The effects of weather variability on the performance and risk of Vietnamese listed companies: evidence from the COVID-19 pandemic

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Abstract: The world has recently experienced the COVID-19 pandemic's unexpected repercussions over the past three years. Regarding Vietnam, one of the countries that have long been among the hardest hit by climate change, the nation has to contend with the combined risk of the pandemic and climate change. Therefore, due to the vulnerability to climate change, especially considering the impact of the COVID-19 pandemic, this paper examines the impact of weather variability on the performance and risks of Vietnamese listed companies under the COVID-19 pandemic. Our empirical results from event study and regression methods indicate that more fluctuating atmospheric pressure, humidity, and precipitation and increasing infected cases were associated with worse financial performance and higher risks. Accordingly, this study suggests that businesses will need to actively prioritise and seriously invest in risk management to deal with the combined dangers of climate change and other unpredictable events like the COVID-19 pandemic.

Keywords: climate change; climate risk; COVID-19; firm performance; firm risk; Vietnam; weather variability.

JEL codes: G32, Q54.

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1 Introduction

According to Turrentine (2021), climate change is referred to as a significant variation of average weather conditions. To be more specific, climate represents the long-term average of weather occurrences in a certain area, typically spanning 30 years or longer, which differentiates climate change from natural weather variability. Naturally, the climate can be changed due to objective factors such as variations in the solar cycle. However, the most popular meaning of the definition is the fluctuation in the climate caused by human activities as a result of the rapid development of industrialisation and urbanisation. It is widely admitted that climate change impacts a number of aspects of society and the economy (Rosenzweig et al., 2014; Merloni et al., 2018).

Meanwhile, Vietnam is always reported as one of the countries most affected by climate change due to its geographical location. In the Global Climate Risk Index 2018 (Eckstein et al., 2017), Vietnam was ranked 6th among countries and territories hit hardest by extreme weather events. Until 2021, Vietnam is still listed among the 11–20 nations most affected by extreme weather events from 2000–2019 in the Germanwatch Global Climate Risk Index 2021 report (Eckstein et al., 2021). In fact, severe climate change events have been on the rise in Vietnam. Specifically, in the period from 1958 to 2018, the annual average temperature has always increased (Phong et al., 2019). The same trend is demonstrated in saltwater. This upward movement of climate poses a practical threat to Vietnam as its coastline stretches over 3,200 km and, especially, various sinking land areas are allocated all over the country.

At the micro level, increasing climate risk is found to have a significantly negative consequence on firm performance, as evidenced by lower returns on asset (ROA) and cash flow from operations (CFO) (Huang et al., 2018). Additionally, the research also implies the two main ways in which businesses are negatively impacted by climate change. First, capital intensive industries that have a high percentage of fixed assets, such as the energy and healthcare sectors, are likely to experience property damages and financial losses. Second, climatic hazards can cause harm to the supporting infrastructure and input supply of firms. Collectively, adverse climate fluctuations constitute both internal and external risks to firms' operations and financial performance. The findings of Tzouvanas et al. (2019) also suggest that temperature significantly influences systemic risk in all companies in the STOXX Europe 600 Index. In particular, hot temperature shocks strongly increase systemic risk, while cold shocks have the opposite impact. However, these effects are all evident in the normal context. Meanwhile, in 2020, the world witnessed the COVID-19 pandemic that has lasted for more than two years. The unexpected pandemic has altered and caused an enormous impact on the world economy. Due to a scarcity of labour, ineffective working from home, sharp decline in demand, and disruptions in the global supply chain, businesses all over the world contended with unexpected events and risks that significantly affect their performance. Therefore, as the COVID-19 pandemic causes unparalleled impacts, the question is in the context of COVID-19, how weather factors affect firms' performance and risks. In the context of a developing country like Vietnam that is extremely sensitive to the weather, and studies on the effects of weather on business performance only focused on the normal period, before COVID-19 including Giang et al. (2021), Thai et al. (2023), we take interest in conducting a study to investigate how weather variability affects financial performance and poses financial risk in Vietnamese listed company during the COVID-19 pandemic.

Our study contributes to the literature on the impact of weather variability on firms' performance and risk by providing new evidence on the negative effects between rainfall, humidity, air pressure and ROA, return on equity (ROE) as well as the positive association between the same above weather variables and Z-Score and systemic risk (beta) in COVID-19. In addition, the findings also suggest some implications for businesses that, under any circumstance, the weather still has a certain influence on firms' performance and risks. Managers should therefore take action to be both proactive and reactive to unforeseen weather changes.

The remainder of this paper proceeds as follows: Section 2 provides an overview of the literature review. Section 3 describes the research methodology. The empirical results are presented in Section 4. Finally, Section 5 summarises the major findings.

2 Literature review

In the Global Risks Report 2019, the World Economic Forum (2019) mentioned climate change and its effects as one of the top risks in the world, especially for economic development. In addition, future predictions indicate that climate will get worse, which will manifest as a warmer atmosphere, higher sea levels, rising greenhouse-gas emissions (Tollefson, 2021). The wine industry (Merloni et al., 2018; Schultz, 2010), mining industry (Liu and Song, 2019), agriculture (Rosenzweig et al., 2014) are just a few of industries that have already been impacted. Climate issues are also found to have a significant impact on society and the legal system (Fonseca and Gibson, 2020). In essence, climate change has an impact on every sector in the world.

Regarding an organisation, climate change has posed novel and unprecedented challenges. In order to address the inconveniences caused by weather volatility, the company can not simply present the traditional set of skills. A comprehensive climate change adoption is necessary and should be applied to a variety of dimensions, including organisational capabilities, culture, structure, and processes (Okereke et al., 2012). In addition, business continuity is inferred to be at risk as a consequence of climate change, which causes the enterprises' physical changes and fluctuations in the goods and services demand of the market (Gasbarro et al., 2017). However, it does not mean that these challenges only include risks, they also include opportunities. Gallego-Álvarez et al. (2014) suggest that during the period of the financial crisis in 2009, the companies that gained more profits had an increasing interest in development, followed by more sustainable behaviour in relation to the emission of CO_2. These characteristics differentiated them from their closest competitors, becoming one of their unique selling points.

Climate risk has become more integrated into an enterprise's operations as a result of its major influence. There are two ways that climate change, in general, and weather variability, in particular, affect an enterprise's financial performance and financial risk. These ways are direct and indirect.

2.1 Direct impact

Initially, the primary consequences of climate change are physical damages, which have direct impacts on businesses. Natural disasters such as flooding, droughts, and storms can cause significant losses, leading to reduced sales growth following these detrimental events (Barrot and Sauvagnat, 2016). As a result of the extreme weather events, the supply chain is disrupted, causing a decrease in the company's performance (Andreoni and Miola, 2015). Moreover, challenging weather conditions can lead to a substantial reduction in the supply of various manufacturing materials. Pankratz et al. (2023) found that an increase in the frequency of unusually hot days can reduce firms' operating income by 0.3%. Additionally, unfavourable weather conditions can cause an increase in operational and administrative expenditures.

Labour is also exposed to challenges from climate change, which in turn places a damaging impact on operation efficiency and firm performance. Specifically, heat stress is forecasted to decrease labour productivity by 11%–27% by 2080 in hot regions such as Asia and the Caribbean, and globally by up to 20% in hot months by 2050 (Zander et al., 2015). Similarly, Yusof et al. (2013) have pointed out the combined effect of temperature, illuminance, and humidity on productivity in the automobile industry, while research by Wolkoff (2018) indicated that high levels of water evaporation favour the transmission and survival of influenza viruses, thereby exerting a negative impact on workers' health. Kang et al. (2010) also provided evidence on the involvement of weather factors in financial instability, as variations in meteorological conditions can lead to increased levels of discomfort among workers, which can in turn affect their productivity and well-being. Additionally, according to Barrot and Sauvagnat (2016) and Huang et al. (2018), higher atmospheric pressure volatility is significantly associated with worse firm performance. Sharafi et al. (2013) indicate that atmospheric pressure fluctuations have a strong negative influence on human psychological self-assessment. Similarly, another study by Delyukov and Didyk (1999) also shows that human body reactions are sensitive to the rate of air pressure variation. Collectively, it can be concluded that weather fluctuations exert a negative impact on human cognitive, mental, and physical wellbeing, thereby adversely affecting worker's productivity and firm performance.

2.2 Indirect impact

In addition to the risk of climate-related threats, there is also a growing trend towards sustainability. Many nations and industries worldwide have a long-term goal of transitioning to a 'green economy', which seeks to reduce pollution, enhance resource and energy efficiency, and preserve ecosystems while creating jobs and generating income (Egorova et al., 2015; Soundarrajan and Vivek, 2016). However, this transition also brings with it a range of risks for businesses. These risks can include financial risks, such as changes in the cost of capital or exposure to stranded assets, as well as reputational risks, such as damage to brand value or loss of investor confidence. However, there are a number of hazards associated with this transformation for firms. Businesses may also be subject to market risks like changes in consumer preferences or disruptive technology, as well as regulatory risks like adjustments to tax or environmental legislation.

The increase in legal pressure on enterprises is another implication of climate change. There are a number of laws that have been introduced by governments, authorities, and international organisations. For example, in the 2005 Kyoto Protocol to the 2016 Paris Agreement, the ground rules were set for all subsequent international treaties in order to limit global temperature rises to less than 2°C above pre-industrial levels by the United Nations Framework Convention on Climate Change (UNFCCC). Obviously, these laws have impacted the business strategies of companies in all participating countries.

In short, there are some studies that have implicated a correlation between climate change or weather variability and firm performance as well as firm risk. Huang et al. (2018), for instance, prove that there is a negative association between climate risk and firm performance measured by ROA and operational cash flow. Additionally, Tzouvanas et al. (2019) indicate that high temperatures lead to an increase in systematic risk. However, to our knowledge, no prior research has been conducted on the relationship between climate change and firm performance as well as the impact of that change on firms' financial risk in the context of the COVID-19 pandemic.

Additionally, in response to the COVID-19 pandemic's rapid spread and dangerous effects, governments imposed lockdowns at various levels and ordered other non-pharmaceutical and pharmaceutical measures. This led to the creation of the Great Lockdown all over the world. The Great Lockdown caused the world economy to slow down like never before since the Great Depression. Global growth shrank to –3%, however the 2009 Global Financial Crisis only resulted in a –0.1% decline (Gopinath, 2020). To be more specific, Ludvigson et al. (2020) calculated that the cumulative loss of US industrial production and employment over the course of ten months was 12.75% and 17%, respectively. In addition, Arntz et al. (2020) found that only 31% of jobs could be carried out entirely from home in Germany. The feasibility of working from home is considerably more problematic in the context of developing nations. In particular, according to Gottlieb et al. (2021), less than 10% of urban employment in developing nations assessed, including Armenia, Bolivia, Colombia, Ghana, Georgia, Kenya, Laos, North Macedonia, Yunnan Province of China, and Vietnam, can be performed remotely. The result is consistent with the structure of labour force by educational attainment and the nature of work positions. In Vietnam specifically, the group of workers with technical qualification only accounts for 23.6%, whereas the largest and second largest groups are those who completed lower secondary and primary, with 28.7% and 20.0%, respectively (GSO, 2020). Moreover, the COVID-19 also brought the certain effects on other industries in Vietnam (Nguyen and Aya, 2021). In terms of individual expenditure, using transactional-level data, Baker et al. (2020) found that total American individual spending increased by 40% due to a stockpile of necessary goods in early March 2020. However, the second half of March 2020 saw a plunge of 25% to 30%, which is consistent with the COVID-19 pandemic's escalating outbreak and stay-at-home order. In terms of global trade, the year 2020 had the sharpest decrease in output volumes and trade, setting the lowest reduction record since World War II (OECD, 2022). Although a V-shaped recovery has shown an astonishingly swift recovery, not all losses have been recovered. The outbreak and repercussions of COVID-19 have had an unprecedented impact on the global economy and individual firms. This has resulted in a significant decrease in firms' performance due to demand and supply shocks, which were caused by reduced consumer consumption as a result of lockdown orders and income loss, as well as inefficient implementation of work-from-home measures, labour shortages due to COVID-19 infections and fatalities, and disruptions in the world supply chain. As a result, COVID-19 has emerged as the biggest risk that firms worldwide have ever had to face, thus significantly lowering firms' performance.

As a result, the enterprises in Vietnam confronted combined risks that arise from the effects of weather variability and the ongoing COVID-19 pandemic. Therefore, we raise the question of how these dual risks exhibit their influence on Vietnamese firms. Based on the above discussion, we propose the following hypotheses:

H1 Weather variability still affects negatively on the Vietnamese firm performance in the COVID-19 pandemic.

H2 There is a positive association between weather variability and the Vietnamese firm risks during the COVID-19 pandemic.

3 Research design

3.1 Data and sample

Our initial sample originally consists of 780 listed companies on the Vietnamese stock exchange, including Ho Chi Minh Stock Exchange – HOSE and Hanoi Stock Exchange – HNX. We employ daily historical stock prices and quarterly financial reports of these firms over the 2020–2022 periods, which are derived from the Fiinpro Platform. We exclude financial companies due to their different characteristics and inadequate information. Therefore, our final data sample comprises 5,819 observations for 529 firms spanning over a period of 11 quarters.

In our study, daily weather data are collected from a total of 691 local meteorological stations located in 60 provinces in Vietnam, over the period from 1st January 2020 till 30th September 2022. The weather index for each province is computed as the average of local weather stations. The quarterly standard deviations of temperature, rainfall, humidity, air pressure and wind speed are then calculated to obtain the weather volatility for each province.

For companies in Binh Duong, Vinh Long and Hau Giang provinces where published weather data are not available, we utilise weather data of neighbouring cities as a substitute to determine the firms' exposure to climate risk.

3.2 Empirical models and variables definitions

To investigate whether the financial performance and financial risk of Vietnamese listed firms are influenced by weather variability during the COVID-19 pandemic, we execute regression analyses for equations (1) and (2) as follows:

$$\begin{aligned} Financial\ performance_{it} = {} & \beta_0 + \beta_1 RAIN_{it} + \beta_2 TEMP_{it} + \beta_3 HUMID_{it} \\ & + \beta_4 AIRit + \beta_5 WIND_{it} + \beta_6 CASE * RAIN_{it} \\ & + \beta_7 CASE * TEMP_{it} + \beta_8 CASE * HUMID_{it} \\ & + \beta_9 CASE * AIR_{it} + \beta_{10} CASE * WIND_{it} + \beta_{11} CASE \\ & + \beta_{12} LEV_{it} + \beta_{13} GROWTH_{it} + \beta_{14} SIZEit + \beta_{15} STATE_{it} + \varepsilon \end{aligned} \tag{1}$$

$$\begin{aligned} Financial\ risk_{it} = {} & \beta_0 + \beta_1 RAIN_{it} + \beta_2 TEMP_{it} + \beta_3 HUMID_{it} \\ & + \beta_4 AIRit + \beta_5 WIND_{it} + \beta_6 CASE * RAIN_{it} \\ & + \beta_7 CASE * TEMP_{it} + \beta_8 CASE * HUMID_{it} \\ & + \beta_9 CASE * AIR_{it} + \beta_{10} CASE * WIND_{it} + \beta_{11} CASE \\ & + \beta_{12} LEV_{it} + \beta_{13} GROWTH_{it} + \beta_{14} SIZEit + \beta_{15} STATE_{it} + \varepsilon \end{aligned} \tag{2}$$

where subscripts i and t indicate the firm and quarter, respectively. Performance indicators include ROA and ROE, while the financial risk is represented by Altman Z-Score and systematic risk. Weather variability is measured by the volatility of different weather factors, including temperature, rainfall, humidity, atmospheric pressure, and wind speed. In our empirical models, we also include interaction terms between weather variables and the percentage change in the number of confirmed COVID-19 cases. We control characteristics which are firm leverage, firm size, ownership structure, and company growth. All variables in equation (1) and equation (2) are defined in Table 1.

3.2.1 Dependent variables – firm risks

In terms of risk indicators, Altman Z-Score can be simply explained as a bankruptcy index while beta is systematic risk. In case Altman Z-Score is near 0, it means that the bankruptcy possibility of the firm in the future is relatively high. The Z-Score formula includes five other ratios as shown in equation (3) below:

$$\begin{aligned} Altman\ Z\text{-}Score = {} & 1.2 \frac{Working\ capital}{Total\ assets} + 1.4 \frac{Retained\ earnings}{Total\ assets} \\ & + 3.3 \frac{Earnings\ before\ interest\ and\ tax}{Total\ assets} \\ & + 0.6 \frac{Market\ capitalization}{Total\ liabilities} + 1.0 \frac{Sales}{Total\ assets} \end{aligned} \tag{3}$$

Regarding the formula, the beta calculation is considered to be more complicated through the capital asset pricing model (CAPM). We run a linear regression on a stock's returns compared to the market using the following (CAMP) model (4) to calculate beta as systemic risk. The beta of a stock or portfolio demonstrates the sensitive level of the stock or portfolio to systematic risk, where the broad market itself always has a beta of 1.0.

$$ER_i = R_f + \beta_i \left(ER_m - R_f \right) \tag{4}$$

where ER_i refers to expected return of investment. R_f is the risk-free rate. $ER_m - R_f$ = market risk premium.

3.2.2 Independent variables – weather variability and interaction terms

A number of previous studies have implied that climate change-related risks negatively affect business activities across various sectors and industries. Lucas et al. (2019) found a fall in stock returns and profit for companies in the food industry following periods of heavy precipitation. Heat stress induced by hot weather affects economic activities through declining labour productivity (Kjellstrom et al., 2009). Jacobs et al. (2016)

confirm that operational productivity is necessary for good financial performance and reduced risk. Hence, it can be inferred that temperature volatility causes a negative impact on the firm's financial performance and increases the risk. In addition, the studies conducted by Lu and Chou (2012) mentioned that air pressure and the wind had a positive effect on the volatility of the stock market, whereas this volatility is considered an expression of systematic risk. Interestingly, the research of Zha et al. (2021) confirms a significant correlation between near-surface wind speed and global warming level. Meanwhile, wind results from the horizontal air pressure, and risks caused by climate change, an aspect of global warming, do have an impact on financial performance in Chinese companies (Sun et al., 2020). Moreover, Giang et al. (2021) study the manufacturing enterprises in Vietnam and conclude that humidity negatively impacts the ROE and ROA of these firms. This weather factor is also proven to significantly influence the volatility of the stock market. Kang et al. (2010) found a negative effect of extremely high humidity on the return of the Shanghai stock market at a 10% significant level. Thus, the result infers the facilitating function of humidity volatility for market risk.

Table 1 Definitions of the variables

Variables	*Explanation*	*Calculation*
Dependent variables		
ROA	Return on total assets	$\frac{Net\ profit}{Total\ assets}$
ROE	Return on equity	$\frac{Net\ profit}{Shareholders'\ equity}$
ZSCORE	Bankruptcy index	Calculated in equation (3)
BETA	Systematic risk	Calculated in equation (4)
Independent variables		
RAIN	Rainfall	Standard deviation (daily rainfall) throughout 1 quarter
TEMP	Temperature	Standard deviation (daily temperature) throughout 1 quarter
HUMID	Humidity	Standard deviation (daily humidity) throughout 1 quarter
AIR	Air pressure	Standard deviation (daily air pressure) throughout 1 quarter
WIND	Wind Speed	Standard deviation (daily wind speed) throughout 1 quarter
Interaction variables		
CASE*RAIN	Percentage change in the number of COVID-19 cases * Rainfall	$\frac{CASE_t - CASE_{t-1}}{CASE_{t-1}} *$ Standard deviation (daily rainfall) throughout 1 quarter
CASE*TEMP	Percentage change in the number of COVID-19 cases * Temperature	$\frac{CASE_t - CASE_{t-1}}{CASE_{t-1}} *$ Standard deviation (daily temperature) throughout 1 quarter

Table 1 Definitions of the variables (continued)

Variables	*Explanation*	*Calculation*
Interaction variables		
CASE*HUMID	Percentage change in the number of COVID-19 cases * Humidity	$\frac{CASE_t - CASE_{t-1}}{CASE_{t-1}} *$ Standard deviation (daily humidity) throughout 1 quarter
CASE*AIR	Percentage change in the number of COVID-19 cases * Air pressure	$\frac{CASE_t - CASE_{t-1}}{CASE_{t-1}} *$ Standard deviation (daily air pressure) throughout 1 quarter
CASE*WIND	Percentage change in the number of COVID-19 cases * Wind Speed	$\frac{CASE_t - CASE_{t-1}}{CASE_{t-1}} *$ Standard deviation (daily wind speed) throughout 1 quarter
Control variables		
CASE	Percentage change in the number of COVID-19 cases	$\frac{CASE_t - CASE_{t-1}}{CASE_{t-1}} *$
LEV	Firm leverage	$\frac{Total\ liabilities}{Total\ assets}$
GROWTH	Sale growth	$\frac{SALES_t - SALES_{t-1}}{SALES_{t-1}}$
SIZE	Firm size	Logarithm of total assets
STATE	State ownership	STATE = 1 for state-owned companies and 0 otherwise

Weather variables are also proven to have a considerable impact on financial stability. Battiston et al. (2021) analysed the impact in three aspects, particularly the related-climate policies, the physical effects, and the specific effect on the financial market. The authors provided evidence to show the impacts of weather on financial stability. Meanwhile, it is apparent that financial risk plays an important role in financial stability, even as a measurement of financial uncertainty. Therefore, it can be inferred that the weather does have a significant correlation with financial risk. Specifically, humidity, temperature, and precipitation are significantly correlated to the sales for the retail categories, thereby directly affecting the cash flow of the firms (Bertrand and Parnaudeau, 2019). However, the correlation is unstable for four seasons in a year due to changes in the indices of the three weather factors. As a result, it is apparent that the volatility of humidity, temperature, and precipitation contributes to financial instability, thereby causing market risk.

On the basis of previous research, our study investigates the impact on financial performance and risks of Vietnamese listed firms caused by five independent variables namely temperature, rainfall, humidity, wind speed, and air pressure. We select the state location of each firm's headquarters to determine its exposure to climate-related risks. In order to compute the quarterly weather index for each province, we calculate the standard deviation of each weather variable from the data collected at local meteorological stations.

In addition, we aim to investigate the impact of weather variability on financial performance and risks under the COVID-19 pandemic. Firms were, therefore, placed in a compound risk environment, in which prevail both the risk from weather variation and the risks associated with the pandemic's impact on the economy and society. To account for this complex environment, the main regression models incorporate interactions between weather variables and the percentage change in the number of confirmed COVID-19 cases. The inclusion of interaction terms is of crucial importance to capture the impact of weather variability on firm performance and risks which may vary depending on the severity of the pandemic. Furthermore, the COVID-19 pandemic has had a mixed impact on the economy, with negative effects stemming from supply chain disruption, job losses, and high medical expenditure, among other factors. However, government responses with lockdown orders and other restrictive measures have also limited the adverse impact of weather variations on human health, thereby potentially enhancing workers' performance. Therefore, it is important to examine the potential significance of the coefficients of the interaction terms and to acknowledge that the combined effect between weather variability and the pandemic may be difficult to anticipate due to the complex and nonlinear nature of their interaction.

4 Empirical results

4.1 Descriptive statistics

Table 2 illustrates the descriptive statistics for the data sample used for estimating the impact of weather variability on firm performance and financial risk. The average values of ROA and ROE are 0.056 and 0.102, respectively; however, the fact that their standard deviations are far larger than the mean values infers a great variation in financial performance among firms and across time. For risk indicators, the average Altman Z-Score of 3.265 means most firms are in solid financial position and not likely to suffer from bankruptcy. Beta has an average of 0.517, suggesting that firm stocks in our data sample are generally less volatile than the market as a whole. The data also show the average sales growth is 7.5% and the rate varies substantially among firms. 75.6% of the companies in the dataset are classified as being in the private sector. Liabilities account for 47.8% of the total assets on average, with a range of ±22.3%, indicating a significant variation in the capital allocation among companies. For the weather variables, regardless of the relatively small standard deviation, the range of rain, temperature, and humidity data is extensive. Specifically, the rain has a mean of 6.613 and a standard deviation of 4.572. However, its range is from 0 to 55.014, with the maximum record roughly ten times higher than the average. The feature means there are outliers in the data set, synonymous with the high frequency of unusual weather that would result in increasing climate risks. Regarding weather volatility, precipitation is the most volatile factor, followed by humidity and atmospheric pressure. Specifically, the average volatility in rainfall, humidity level, and atmospheric pressure is 6.613, 6.187 and 2.991 respectively. Such great volatility in weather conditions might be synonymous with a high frequency of unusual weather and climate risks.

4.2 Correlation result

The Pearson correlation matrix, presented in Table 3, shows that all correlations between the variables are at an acceptable level, with the exception of the relationship between temperature and air pressure volatility. This can be explained by the fact that as temperature rises; the molecules of air move and occupy more space, resulting in an increase in atmospheric pressure. Considering that this high correlation is a natural phenomenon happening to meteorological data, we decided that ignoring the problem of highly related weather variables in our research model is acceptable.

Table 2 Descriptive statistics

Variables	*Observation*	*Mean*	*SD*	*Min*	*Max*
Dependent variables					
ROA	5,819	0.056	0.074	–0.334	0.616
ROE	5,819	0.102	0.259	–8.328	13.617
ZSCORE	5,819	3.265	10.814	–37.821	108.734
BETA	5,819	0.517	0.575	–3.617	5.521
Weather variables					
RAIN	5,819	6.613	4.572	0.000	55.014
TEMP	5,819	1.955	1.118	0.694	4.6232
HUMID	5,819	6.187	2.199	2.195	12.936
AIR	5,819	2.991	1.655	0.925	16.835
WIND	5,819	0.584	0.268	0.161	2.203
Control variables					
CASE	5,819	5.806	13.577	–0.280	61.647
LEV	5,819	0.478	0.223	–0.011	1.277
GROWTH	5,819	0.075	2.953	–0.843	224.919
SIZE	5,819	27.565	1.593	23.251	32.966
STATE	5,819	0.756	0.429	0.000	1.000

In addition, it can be seen that most climate risk measures are negatively related to ROA, ROE and Altman Z-Score, and positively correlated with beta. These univariate correlations are consistent with our hypotheses.

4.3 Regression results

4.3.1 The effects of weather variability on firm performance in the COVID-19

Table 4 summarises the regression results of weather variability related impact on the financial performance of listed companies on the Vietnamese stock market. To find the most suitable regression model, we conduct three regression models simultaneously consisting of pooled ordinary least square (pool OLS), fixed effect model (FEM) and random effect model (REM). Then, we implement the Hausman test, Breusch and Pagan Lagrangian multiplier (LM) and give the results that FEM is the most suitable model to assess this relationship. Finally, we use robust standard errors to fix heteroscedasticity.

Following prior research, we winsorise all variables at 1% and 99% to moderate the impact of the outliers.

The estimation results show that changes in some weather factors including rainfall, humidity and air pressure influence negatively on firm performance as ROA and ROE of Vietnamese listed companies during the COVID-19. These findings support our first hypothesis and align with the studies of Barrot and Sauvagnat (2016), and Huang et al. (2018), however contradict the results from the study of Thai et al. (2023) conducted before the COVID-19 period with listed agricultural companies in Vietnam. According to Uddin et al. (2020), high fluctuations in the amount of rainfall are associated with more frequent occurrence of droughts and precipitation extremes. Hydrological disasters can cause harm to tangible properties and disrupt business operation activities, thereby having a devastating impact on firm performance (Barrot and Sauvagnat, 2016; Huang et al., 2018).

Variations in humidity level are also found to have a significantly negative impact on both ROA and ROE. This finding is consistent with previous research by Yusof et al. (2013), which showed a correlation between humidity and firm performance. Specifically, the studies have indicated that radical changes in humidity level and other environmental factors adversely influenced worker performance in the automobile industry, reduced the assembly efficiency and ultimately lowered the production output. Similarly, Kang et al. (2010) and Wolkoff (2018) who concluded a negative relationship between high levels of water evaporation and workers' mental and physical health, also provided support to our findings.

At a 10% level of significance, atmospheric pressure volatility has a negative effect on firm profitability, which is consistent with the studies of Barrot and Sauvagnat (2016), Huang et al. (2018). Firstly, higher volatility in atmospheric pressure is significantly associated with worse firm performance. Sharafi et al. (2013) indicate atmospheric pressure fluctuations have a strong negative influence on human psychological self-assessment. Similarly, another study by Delyukov and Didyk (1999) also shows that human body reactions are sensitive to the rate of air pressure variation. Therefore, during periods of considerable atmospheric fluctuations, mental and physical wellbeing of employees may be adversely influenced, thus causing a reduction in labour productivity and firm performance.

However, other weather variability measures, namely temperature and wind speed volatility, are found to have no impact on financial performance. One possible reason is that the majority of quoted companies on HOSE and HNX do not belong to climate-sensitive sectors. According to existing literature by Wilbanks et al. (2007), Hsiang (2010) and Challinor et al. (2014), agriculture, food manufacturing, healthcare, communications and transportation are considered to be vulnerable industries. As such, only 68 out of 529 companies in our data sample are considered to be vulnerable to threat from climate risks. In this paper, firms are also highly concentrated in big cities in northern and southern centres, namely Hanoi and Ho Chi Minh City, which have geological advantages, thereby being less vulnerable to climate change hazards such as cyclones and heat waves. According to research by Trinh et al. (2018) and Ngo-Duc (2014), the central coast region has the highest level of exposure to climate risks in Vietnam.

Table 3 Correlation matrix

	ROA	*ROE*	*ZSCORE*	*BETA*	*RAIN*	*TEMP*	*HUMID*	*AIR*	*WIND*	*LEV*	*GROWTH*	*SIZE*	STATE
ROA	1												
ROE	0.4626	1											
ZSCORE	0.0594	0.0117	1										
BETA	–0.024	0.0146	–0.0309	1									
RAIN	–0.0729	–0.0292	0.0536	0.026	1								
TEMP	–0.1121	–0.051	–0.0216	0.0383	–0.0347	1							
HUMID	–0.0983	–0.0485	–0.0191	0.0464	0.0705	0.7346	1						
AIR	–0.1292	–0.0604	–0.012	0.0459	0.0923	0.8524	0.6968	1					
WIND	0.0597	0.0208	0.0153	–0.0572	–0.083	–0.2132	–0.2535	–0.2155	1				
LEV	–0.3863	–0.0668	–0.136	0.0608	0.0406	0.0834	0.0819	0.0973	–0.0858	1			
GROWTH	0.0044	0.0039	–0.0021	–0.0198	–0.0129	0.0106	–0.009	0.0075	–0.0027	0.0087	1		
SIZE	0.0044	0.0233	–0.0783	0.4362	–0.0542	–0.0669	–0.0008	–0.0854	–0.0445	0.3006	0.0162	1	
STATE	0.0126	0.0347	0.0122	0.0155	–0.0302	–0.0029	0.0161	0.0067	–0.0208	0.0293	0.0106	–0.002	1

Table 4 The effects of weather variability on financial performance during the COVID-19

	OLS		*REM*		*FEM*		*Robust FEM*	
	ROA	*ROE*	*ROA*	*ROE*	*ROA*	*ROE*	*ROA*	*ROE*
RAIN	–0.0005**	–0.0006**	0.0000	–0.0001*	–0.0001*	–0.0002**	–0.0001*	–0.0002**
	(–2.22)	(–0.69)	(0.20)	(–0.19)	(–0.05)	(–0.24)	(–0.06)	(–0.51)
TEMP	–0.0020	–0.0023	–0.0005	–0.0050	0.0008	–0.0038	0.0008	–0.0038
	(–1.04)	(–0.31)	(–0.40)	(–0.71)	(0.66)	(–0.50)	(0.81)	(–0.38)
HUMID	0.0000	–0.0009	–0.0009**	–0.0031	–0.0007*	–0.0039**	–0.0007**	–0.0039 **
	(–0.04)	(–0.33)	(–2.05)	(–1.21)	(–1.67)	(–1.46)	(–2.01)	(–1.36)
AIR	–0.0026**	–0.0052	0.0005	–0.0001	–0.0001 *	–0.0006 **	–0.0001*	–0.0006**
	(–2.24)	(–1.14)	(0.68)	(–0.02)	(–0.14)	(–0.12)	(–0.16)	(–0.21)
WIND	0.0014	–0.0095	0.0035	–0.0062	0.0060	0.0064	0.0060	0.0064
	(0.36)	(–0.66)	(1.17)	(–0.39)	(1.97)	(0.34)	(1.79)	(0.67)
CASE *RAIN	–0.0001*	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001
	(–1.83)	(–0.18)	(–0.87)	(0.46)	(–0.28)	(0.98)	(–0.31)	(1.17)
CASE *TEMP	0.0005	0.0002	0.0003	–0.0001	0.0001	–0.0008	0.0001	–0.0008
	(1.03)	(0.12)	(1.18)	(–0.06)	(0.40)	(–0.51)	(0.35)	(–0.81)
CASE *HUMID	–0.0001	–0.0002	0.0000	–0.0001	0.0000	0.0000	0.0000	0.0000
	(–0.65)	(–0.55)	(–0.33)	(–0.17)	(–0.38)	(0.030)	(–0.42)	(0.06)
CASE *AIR	0.0000	–0.0001	0.0000	–0.0002*	0.0001	–0.0001*	0.0001	–0.0001*
	(0.08)	(–0.19)	(0.29)	(–0.52)	(1.13)	(–0.31)	(1.12)	(–0.40)

Notes: This table presents the OLS, REM, FEM regression results for the effects of weather variability on firm performance of equation (1):

$$Financial\ performance_{it} = \beta_0 + \beta_1 RAIN_{it} + \beta_2 TEMP_{it} + \beta_3 HUMID_{it} + \beta_4 AIR_{it} + \beta_5 WIND_{it} + \beta_6 CASE{*}RAIN_{it} + \beta_7 CASE{*}TEMP_{it} + \beta_8 CASE{*}HUMID_{it} + \beta_9 CASE{*}AIR_{it} + \beta_{10} CASE{*}WIND_{it} + \beta_{11} CASE + \beta_{12} LEV_{it} + \beta_{13} GROWTH_{it} + \beta_{14} SIZE_{it} + \beta_{15} STATE_{it} + \varepsilon.$$

The definitions for the variables are provided previously. *, **, and *** indicate statistical significance at 10%, 5%, and 1%, respectively.

The Breusch and Pagan Lagrangian multiplier (LM) test and Hausman test are presented in Table 4a in the Appendix. The modified Wald test is presented in Table 4b in the Appendix.

Table 4 The effects of weather variability on financial performance during the COVID-19 (continued)

	OLS		*REM*		*FEM*		*Robust FEM*	
	ROA	*ROE*	*ROA*	*ROE*	*ROA*	*ROE*	*ROA*	*ROE*
CASE *WIND	0.0002	0.0025	0.0005*	0.0032	0.0004	0.0032	0.0004	0.0032
	(0.51)	(1.44)	(2.10)	(2.05)	(1.71)	(2.07)	(1.62)	(2.05)
CASE	0.0000	–0.0007	–0.0005**	–0.0019	–0.0004	–0.0020	–0.0004*	–0.0020*
	(–0.04)	(–0.40)	(–2.12)	(–1.19)	(–1.54)	(–1.25)	(–1.70)	(–1.95)
LEV	–0.1367***	–0.0859***	–0.128***	–0.0923***	–0.1617***	–0.2160***	–0.1617***	–0.2160**
	(–32.69)	(–5.33)	(–18.09)	(–3.57)	(–17.78)	(–3.84)	(–5.66)	(–2.27)
GROWTH	0.0002	0.0003	0.0002	0.0004	–0.0001	–0.0002	–0.0001	–0.0002
	(0.52)	(0.27)	(1.04)	(0.38)	(–0.59)	(–0.23)	(–1.52)	(–1.21)
SIZE	0.0055***	0.0066***	0.0159***	0.0104***	0.0468***	0.0900***	0.0468***	0.0900***
	(9.41)	(2.92)	(11.22)	(2.65)	(16.93)	(5.26)	(3.47)	(2.80)
STATE	0.0040*	0.0218***	0.0042	0.0221	0.0012	0.0053	0.0022	0.0034
	(1.95)	(2.76)	(0.72)	(1.57)	(0.34)	(0.23)	(0.87)	(1.12)
Constant	–0.0201	–0.0182	–0.3225***	–0.1202	–1.1577***	–2.2429***	–1.1577***	–2.2429**
	(–1.22)	(–0.29)	(–8.34)	(–1.11)	(–15.58)	(–4.88)	(–3.16)	(–2.58)
N	5819	5819	5819	5819	5819	5819	5819	5819
R-squared	0.1749	0.0123	0.1242	0.0283	0.0750	0.0089	0.0750	0.0089

Notes: This table presents the OLS, REM, FEM regression results for the effects of weather variability on firm performance of equation (1):

$Financial\ performance_{it} = \beta_0 + \beta_1 RAIN_{it} + \beta_2 TEMP_{it} + \beta_3 HUMID_{it} + \beta_4 AIR_{it} + \beta_5 WIND_{it} + \beta_6 CASE{*}RAIN_{it} + \beta_7 CASE{*}TEMP_{it} + \beta_8 CASE{*}HUMID_{it} + \beta_9 CASE{*}AIR_{it} + \beta_{10} CASE{*}WIND_{it} + \beta_{11} CASE + \beta_{12} LEV_{it} + \beta_{13} GROWTH_{it} + \beta_{14} SIZE_{it} + \beta_{15} STATE_{it} + \varepsilon$. The definitions for the variables are provided previously. *, **, and *** indicate statistical significance at 10%, 5%, and 1%, respectively.

The Breusch and Pagan Lagrangian multiplier (LM) test and Hausman test are presented in Table 4a in the Appendix. The modified Wald test is presented in Table 4b in the Appendix.

As can be seen from the regression results, interaction terms between weather variables and COVID-19 cases are proven to be insignificant except CASE*AIR, suggesting that the relationship between atmospheric pressure volatility and firm performance was also affected as the number of COVID-19 cases increased. The findings can be justified considering the fact that the pandemic exerts a mixed impact on the companies. On the one hand, restrictions on transportations and outdoor activities, which were imposed by governments to prevent the spread of coronavirus, have significantly reduced the level at which people were exposed to meteorological conditions, thereby mitigating the adverse impact of weather variations on worker's performance. On the other hand, the growth in the number of COVID-19 cases is negatively correlated with returns, since lockdown order and other restrictive measures caused disruptions in the supply chain, demand and supply shocks as well as reduced consumer consumption, which collectively resulted in a significant decrease in firms' performance. Therefore, the moderate impact that the pandemic may have on the relationship between weather variations and firm performance was offset by its detrimental effects, making the interactions between weather and COVID-19 cases become significant for only air pressure.

The Breusch and Pagan LM test and Hausman test are presented in Table 4a in Appendix. The modified Wald test is presented in Table 4b in Appendix.

4.3.2 The effects of weather variability on firm risks in the COVID-19

Table 5 shows the regression results of weather variability impact on the credit risk (Altman Z-Score) and systematic risk (Beta) of listed companies on the Vietnamese stock market.

The regression results indicate that volatility in precipitation, humidity and atmospheric pressure was positively correlated with both Altman Z-Score and beta, indicating that as the amount of rainfall, the level of humidity or air pressure became more volatile, the probability of bankruptcy surprisingly increased, yet the systematic risk of firm stocks is more substantial. This finding is consistent with our second hypothesis and the studies of Jongman et al. (2014), Sušnik et al. (2015), Price and Dupont (2023). In their papers, they have implied firm instability induced by droughts and extreme precipitations, justifying the positive relationship discovered between rainfall and humidity variability and systematic risk. Regarding air pressure, it is shown to have an indirect correlation with investors' mood (Howarth and Hoffman, 1984), whereas Bassi et al. (2013) proved that moods affect performance. Collectively, the preceding literature provides a comprehensive explanation for the persistent impact of air pressure effect on firm risks. However, that Altman Z-Score unexpectedly increases with fluctuations in these weather variables appears to be inconsistent with previous research. This can be explained by the fact that there exist several recently-established firms in our data sample, while the Altman Z-Score also is not of good use for new companies with little or no earnings. Other weather factors are found to have no significant effect on financial risk measures. As aforementioned, the climatic insensitivity of industries and limited exposure to weather conditions of employees during the COVID-19 pandemic are the major reasons for the insignificance of the results.

Table 5 The effect of weather variability on financial risks during the COVID-19

	OLS		*REM*		*FEM*		*Robust FEM*	
	Z–Score	*BETA*	*Z–Score*	*BETA*	*Z–Score*	*BETA*	*Z–Score*	*BETA*
RAIN	0.3905***	0.0078***	0.3905***	0.007***	0.5060***	0.0054***	0.5060***	0.0054***
	(4.32)	(4.68)	(4.32)	(4.7)	(5.64)	(3.47)	(1.13)	(3.4)
TEMP	–0.3860	–0.0032	–0.3860	–0.0236*	–1.1163	–0.0362	–1.1163	–0.0362
	(–0.49)	(–0.22)	(–0.49)	(–1.8)	(–1.39)	(–2.58)	(–2.21)	(–2.43)
HUMID	–0.0390	–0.0052	–0.0390	0.0077	0.1058*	0.0079*	0.1058**	0.0079*
	(–0.14)	(–1)	(–0.14)	(1.6)	(0.37)	(1.59)	(1.07)	(1.68)
AIR	0.1300	0.0253***	0.1300	0.0266***	0.9076*	0.0207**	0.9076*	0.0207**
	(0.27)	(2.82)	(0.27)	(3.27)	(1.88)	(2.46)	(1.75)	(1.94)
WIND	0.3703	–0.0631**	0.3703	–0.1175***	–6.1616	–0.1113	–6.1616	–0.1113
	(0.24)	(–2.22)	(0.24)	(–3.8)	(–3.09)	(–3.2)	(–0.97)	(–2.85)
CASE*RAIN	–0.0065	–0.0004*	–0.0065	–0.0004*	–0.033	–0.0003	–0.033	–0.0003
	(–0.54)	(–1.93)	(–0.54)	(–1.87)	(–3.01)	(–1.4)	(–1.25)	(–1.5)
CASE*TEMP	0.0400	0.0115***	0.0400	0.0113***	0.3797	0.0102	0.3797	0.0102
	(0.21)	(3.19)	(0.21)	(3.73)	(2.18)	(3.37)	(1.79)	(3.1)
CASE*HUMID	–0.0211	–0.0017**	–0.0211	–0.0014**	–0.0258	–0.0013*	–0.0258	–0.0013
	(–0.49)	(–2.12)	(–0.49)	(–2.06)	(–0.65)	(–1.81)	(–1.52)	(–2.04)
CASE*AIR	0.0038	0.0005	0.0038	0.0012*	0.0432**	0.0015*	0.0432**	0.0015**
	(0.09)	(0.60)	(0.09)	(1.83)	(1.1)	(2.22)	(1.71)	(2.42)

Notes: This table presents the OLS, REM, FEM regression results for the effects of weather variability on firm risk of equation (2): $Financial\ risk_{it} = \beta_0 + \beta_1 RAIN_{it} + \beta_2 TEMP_{it} + \beta_3 HUMID_{it} + \beta_4 AIR_{it} + \beta_5 WIND_{it} + \beta_6 CASE*RAIN_{it} + \beta_7 CASE*TEMP_{it} + \beta_8 CASE*HUMID_{it} + \beta_9 CASE*AIR_{it} + \beta_{10} CASE*WIND_{it} + \beta_{11} CASE + \beta_{12} LEVit + \beta_{13} GROWTH_{it} + \beta_{14} SIZE_{it} + \beta_{15} STATE_{it} + \varepsilon$. The definitions for the variables are provided previously. *, **, and *** indicate statistical significance at 10%, 5%, and 1%, respectively.

Table 5 The effect of weather variability on financial risks during the COVID-19 (continued)

	OLS		*REM*		*FEM*		*Robust FEM*	
	Z–Score	*BETA*	*Z–Score*	*BETA*	*Z–Score*	*BETA*	*Z–Score*	*BETA*
CASE*WIND	–0.0201	0.0032	–0.0201	0.0028	0.1427	0.0026	0.1427	0.0026
	(–0.11)	(0.93)	(–0.11)	(0.95)	(0.86)	(0.87)	(1.63)	(1.04)
CASE	0.1050	–0.0036	0.1050	–0.0039	–0.0729	–0.0037	–0.0729	–0.0037
	(0.58)	(–1.07)	(0.58)	(–1.36)	(–0.44)	(–1.26)	(–1.17)	(–1.45)
LEV	–15.76***	–0.2431***	–15.76***	–0.2851***	21.0235***	–0.5602***	21.0235	–0.5602***
	(–9.17)	(–7.6)	(–9.17)	(–5.1)	(3.54)	(–5.4)	(0.96)	(–3.27)
GROWTH	0.0031	–0.0052**	0.0031	–0.0041**	–0.8176***	–0.0048**	–0.8176***	–0.0048***
	(0.03)	(–2.29)	(0.03)	(–2.13)	(–7.22)	(–2.43)	(–3.04)	(–4.45)
SIZE	–0.6632***	0.1706***	–0.6632***	0.1767***	–46.2405***	0.2893***	–46.2405	0.2893***
	(–2.75)	(38.03)	(–2.75)	(19.85)	(–25.63)	(9.15)	(–1.49)	(2.86)
STATE	1.1336	0.0269*	1.1336	0.0269	0.0001	0.0012	0.0060	0.0015
	(1.35)	(1.72)	(1.35)	(0.83)	(0.23)	(0.46)	(0.83)	(0.52)
Constant	26.1428***	–4.1521***	26.1428***	–4.2057***	1,267.832***	–7.1043***	1,267.832	–7.1043**
	(3.85)	(–32.91)	(3.85)	(–17.24)	(26.14)	(–8.36)	(1.5)	(–2.59)
N	5,819	5,819	5,819	5,819	5,819	5,819	5,819	5,819
R-squared	0.0241	0.2098	0.0581	0.2090	0.1495	0.1995	0.1495	0.1995

Notes: This table presents the OLS, REM, FEM regression results for the effects of weather variability on firm risk of equation (2): $Financial\ risk_{it} = \beta_0 + \beta_1 RAIN_{it} + \beta_2 TEMP_{it} + \beta_3 HUMID_{it} + \beta_4 AIR_{it} + \beta_5 WIND_{it} + \beta_6 CASE{*}RAIN_{it} + \beta_7 CASE{*}TEMP_{it} + \beta_8 CASE{*}HUMID_{it} + \beta_9 CASE{*}AIR_{it} + \beta_{10} CASE{*}WIND_{it} + \beta_{11} CASE + \beta_{12} LEVit + \beta_{13} GROWTH_{it} + \beta_{14} SIZE_{it} + \beta_{15} STATE_{it} + \varepsilon$. The definitions for the variables are provided previously. *, **, and *** indicate statistical significance at 10%, 5%, and 1%, respectively.

Regarding the interaction between weather variables and changes in the number of COVID-19 cases, only CASE*AIR is only shown to be statistically significant. This is consistent with the results of the preceding regression models on financial performance, indicating that the effect of weather variations on firm risks remained influenced only for atmospheric pressure volatility as the COVID-19 cases rise.

The Breusch and Pagan LM test and Hausman test are presented in Table 5a in Appendix. The modified Wald test is presented in Table 5b in Appendix.

4.4 Supplementary analysis

Our research study conducts a supplementary analysis on firms in the northern, central, and southern regions of Vietnam separately in order to provide a more comprehensive and detailed understanding of how weather variability impacts the performance and risks of Vietnamese listed companies, as well as to identify potential regional differences in these effects. We employed the robust FEM model, which is the most appropriate to estimate the weather impact as both pre-and post-estimation tests suggested. The results of the analysis are presented in Tables 6, 7 and 8.

Table 6 Supplementary test's results on the impact of weather variability on the performance and risks of Vietnamese listed companies located in the North Vietnam

	ROA	*ROE*	*Z-Score*	*BETA*
RAIN	–0.0002*	–0.001**	0.0119**	0.0142***
	(–0.72)	(–0.8)	(0.55)	(3.41)
TEMP	–0.0003	–0.0086	–0.1321	–0.1116
	(–0.13)	(–0.53)	(–1.16)	(–3.39)
HUMID	–0.0015**	–0.0079*	–0.0038	0.0127**
	(–2.51)	(–1.63)	(–0.09)	(2.18)
AIR	–0.0016**	–0.0031*	0.1112*	0.0769***
	(–0.94)	(–0.36)	(1.47)	(3.23)
WIND	0.0039	0.0155	0.7005	–0.0407
	(0.29)	(0.57)	(0.66)	(–0.37)
CASE*RAIN	–0.0001	0.0002	0.0001	–0.0009
	(–0.56)	(0.11)	(0.04)	(–2.08)
CASE*TEMP	0.0023	–0.0013	0.0554	0.0234
	(–0.04)	(–1.25)	(3.03)	(4.18)
CASE*HUMID	–0.0001	0.0001	–0.0024	–0.0056
	(–0.02)	(0.19)	(–0.36)	(–2.97)
CASE*AIR	–0.0003	–0.0008*	0.0148*	0.0034
	(–0.19)	(–1.17)	(1.14)	(1.61)
CASE*WIND	0.0011	0.0074	–0.0124	–0.009
	(0.92)	(2.14)	(–0.31)	(–1.15)
CASE	–0.0003	–0.007*	0.0189	0.0158
	(–0.3)	(–1.41)	(0.27)	(1.39)

Table 6 Supplementary test's results on the impact of weather variability on the performance and risks of Vietnamese listed companies located in the North Vietnam (continued)

	ROA	*ROE*	*Z-Score*	*BETA*
LEV	–0.2192***	–0.2841	–12.4637***	–0.581**
	(–3.43)	(–1.2)	(–4.12)	(–2.46)
GROWTH	0.0381***	0.0753**	1.1902***	–0.0968
	(5.32)	(2.38)	(2.82)	(–1.14)
SIZE	0.0541***	0.1096*	–1.0641	0.3372***
	(2.95)	(1.85)	(–1.05)	(3.56)
STATE	0.0040	0.0215	0.0042	0.0024
	(7.01)	(2.34)	(0.65)	(0.36)
Constant	–1.3269***	–2.7033*	37.071	–8.6249***
	(–2.63)	(–1.73)	(1.28)	(–3.37)
N	2,310	2,310	2,310	2,310
R-squared	0.1126	0.0108	0.2316	0.1813

Table 7 Supplementary test's results on the impact of weather variability on the performance and risks of Vietnamese listed companies located in the Central Vietnam

	ROA	*ROE*	*Z-Score*	*BETA*
RAIN	–0.0001*	–0.0002*	0.7793**	0.0019**
	(–0.46)	(–0.43)	(1.2)	(0.8)
TEMP	–0.002	0.0009	–2.5625	0.0546
	(–1.05)	(0.2)	(–1.05)	(2.48)
HUMID	–0.0001*	–0.0005	0.6541*	0.0228*
	(–0.12)	(–0.17)	(0.83)	(1.11)
AIR	–0.000	–0.0008	0.0945	–0.0102
	(–0.24)	(–0.66)	(0.14)	(–1.24)
WIND	0.0057	0.0148	–12.3168	–0.0511
	(1.27)	(1.21)	(–1.05)	(–1.12)
CASE*RAIN	0.0000	–0.0001	–0.0298	0.0000
	(–1.71)	(–1.31)	(–1.55)	(–0.04)
CASE*TEMP	0.0009	0.0014	0.5173	–0.003
	(1.43)	(0.83)	(1.48)	(–0.24)
CASE*HUMID	–0.0001	–0.0001	–0.0199	0.0007
	(–1)	(–0.59)	(–0.46)	(0.54)
CASE*AIR	–0.0001	–0.0007	–0.1093	0.0003
	(–0.27)	(–0.82)	(–0.84)	(0.07)
CASE*WIND	0.0001	–0.0013	0.7216	–0.0022
	(0.19)	(–0.65)	(1.93)	(–0.23)
CASE	–0.0003	0.0028	–0.4948	0.0013
	(–0.19)	(0.64)	(–1)	(0.1)

Table 7 Supplementary test's results on the impact of weather variability on the performance and risks of Vietnamese listed companies located in the Central Vietnam (continued)

	ROA	*ROE*	*Z-Score*	*BETA*
LEV	–0.1884***	–0.3299***	105.8145***	–0.1938
	(–4.7)	(–3.45)	(2.79)	(–0.55)
GROWTH	0.0001	–0.0003	–0.3139	–0.0033***
	(0.11)	(–0.07)	(–1.24)	(–5.2)
SIZE	0.0307**	0.0629**	–108.2472***	0.0662
	(2.28)	(2.05)	(–3.97)	(0.8)
STATE	0.0007	0.0060	0.0087	0.0021
	(0.40)	(1.95)	(0.65)	(1.24)
Constant	–0.6903*	–1.4709*	2,867.284***	–1.2401
	(–1.98)	(–1.86)	(3.93)	(–0.59)
N	880	880	880	880
R-squared	0.1154	0.0687	0.305	0.138

Table 8 Supplementary test's results on the impact of weather variability on the performance and risks of Vietnamese listed companies located in the South Vietnam

	ROA	*ROE*	*Z-Score*	*BETA*
RAIN	–0.0003*	–0.001***	–0.0651	0.0094***
	(–1.8)	(–2.91)	(–1.51)	(3.59)
TEMP	0.0001	0.0019	–1.1504	–0.0258
	(–0.01)	(0.25)	(–1.54)	(–0.65)
HUMID	–0.0004*	–0.0018*	0.0061*	0.0567***
	(–0.38)	(–0.86)	(0.04)	(4.34)
AIR	–0.0076**	–0.0132**	0.8853**	0.1467***
	(–2.38)	(–2.12)	(2.16)	(4.08)
WIND	0.0089	0.0103	–0.1961	–0.1385
	(1.48)	(0.94)	(–0.21)	(–1.38)
CASE*RAIN	0.0001*	0.0001	0.0195	–0.0002
	(1.8)	(2.51)	(1.6)	(–0.55)

Notes: Tables 6, 7, 8 show supplementary analysis results for the effects of weather variability on firm performance in the North, Central and South of Vietnam of equation (1): $Financial\ performance_{it} = \beta_0 + \beta_1 RAIN_{it} + \beta_2 TEMP_{it} + \beta_3 HUMID_{it} + \beta_4 AIR_{it} + \beta_5 WIND_{it} + \beta_6 CASE{*}RAIN_{it} + \beta_7 CASE{*}TEMP_{it} + \beta_8 CASE{*}HUMID_{it} + \beta_9 CASE{*}AIR_{it} + \beta_{10} CASE{*}WIND_{it} + \beta_{11} CASE + \beta_{12} LEV_{it} + \beta_{13} GROWTH_{it} + \beta_{14} SIZE_{it} + \beta_{15} STATE_{it} + \varepsilon$ and firm risks of equation (2): $\beta_0 + \beta_1 RAIN_{it} + \beta_2 TEMP_{it} + \beta_3 HUMID_{it} + \beta_4 AIR_{it} + \beta_5 WIND_{it} + \beta_6 CASE{*}RAIN_{it} + \beta_7 CASE{*}TEMP_{it} + \beta_8 CASE{*}HUMID_{it} + \beta_9 CASE{*}AIR_{it} + \beta_{10} CASE{*}WIND_{it} + \beta_{11} CASE + \beta_{12} LEV_{it} + \beta_{13} GROWTH_{it} + \beta_{14} SIZE_{it} + \beta_{15} STATE_{it} + \varepsilon$. The definitions for the variables are provided previously. *, **, and *** indicate statistical significance at 10%, 5%, and 1%, respectively.

Table 8 Supplementary test's results on the impact of weather variability on the performance and risks of Vietnamese listed companies located in the South Vietnam (continued)

	ROA	*ROE*	*Z-Score*	*BETA*
CASE*TEMP	–0.0003	–0.0002	0.0295	–0.0046
	(–0.45)	(–0.21)	(0.55)	(–0.68)
CASE*HUMID	0.0003	0.0004	–0.0192	–0.0023
	(2.15)	(1.82)	(–0.61)	(–1.97)
CASE*AIR	–0.0001*	–0.0001*	0.0309*	0.0024**
	(–0.84)	(–0.42)	(1.43)	(1.9)
CASE*WIND	0.0004	0.0003	0.1473*	–0.0012
	(0.08)	(0.62)	(1.79)	(–0.4)
CASE	–0.0014	–0.0027*	–0.1321*	0.018**
	(–1.58)	(–1.85)	(–1.86)	(2.61)
LEV	–0.1397***	–0.1586**	–14.0554***	–0.49*
	(–3.75)	(–2.15)	(–3.06)	(–1.96)
GROWTH	0.0199***	0.0235*	0.2047	–0.1313**
	(3.23)	(1.78)	(0.5)	(–2.07)
SIZE	0.0564***	0.1059***	–0.7456	0.4645***
	(3.43)	(3.17)	(–0.76)	(4.89)
STATE	0.0002	0.0061	0.0003	0.0008
	(0.82)	(1.25)	(0.38)	(2.55)
Constant	–1.4331***	–2.7459***	30.6231	–12.0669***
	(–3.2)	(–3.01)	(1.09)	(–4.62)
N	2,629	2,629	2,629	2,629
R-squared	0.0819	0.0635	0.1384	0.2616

Notes: Tables 6, 7, 8 show supplementary analysis results for the effects of weather variability on firm performance in the North, Central and South of Vietnam of equation (1): $Financial\ performance_{it} = \beta_0 + \beta_1 RAIN_{it} + \beta_2 TEMP_{it} + \beta_3 HUMID_{it} + \beta_4 AIR_{it} + \beta_5 WIND_{it} + \beta_6 CASE*RAIN_{it} + \beta_7 CASE*TEMP_{it} + \beta_8 CASE*HUMID_{it} + \beta_9 CASE*AIR_{it} + \beta_{10} CASE*WIND_{it} + \beta_{11} CASE + \beta_{12} LEV_{it} + \beta_{13} GROWTH_{it} + \beta_{14} SIZE_{it} + \beta_{15} STATE_{it} + \varepsilon$ and firm risks of equation (2): $\beta_0 + \beta_1 RAIN_{it} + \beta_2 TEMP_{it} + \beta_3 HUMID_{it} + \beta_4 AIR_{it} + \beta_5 WIND_{it} + \beta_6 CASE*RAIN_{it} + \beta_7 CASE*TEMP_{it} + \beta_8 CASE*HUMID_{it} + \beta_9 CASE*AIR_{it} + \beta_{10} CASE*WIND_{it} + \beta_{11} CASE + \beta_{12} LEV_{it} + \beta_{13} GROWTH_{it} + \beta_{14} SIZE_{it} + \beta_{15} STATE_{it} + \varepsilon$. The definitions for the variables are provided previously. *, **, and *** indicate statistical significance at 10%, 5%, and 1%, respectively.

Regarding the north region, the supplementary analysis reveals that variations in rainfall, humidity level and air pressure had an adverse effect on firm performance, or ROA and ROE specifically. The findings are consistent with previous studies by Giang et al. (2021), who conclude that humidity negatively impacts profitability of companies in the manufacturing industry in Vietnam. Additionally, Kang et al. (2010) also pointed out the involvement of weather variability in financial instability. This could be due to the fact that variations in weather conditions can lead to increased levels of discomfort among workers, which can in turn negatively impact their productivity and the quality of operations. The results also indicate an increase in air pressure, humidity and precipitation volatility induced higher Z-Score and systematic risk for listed companies. This is in line with our main findings, and can be attributed to the fact that the northern part is prone to extreme weather events such as typhoons and storms, which are often associated with volatile rainfall and atmospheric conditions, causing significant damage to infrastructure and disrupting business operations.

Table 9 Robustness test results

	ROA	*ROE*	*Z-Score*	*BETA*
RAIN	–0.0002	–0.001*	0.7947**	0.0075**
	(–0.82)	(–0.52)	(1.13)	(2.34)
TEMP	0.0006**	0.0019	–0.1428	0.0028
	(2.09)	(1.54)	(–0.62)	(0.61)
HUMID	–0.0002*	–0.0002*	–0.2069	0.0036
	(–0.97)	(–0.35)	(–1.01)	(1.54)
AIR	–0.0003**	–0.0005**	0.1075**	0.0018*
	(–1.39)	(–0.98)	(0.7)	(0.56)
WIND	0.0005	0.003	–3.7949	–0.1222
	(0.17)	(0.38)	(–1.26)	(–3.75)
CASE*RAIN	0.0012	–0.0001	–0.0315	0.0002
	(0.19)	(–1.03)	(–0.75)	(0.5)
CASE*TEMP	–0.0001	–0.0003	–0.0688	–0.0023
	(–0.99)	(–1.31)	(–1.64)	(–4.02)
CASE*HUMID	0.0025	0.0001	–0.0093	–0.0004
	(0.25)	(1.19)	(–1.56)	(–2.39)
CASE*AIR	–0.0016	–0.0056*	0.0068*	0.0035
	(–0.95)	(–1.1)	(1.58)	(1.5)
CASE*WIND	0.0003*	0.0008	0.0977	0.002
	(1.79)	(2.65)	(2.08)	(1.81)
CASE	–0.0024	–0.0131*	0.8896	0.0499*
	(–0.62)	(–1.15)	(0.81)	(1.91)
LEV	–0.1618***	–0.2129**	22.2494	–0.5022***
	(–5.57)	(–2.28)	(0.97)	(–2.91)

Notes: Table 9 shows robustness test results for the effects of weather variability on firm performance of equation (1): $Financial\ performance_{it} = \beta_0 + \beta_1 RAIN_{it} + \beta_2 TEMP_{it} + \beta_3 HUMID_{it} + \beta_4 AIR_{it} + \beta_5 WIND_{it} + \beta_6 CASE{*}RAIN_{it} + \beta_7 CASE{*}TEMP_{it} + \beta_8 CASE{*}HUMID_{it} + \beta_9 CASE{*}AIR_{it} + \beta_{10} CASE{*}WIND_{it} + \beta_{11} CASE + \beta_{12} LEV_{it} + \beta_{13} GROWTH_{it} + \beta_{14} SIZE_{it} + \beta_{15} STATE_{it} + \varepsilon$ and firm risks of equation (2): $Financial\ risk_{it} = \beta_0 + \beta_1 RAIN_{it} + \beta_2 TEMP_{it} + \beta_3 HUMID_{it} + \beta_4 AIR_{it} + \beta_5 WIND_{it} + \beta_6 CASE{*}RAIN_{it} + \beta_7 CASE{*}TEMP_{it} + \beta_8 CASE{*}HUMID_{it} + \beta_9 CASE{*}AIR_{it} + \beta_{10} CASE{*}WIND_{it} + \beta_{11} CASE + \beta_{12} LEV_{it} + \beta_{13} GROWTH_{it} + \beta_{14} SIZE_{it} + \beta_{15} STATE_{it} + \varepsilon$. The definitions for the variables are provided previously. *, **, and *** indicate statistical significance at 10%, 5%, and 1%, respectively.

Table 9 Robustness test results (continued)

	ROA	*ROE*	*Z-Score*	*BETA*
GROWTH	–0.0001	–0.0002	–0.8248***	–0.0049***
	(–1.42)	(–0.96)	(–3.1)	(–4.49)
SIZE	0.0464***	0.0875***	–46.0064	0.2796***
	(3.41)	(2.78)	(–1.48)	(2.77)
STATE	0.0013	0.0007	0.0826	0.0019
	(0.19)	(0.52)	(1.5)	(0.8)
Constant	–1.4712***	–2.7496***	1,391.69	–8.9785**
	(–3.43)	(–2.79)	(1.41)	(–2.05)
N	5,819	5,819	5,819	5,819
R-squared	0.0743	0.0075	0.1466	0.1970

Notes: Table 9 shows robustness test results for the effects of weather variability on firm performance of equation (1): $Financial\ performance_{it} = \beta_0 + \beta_1 RAIN_{it} + \beta_2 TEMP_{it} + \beta_3 HUMID_{it} + \beta_4 AIR_{it} + \beta_5 WIND_{it} + \beta_6 CASE{*}RAIN_{it} + \beta_7 CASE{*}TEMP_{it} + \beta_8 CASE{*}HUMID_{it} + \beta_9 CASE{*}AIR_{it} + \beta_{10} CASE{*}WIND_{it} + \beta_{11} CASE + \beta_{12} LEV_{it} + \beta_{13} GROWTH_{it} + \beta_{14} SIZE_{it} + \beta_{15} STATE_{it} + \varepsilon$ and firm risks of equation (2): $Financial\ risk_{it} = \beta_0 + \beta_1 RAIN_{it} + \beta_2 TEMP_{it} + \beta_3 HUMID_{it} + \beta_4 AIR_{it} + \beta_5 WIND_{it} + \beta_6 CASE{*}RAIN_{it} + \beta_7 CASE{*}TEMP_{it} + \beta_8 CASE{*}HUMID_{it} + \beta_9 CASE{*}AIR_{it} + \beta_{10} CASE{*}WIND_{it} + \beta_{11} CASE + \beta_{12} LEV_{it} + \beta_{13} GROWTH_{it} + \beta_{14} SIZE_{it} + \beta_{15} STATE_{it} + \varepsilon$. The definitions for the variables are provided previously. *, **, and *** indicate statistical significance at 10%, 5%, and 1%, respectively.

For companies located in the south, volatility in rainfall, humidity and air pressure are found to have a negative impact on financial performance and increase risks. Rainfall and humidity volatility is shown to have a negative relationship with performance indicators, namely ROA and ROE, while positively correlated with firms' systematic risks. Similarly, as atmospheric pressure becomes more volatile, firms tend to perform poorly and suffer from instability. The results are consistent with our main findings, which can be explained by the predominance of firms in this region. Another reason is that this region is prone to flooding and other forms of water damage. According to Barrot and Sauvagnat (2016), natural disasters, namely flooding, droughts, and storms generally make businesses incur tremendous losses, particularly in the sales growth following the detrimental events. Flooding specifically can disrupt business operations and thereby cause financial losses. Additionally, the high humidity levels in this region can also increase the risk of mould growth and other forms of moisture damage, which can lower productivity and quality of operations.

In the central region, only variations in rainfall and humidity are found to have a significant impact on firm performance and risks. The main difference between Central Vietnam and the other regions is the absence of air pressure effect on financial risks and performance. This could be explained by the stability in atmospheric pressure of the region throughout the study period compared to the north and south.

The interactions between weather variables and changes in the number of COVID-19 cases still remain statistically significant for air pressure volatility. This is in line with results from the main models, reaffirming that the relationship between weather variations and firm performance was moderated by the impact of the COVID-19 pandemic.

Overall, the results of the supplementary analysis provide additional evidence that supports the main findings of our study while suggesting that the effects of weather variability on firm performance and risks tend to remain quite consistent across regions due to the relative similarity in their climatic patterns.

4.5 Robustness test

To ensure the reliability of our findings, we conducted a robustness test, computing the average for each weather variable from the same data set as in the main model, and using it as a proxy for weather effect in our analysis. The results, which are given in Table 9, suggest that the effect of weather variability on financial performance and firm risks remains largely unchanged. Specifically, average rainfall, humidity and air pressure negatively affected ROA and returns on equity (ROE), while higher precipitation and atmospheric pressure were found to induce a significant increase in bankrupt and systematic risks. These findings are consistent with the main model results, which helps to increase confidence in the validity of the results and the robustness of our conclusions.

5 Conclusions

Our study focuses on investigating the impact of weather variability on firm performance and financial risk of listed companies on the Vietnamese stock markets from 2020 to 2022, covering the occurrence of COVID-19 pandemic. The regression results reveal that rainfall; humidity and air pressure volatility have an adverse influence on the financial performance consisting of ROA and ROE, which coincides with the studies of Barrot and Sauvagnat (2016), and Huang et al. (2018). In addition, we also find evidence to prove the positive relationship between weather variables including rainfall, humidity and air pressure variability and financial risk indicators such as Altman Z-Score and systemic risk. However, the impact of other climate factors is insignificant for both firm performance and firm risks in Vietnamese listed companies in the COVID-19. This may be due to the effects that the COVID-19 brings to businesses including the national lockdown, the transformation of business models or the prevalence of working from home.

From the aforementioned findings, it is indicated that due to the COVID-19 pandemic outbreak and weather variability, Vietnamese firms have faced declining financial performance and rising risk. Obviously, businesses had to contend with the combined risk of weather fluctuations and the pandemic. Since climate change has always been on the rise, as evidenced by extreme weather occurrences and the severity of meteorological variability, its risk will continue to present and coexist with other risks. Specifically, there have been many crises and unforeseen occurrences throughout world history, including but not limited to the Great Depression, the SARS pandemic, the global financial crisis, and the current COVID-19 pandemic, which have all had unprecedented and lasting repercussions. Additionally, fast technological development and aging population and other factors also raise concerns. Accordingly, these unanticipated occurrences and perilous factors send a cautionary message that the world is inherently characterised by risk and uncertainty. As a result, businesses will always be exposed to climate risk as well as other types of risk, it is therefore crucial for companies to implement risk management strategies to prevent losses and ensure long-term sustainability and growth.

Our study provides further evidence that though the effects of weather on Vietnamese businesses may vary by region, all firms are adversely affected by volatility from weather variables, including humidity, precipitation, and air pressure. Hence, we would like to offer some suggestions for Vietnamese listed companies to manage extreme weather fluctuations. To address the issue of mould growth resulting from elevated humidity levels, it is recommended that organisations allocate resources towards constructing a robust building envelope that can effectively hinder moisture penetration. This may involve the use of sturdy and waterproof cladding systems for the building's exterior, as well as the installation of effective drainage systems for the roof and windows that can prevent water accumulation. Additionally, interior measures such as proper ventilation and air circulation, the use of moisture-resistant materials, and the implementation of moisture control mechanisms including dehumidification systems are also suggested strategies to prevent mould growth resulting from moisture intrusion.

Moreover, due to the fact that weather variability could become more unpredictable due to climate change's rising tendency, businesses are anticipated to suffer more frequent and severe weather variations that could damage their operations and financial performance, therefore, we suggest that climate change adaptation is essential. First and foremost, companies should educate themselves on climate change, its causes, and the risks it poses to their operations. Only then will they be able to develop both short-and long-term strategies for adjusting to the changing environment. Secondly, due to the fact that adaptation initiatives usually take the form of a reactive approach, responding to unanticipated climate events rather than being planned and performed proactively, businesses should prioritise their climate change adaptation strategy as much as their other plans. The manufacturing companies in Jakarta, for instance, decided to adopt a proactive approach rather than a reactive one following the devastating floods of 2007 (Neise and Diez, 2019). Specifically, they made significant investments in improving their infrastructure to increase its capacity to withstand flooding, built an emergency response and forecasting team and stored raw materials to avoid operation disruption. In addition, firms should consider increasing their inventory reserves, implementing diversification strategies for sourcing and developing alternative production locations, all of which are especially crucial for maintaining supply chain flow. Furthermore, the typical method of problem-solving involves taking action first, evaluating the outcomes, and then making a subsequent move based on those outcomes. Technology, however, can now assist in making decisions that are both solid and resilient by aiding in the provision of alternative strategies as well as the prediction of problematic future scenarios. Particularly, Lempert and Groves (2010) propose a computer-assisted tool called robust decision making (RDM) that simulates over thousands of possible futures under various combined uncertainty conditions of climate change and other factors to assess the performance of the candidate strategies under such future states, characterise their weaknesses, and finally demonstrate alternative strategies that alleviate those vulnerabilities. Therefore, thirdly, we advise that business decision-makers employ technology to increase their competitiveness, make more accurate decisions, and avoid losses and disruption in the face of the profound uncertainty brought on by climate change. Fourthly, the most extreme level of response, which is a relocation strategy, may be necessary for the companies to consider if the risks become intolerable, consistently occur, result in significant losses, and can no longer be solved by taking both proactive and reactive measures. The method does, however, call for a substantial amount of financial resources and could result in losses for businesses with strong ties to the local community.

Furthermore, in response to the unpredictable risks posed by climate change, relying solely on individual efforts to prepare for and adapt to these changes may not be sufficient. Therefore, it is crucial for companies, especially those categorised as small or medium-sized enterprises, to collaborate with each other and with the government to maximise their level of protection and minimise potential losses. This can be accomplished by engaging in joint initiatives such as sharing information regarding possible threats, consolidating resources to implement security measures, linking firms' climate change adaptation infrastructure and coordinating emergency response plans. Ultimately, in order to increase their capacity to withstand climate-related risks, companies should contemplate incorporating a variety of solutions rather than relying solely on a single approach.

This research also contributes to a growing literature on the impact of weather variability on financial health at firm level, yet being one of the first studies to explore such a relationship in the context of COVID-19 pandemic. Working from home and mobility restrictions, as a measure against the spread of coronavirus, reduced the exposure of employees and business activities to weather factors, thereby alleviating the effect of climate risk on firm performance.

Our study is still subjected to certain limitations. First, the research was only conducted during the COVID-19 pandemic; therefore, it is impossible to compare the research findings with the pre-and post-pandemic periods. Moreover, although there is a wide range of data used in this study, firm data is derived from large enterprises listed on the Vietnamese stock market, automatically excluding a number of small businesses and start-ups. Additionally, the data is collected from HOSE and HNX, whereas Vietnam has more than two stock exchanges, such as Upcom and OTC. As a result, the data utilised in our research could not completely reflect the big picture of the Vietnamese financial market and economy in general.

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Appendix

- Tables 4a and 4b belong to Table 4 in the Subection 4.3.1.

  Table 4a presents the results of Breusch and Pagan LM and Hausman tests, which indicate fixed effects model is the most appropriate model to estimate the effect of weather variability on ROA and ROE.

Table 4a Breusch and Pagan LM test and Hausman test

	ROA		*ROE*	
	LM test	*Hausman test*	*LM test*	*Hausman test*
Chi-squared	13,410.65	199.95	1,350.29	31.30
p-value	0.0000	0.0000	0.0000	0.0001

Modified Wald test, presented in Table 4b were performed post the estimation, which found the problem of heteroskedasticity prevailed in our regression models. Hence, we decided that the FEM with robust standard errors is calibrated in assessing weather variability impact on these performance indicators.

Table 4b Modified Wald test

	ROA	*ROE*
Chi-squared	3.9e+07	5.1e+08
p-value	0.0000	0.0000

- Tables 5a and 5b belong to Table 5 in the Subsection 4.3.2.

  In order to determine the most appropriate model for our estimation, Breusch and Pagan LM and Hausman tests were performed, which suggests fixed-effects model for measuring the effect of weather variability on Z-Score and BETA.

Table 5a Breusch and Pagan LM test and Hausman test

	Z-Score		*BETA*	
	LM test	*Hausman test*	*LM test*	*Hausman test*
Chi-squared	773.627	2,094.30	2,970.00	35.98
p-value	0.0000	0.0000	0.0000	0.0000

Modified Wald test, presented in Table 5b were performed after the estimation, which found the problem of heteroskedasticity prevailed in our regression models. Hence, we decided that the FEM with robust standard errors is calibrated in assessing weather variability impact on these risk indicators.

Table 5b Modified Wald test

	Z-score	*BETA*
Chi-squared	2.6e+07	20,555.38
p-value	0.0000	0.0000