.69E-07	9.213629	0.000[b]
α	0.119139	0.007712	15.44822	0.000[b]
β	0.860213	0.008456	101.7242	0.000[b]

Note: We have applied weather effect on volatility through GARCH (1,1) model and highlighted significance level at *$p < 0.1$.
[a] $p < 0.05$.
[b] $p < 0.01$.

Table 7
Number of significant dummy variables in all models used in this study.

Models	Number of Significant Dummy Variables
Weather effect on returns using 21-day MA-MSD method (Model Equation (4))	5
Weather effect on returns using 21-day MA-MSD method (Model Equation (5))	5
Weather effect on the returns using 21-day MA-MSD method – (Adding Day Effects _ Model Equation (6))	9
Weather effect on the returns using 21-day MA-MSD method – (Adding Month Effects _ Model Equation (7))	5
Logit Model Analysis (with stretL = extreme low stock index returns - Model Equation (8))	2
Logit Model Analysis (with stretH = extreme high stock index returns - Model Equation (9))	5
Weather Effect on Volatility -Using GARCH model (Model Equation – 10)	9

Note: Number of significant dummy variables in this table indicate the significance of weather dummy variable at least 10% level.

4.5. Discussion on the results

The findings of this study, which examines the influence of severe weather conditions on the UK stock market, uncover several critical insights. Firstly, the regression analysis utilizing the 21-day MA-MSD approach indicates that exceptionally high humidity and visibility have a detrimental impact on stock returns, whereas low temperatures and high cloud cover have a beneficial influence on returns. This discovery highlights the intricate connection between diverse weather factors and market dynamics, indicating that investors respond distinctively to different forms of extreme weather (U-Din et al., 2022). The presence of interaction factors, such as the notable beneficial impact of low temperatures in conjunction with heavy cloud cover, emphasizes the complex relationship between meteorological conditions and stock returns. The findings of this study contradict the oversimplified notion that all severe weather events have a detrimental effect on financial markets. Instead, they show that specific circumstances might provide favorable conditions for investors (Busch and Hoffmann, 2009). Furthermore, the logit model analysis conducted in the study distinguishes between extremely low and high stock returns. The findings suggest that weather circumstances have a greater impact on extremely high returns compared to extremely low returns. The lack of symmetry indicates that market responses to severe weather events are not consistent, with positive extremes resulting in more pronounced reactions. For instance, there is a negative relationship between high temperatures and exceptionally high returns, whereas no factor except low humidity with cloud cover has a significant impact on the exceptionally low returns. This finding is consistent with salience theory, which suggests that investors' behavior is influenced by their attention to significant risks and opportunities (Bordalo et al., 2012). Investors may experience possible profits in certain extreme weather events, perhaps due to expected market adjustments or sector-specific advantages, such as the strong performance of energy or agricultural equities in certain weather patterns (Nasir et al., 2019).

Finally, the outcomes of the GARCH model, which analyze the effect of weather on market volatility, demonstrate noteworthy impacts from different weather indicators. For example, high temperatures and high humidity significantly enhance volatility, indicating that these conditions intensify market uncertainty (Rao et al., 2022). The importance of interaction terms, such as the combination of high temperatures and high humidity, highlights how certain meteorological conditions can worsen market responses. The findings presented in this study enhance our overall comprehension of the impact of climate hazards on financial stability. They emphasize the necessity for investors to integrate sophisticated risk assessment techniques to effectively handle market volatility (Huang et al., 2018). The study showcases the complex effects of weather on financial markets, urging investors to carefully evaluate both the direct and indirect consequences of meteorological conditions on their portfolios.

5. Conclusion

In light of our consistent empirical results, we conclude that extremely high visibility has a significantly negative influence on stock returns, while extremely high cloud cover has a significantly positive influence on stock index returns. Among the interaction terms for all weather variables and showing that extremely low temperature with low humidity, and extremely high temperature with high cloud cover have a significantly positive impact on stock index returns. It was discovered that extremely low temperatures with low cloud cover, and extremely high temperatures with high humidity, and extremely high temperatures with high visibility influence the extreme high stock returns. Meanwhile only extreme low humidity with low cloud cover affects on the extreme low stock returns in terms of the interaction terms for all weather variables. Overall, we conclude and can hence predict that extreme temperature conditions, which are manifestations of climate change, have a strong influence on UK stock returns.

Our study provides several contributions to the ongoing debate on climate change and its implications for financial markets. We have identified important lessons from our empirical findings that have significant implications for policy strategy. Extreme weather conditions regularly impact stock index returns and volatility. As a result, investors may decide to adjust their portfolios to reduce potential losses. Similarly, investors may seek opportunities to invest in sectors or businesses likely to profit from these circumstances if consistently low temperatures are linked to higher stock returns.

We also highlight the connection between extreme climate conditions and stock returns, offering valuable market insights that help investors make better investment choices. The empirical findings suggest that stock market investors quickly adjust index moments in response to changing and extreme climate conditions, which the UK stock market acknowledges. Our study extends the salience theory to analyze stock market behavior in the context of climate change. By examining the relationship between extreme climate conditions and stock market returns and volatility, we add to the literature on economic behavior and market-based firm valuation. Based on the research findings, investors should consider measures to bolster the resilience of their portfolios against climate-related risks. The research suggests adopting a diversified investment strategy that prioritizes industries less susceptible to the impacts of extreme weather events and climate change. It is recommended that investors incorporate evaluations of climate risk into their investment research by utilizing tools like Environmental, Social, and Governance (ESG) criteria to identify firms with strong climate adaptation plans (Nasir et al., 2019). Incorporating real options theory, investors can maintain flexibility by postponing investments in situations with high levels of uncertainty, thereby reducing the risk of potential losses (Busch and Hoffmann, 2009). The study emphasizes the significance of employing financial tools such as weather derivatives to mitigate climate risks (Rao et al., 2022). Investors may enhance the resilience of their investment strategy by closely monitoring climate projections and market reactions to catastrophic weather events, making dynamic adjustments to their portfolios accordingly.

Our study suggests potential avenues for future research to improve comprehension in this area. A significant omission is the restricted attention given to the enduring consequences of gradual climate changes, in contrast to the rapid repercussions of severe weather events. Subsequent investigations might examine the impact of gradual climatic changes on investor mood and long-term market stability. Furthermore, it is crucial to explore developing economies, which have distinct climatic vulnerabilities and financial structures, in addition to the prevailing focus on established markets (Nasir et al., 2019). Another challenge is incorporating climate risk into financial models, requiring the use of advanced techniques to consider intricate, non-linear relationships between climatic factors and market reactions (Busch and Hoffmann, 2009). Ultimately, it is necessary to conduct cross-sectoral research to comprehend the responses of several industries in the same market to climate risks. This will assist investors in refining their plans specific to each sector (Rao et al., 2022). By addressing these shortcomings, a more complete framework may be established to analyze and mitigate the financial effects of climate change on stock markets globally. Based on the gaps and trends found in the literature analysis, the study proposes numerous specific and relevant topics. Firstly, it highlights the importance of conducting longitudinal studies to investigate the lasting consequences of gradual climate changes on market dynamics. This is crucial since existing research mostly concentrates on the immediate effects of catastrophic weather events, rather than the long-term ramifications (Huang et al., 2018). In addition, the article advocates for more investigation into developing markets, which pose distinctive challenges and potential due to their financial systems and climatic vulnerabilities (Nasir et al., 2019). It also supports the creation of sophisticated financial models that can more effectively reflect the intricate, non-linear relationships between climatic factors and market reactions, hence enhancing prediction precision and risk evaluation (Busch and Hoffmann, 2009). Moreover, it is advisable to conduct sector-specific analysis to comprehend the varying effects on various industries within the same market. This will assist investors in formulating more focused plans (Rao et al., 2022). Further, to ensure robust results, we will employ techniques that mitigate or eliminate endogeneity issues (Ullah et al., 2018, 2021). These recommendations align perfectly with the literature evaluation and provide useful insights for furthering research in climate finance.

Like any other research, this study has some limitations. First, while we find evidence of calendar effects and month effects on stock returns, it is important to consider other possible explanations for these findings. For example, these effects may be driven by other factors, such as changes in investor sentiment or macroeconomic conditions. The results emphasize the necessity of including climate risk evaluations in financial market regulations, supporting transparency and robustness against weather-induced fluctuations. Policymakers should promote the incorporation of climate risk disclosures and stress testing for extreme weather occurrences. Financial advisers should include weather forecasts in their investing plans to effectively mitigate risks and take advantage of opportunities arising from climatic circumstances.

CRediT authorship contribution statement

Rizwan Ahmed: Writing – review & editing, Writing – original draft, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Xihui Haviour Chen:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Conceptualization. **Yen Hai Hoang:** Writing – review & editing, Writing – original draft, Funding acquisition. **Chi Do-Linh:** Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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