Corporate Social Responsibility and Environmental Management

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RESEARCH ARTICLE OPEN ACCESS

The Impact of Climate Change on the Performance of Agricultural Companies Worldwide

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Received: 13 December 2024 | **Revised:** 22 May 2025 | **Accepted:** 13 June 2025

Funding: This work was supported by the Agencia Estatal de Investigación (Spain): Research Project (PID2020-117792RA-I00).

Keywords: agricultural companies | climate change | operating performance | physical risk

ABSTRACT

This study examines the impact of climate change on agricultural firms, focusing on physical risks, both chronic (e.g., temperature and precipitation) and acute (e.g., droughts and floods). We conduct a panel data analysis of 19,929 companies in 69 countries across five continents from 2013 to 2021. We evaluate firms' vulnerability based on size and geographical location across various climate zones. The study highlights the rising costs that climate risks impose on smaller companies, compromising their operations and profitability. Contrary to previous studies, our findings suggest that companies in continental and temperate climates are the most affected. This challenges the existing literature and demonstrates that the relationship between temperature and agricultural performance is more complex than previously thought. As climate variability increases, it is critical that policymakers and companies adopt tailored strategies to mitigate these risks and enhance resilience, especially for the most vulnerable companies.

JEL Classification: G32, Q14, Q54

1 | Introduction

Climate change has significant impacts on the economy, affecting businesses directly. In this context, companies face two main types of climate-related risks: transition risks and physical risks (Giglio et al. 2021). Transition risks are associated with regulatory, technological, and preference changes resulting from the adoption of measures to mitigate climate change. These risks are linked to the implementation of laws and regulations to reduce greenhouse gas (GHG) emissions, the adoption of low-carbon technologies, and the growing demand from consumers and investors for greater corporate responsibility (Venturini 2022).

In contrast, physical risks are directly linked to the impact of climate on a company's operations, which varies depending on its geographical location and the specific attributes of exposed assets or systems (Tankov and Tantet 2019). The increase in GHG concentrations in the atmosphere has led to changes in the climate system, manifesting in both the frequency and intensity of meteorological events. Tankov and Tantet (2019) categorise physical risks into two types: acute and chronic. Acute physical risks are related to event-driven risks such as floods, droughts, heat waves, cold waves and hurricanes, while chronic physical risks are associated with gradual changes, such as rising temperatures and shifting rainfall patterns.

Both chronic and acute risks have substantial implications for all sectors, although some are more affected, particularly agriculture, where the increased prevalence of extreme weather events has posed significant challenges. Developing countries are especially susceptible to these impacts due to their geographic location in warmer regions and their limited adaptive capacity.

These limitations stem from restricted access to financial and technological resources, insufficient political support for infrastructure development and heavy reliance on agriculture, which makes them more exposed to climate variations with potentially severe consequences for economic growth. Given that the impact of climate change on businesses is a broad and complex issue, this study focuses exclusively on physical risks and analyses how these risks affect business operations and profitability, considering their vulnerability by looking at both extreme weather events and gradual environmental changes.

The 2022 report by the Intergovernmental Panel on Climate Change (IPCC) highlights the adverse effects of climate change on agricultural productivity primarily due to rising temperatures that compromise crop quality and stability, thereby jeopardising food security and livelihoods. As a result, climate change presents a significant challenge for agriculture, posing risks to crops and water resources that are essential for the sector's development (IPCC 2022). These pressures are expected to intensify and, in response, businesses are increasingly raising concerns about meteorological conditions in their reports (Chou et al. 2023). While some firms may mitigate the effects of these physical hazards through insurance, the emergence of new threats exacerbates their vulnerability and increases their exposure to adverse financial consequences (Secinaro et al. 2020). A growing body of research has examined the effects of climate phenomena on agriculture. Evidence shows that rising temperatures during crop growth and reproductive stages often lead to reductions in both yield quantity and quality (FAO 2023a, 2023b; Lachaud et al. 2022; Shi and Tao 2014; Taraz 2018). In contrast, adequate rainfall generally improves agricultural productivity (Archer et al. 2019; Lachaud et al. 2022; Mendelsohn and Massetti 2017; Thai et al. 2023). Acute risks, such as droughts and floods, are also well-documented as negatively impacting crop yields by reducing soil fertility, damaging infrastructure, and increasing the prevalence of pests and diseases (Hlavinka et al. 2009; Posthumus et al. 2009; Venkatappa and Sasaki 2021).

Despite the growing literature on the impacts of climate variability on the financial performance of agricultural companies, most studies focus on North America and Asia (Addoum et al. 2020; Hugon and Law 2019; Thai et al. 2023). In this context, this research seeks to expand the scope by analysing the impact of chronic and acute physical risks—particularly temperature, rainfall, droughts and floods—on the performance of agricultural companies globally. Employing panel data methodology, this study examines 19,929 companies located in 69 countries across the five continents from 2013 to 2021, leading to a sample of 141,473 company-year observations. For a more in-depth analysis, we explore vulnerability (firm size) and exposure (climatic zone location), which are two key drivers of climate physical risk. Therefore, the data set is divided into two ways: by firm size and by climatic zone, using the Köppen climate classification as a reference.

We believe this study contributes to the climate finance literature by providing the first global analysis of how physical risks are transferred to the performance of agricultural companies based on their vulnerability and exposure, representing a step towards modelling and valuing this type of risk. Our findings are particularly relevant as regulators and investors increasingly focus on the environmental and climate-related impacts of corporate activities (Lee et al. 2023).

Our results reveal that chronic physical risks impact agricultural profitability. Specifically, higher temperatures negatively affect performance measures, likely due to the stress plants experience under elevated temperatures, which hinders their growth and development, ultimately reducing crop yields. This impact is especially pronounced in smaller companies and those located in continental and temperate climate regions. Conversely, rainfall shows a positive and significant relationship with profitability, suggesting that increased rainfall benefits agricultural production and, consequently, company profitability, while its decrease can introduce risks to crops that negatively affect agricultural businesses. Companies located in continental and tropical regions are the most affected.

Regarding acute physical risks, we find that droughts and floods have a detrimental effect on performance measures. The decrease in profitability can be attributed to factors such as impaired plant development, increased soil salinity or erosion, the spread of diseases and pests, and significant damage to agricultural infrastructure. These effects can lead to substantial reductions in crop yields, negatively impacting revenue and increasing costs, ultimately reducing company profitability. Notably, micro and small companies are the most vulnerable to these climate events, while large companies show no significant impact, likely due to their greater technical and economic resources to cope with the consequences of climate change. In this line, its consequences will have an impact on the profitability of the following period in almost all companies except the large ones. It is also important to note that climate data are collected based on the location of the parent company, making smaller companies more susceptible to adverse weather conditions in the country where their headquarters are located, as they are less likely to have geographically diversified operations compared to larger companies.

Our findings suggest that companies in the primary sector, particularly micro, small and medium-sized companies, are indeed affected in their profitability by climate influences on production volume, agricultural infrastructure, and the costs associated with these events. Consequently, various strategies are needed at both the company and country levels to mitigate the damage caused by physical risks. Given that future harms will likely be greater, an increasing number of adaptation measures will be required, based on both current and future risks (Sonwa et al. 2017).

We address a key gap in the literature by analysing how micro and small agricultural companies, which make up a significant part of the agricultural sector in many developing economies, face climate-related challenges. While existing research often focuses on larger firms (Addoum et al. 2020) or examines aggregate impacts on the sector, less empirical evidence exists on how smaller companies—with limited adaptive capacity—are affected by different climatic conditions. In addition, we contribute by exploring the impact of physical risks on profitability and how company size amplifies vulnerability to climate change. We also find that the gradual changes in temperature and rainfall have different effects depending on the climatic zone. This could

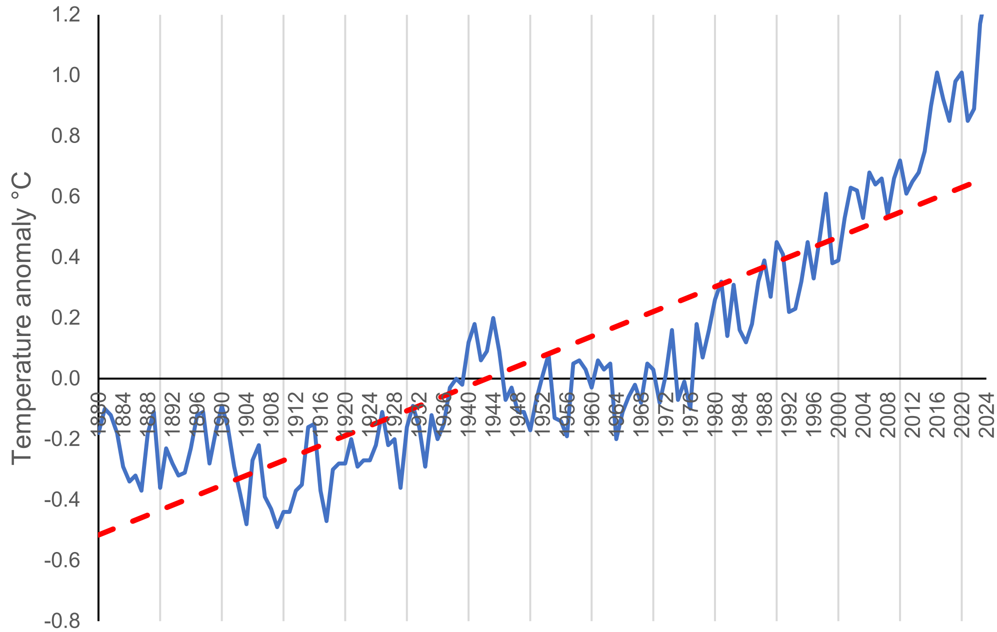

FIGURE 1 | Land-ocean temperature index, 1880 to present, with base period 1951–1980. *Source:* Data from NASA's Goddard Institute for Space Studies (GISS). Available online: https://data.giss.nasa.gov/gistemp/graphs_v4/.

offer valuable insights for climate adaptation policies and risk mitigation strategies for small and medium-sized agricultural enterprises.

The remainder of the paper is organised as follows. Section 2 provides an analysis of the previous literature and the development of hypotheses. Section 3 describes the data and methodology used. Section 4 discusses the main empirical findings. Section 5 presents robustness analyses. Section 6 discusses the results and concludes. Section 7 highlights some practical implications.

2 | Previous Literature and Hypotheses

In recent years, the effects of climate change have become increasingly evident, and the frequency of extreme weather and climate events is increasing globally. Data from the World Meteorological Organization (WMO) shows that the last decade has been one of the warmest on record (WMO 2025), and according to the Centre for Research on the Epidemiology of Disasters (CRED), 390 natural disasters have been recorded over the course of 2023, including floods, droughts, wildfires and storms.

Several authors have shown that climate and meteorological anomalies resulting from climate change do indeed represent a risk since they have an impact on companies and the economy (physical risk). Dell et al. (2012, 2014) conclude that a 1°C increase can reduce economic growth by 1%–2% in low-income countries, while in richer countries, there is no significant effect. These results highlight that the impact is more severe in countries with high dependence on agriculture, as temperature increases could affect their level of production. Along these lines, Hsiang (2010) estimates for the countries of the Caribbean and Central America a reduction of 2.5% in the country's total production when there is a temperature increase of 1°C, although the loss of agricultural production is smaller compared to other sectors. Similar results are found by Jain et al. (2020) in India, although, unlike Hsiang (2010), the impact is more severe in the primary sector.

In this research, four climatic variables have been selected to evaluate the impact on the performance of agricultural companies, two of which are related to chronic risk (temperature and precipitation level), and the other two variables refer to extreme events related to acute risk (floods and droughts).

2.1 | Temperature

Human activity is responsible for global warming through GHG emissions (IPCC 2023). If current emission levels are maintained, the average temperature of the planet is expected to exceed 1.5°C above pre-industrial levels agreed upon in the Paris Agreement in the short term, and with each increase, the climate hazards on the environment will intensify. Temperature increases will have effects on countries' economies but will vary depending on geographic location (risk of exposure), that is, those countries located in warmer areas will experience more significant adverse consequences (Tan et al. 2021).

The global temperature in the decade 2011–2020 was 1.09°C higher than that recorded in the period 1850–1900 (IPCC 2023). In addition, globally, the period 2015–2024 has been the warmest on record, with an increase in global average temperature of $1.55^\circ C \pm 0.13^\circ C$ if the period 1850–1900 is taken as a baseline (WMO 2025) or 1.28°C according to data provided by NASA taking the period 1951–1980 as a baseline (see Figure 1).

Studies such as Griffin et al. (2024) examine the impact of extremely high temperatures on the financial performance of firms in the European Union and the United Kingdom, revealing a curvilinear effect on their behaviour. Their findings suggest that in warmer regions, extreme temperature episodes tend to deteriorate financial performance, while in cooler regions, these episodes lead to improvements.

In the agricultural sector, climatic variations have a negative impact on crop production, as high temperatures can cause irreversible physical damage to the plants, affecting the company's operations. The type of damage will depend on the magnitude and duration of the event, as well as the ability of the species to adapt to extreme conditions and the stage of development (FAO 2023a, 2023b). Several studies conclude that temperature can have an effect on crop yields during the growing season when the average temperature rises, as plants tend to require a greater amount of energy to breathe, which can affect their ability to grow and produce fruit by limiting energy use. Likewise, temperate climate species are generally affected by temperature increases in the growth stage, due to the need for an adequate period of cold hours during their dormancy to resume their growth, thus impacting the development of reproductive organs (FAO 2023a, 2023b). In the case of crops of high relevance to food security, such as wheat, maize and barley, Lobell and Field (2007) find that recent climate trends have had a negative impact on their yield, largely attributable to warmer temperatures.

Taraz (2018) and Nguyen and Scrimgeour (2022) conclude that in India and Vietnam, extremely high temperatures pose a risk to agricultural crops. In Latin America, empirical evidence supports similar findings. Lachaud et al. (2022) confirm that climate change will exert a significant impact on agricultural production, demonstrating that rising average monthly and annual temperatures negatively affect output. Moreover, these negative effects tend to intensify over time and display significant variation across countries. Aragón et al. (2021) report that climate change, particularly the extreme temperatures, has a significant impact on agricultural production among subsistence farmers in Peru. The study's findings reveal that, in response to extreme heat events, farmers expand their cultivated land and modify their crop composition.

In Africa, a 1°C increase in temperature has led to losses in maize cultivation in warmer countries in the period 1961–2010 (Shi and Tao 2014). Tibesigwa et al. (2017) conclude that rising temperatures will have a significant adverse impact on commercial agricultural production in South Africa. The findings indicate that higher temperatures have a greater negative impact on agriculture than reduced rainfall, and among different farming systems, specialised crop farms are the most vulnerable to temperature increases. Similarly, Ousayd et al. (2024) demonstrate that temperature is a key factor influencing wheat production in Morocco, indicating that rising temperatures can lead to water and heat stress, adversely affecting grain development during critical growth stages and significantly reducing yield. On the other hand, Mendelsohn and Massetti (2017) argue that climate change has an effect on crops, but this is not necessarily negative, as the increase in temperature will be positive in regions with cold climates and negative in tropical climates.

Pastor-Sanz et al. (2025) show that extreme climatic conditions have a direct impact on the productive resources of agricultural enterprises, while also contributing indirectly to a decline in asset values, increased operating costs, reduced income, and higher insurance premiums. The authors conclude that extreme temperature anomalies, particularly unusually high temperatures, significantly increase the likelihood of bankruptcy among these firms. Pankratz et al. (2023) examine the effects of extreme heat on the financial performance of more than 17,000 firms across 93 countries during the period 1995–2019. Their findings suggest that an increase in the number of extremely hot days is associated with significant declines in both revenue and operating income, affecting firms in both agricultural and non-agricultural sectors. Additionally, the study reports that higher heat exposure leads to increased costs of goods sold and higher selling, general, and administrative expenses, ultimately reducing overall firm profitability.

Regarding the operational performance of agricultural companies, Addoum et al. (2020) analyse the impact of temperature on subsidiaries of US-listed companies, including those in the agricultural sector, in the period 1990–2015 and find that temperature shocks do not have an impact on sales growth, even in those companies that are more sensitive to temperature changes. This is mainly because listed companies have the resources to adapt to these changes and cope with extreme weather conditions. In this line, Thai et al. (2023) analysed 77 listed companies in Vietnam in the period 2015–2019 and found that temperature has a positive effect on the profitability of agricultural companies.

Conversely, Hugon and Law (2019) claim that temperature anomalies do affect US corporate profits, concluding that a 1°C increase leads to a 1.6% decrease in profits, with the most severe impact in warmer areas. Traore and Foltz (2018) also find that there is a negative association between temperature and income and profits in agricultural companies in Côte d'Ivoire.

Given that most of the empirical evidence shows that temperature shocks directly impact agricultural productivity (Ousayd et al. 2024; Shi and Tao 2014; Lobell and Field 2007), companies with fewer resources for adaptation are more likely to experience financial losses (Traore and Foltz 2018), and that temperature effects are context-dependent, varying by climatic region and adaptation capacity (Griffin et al. 2024; Mendelsohn and Massetti 2017), the following hypothesis is proposed in its alternative form:

H1. *There is a negative relationship between temperature and the profitability of agricultural companies. This relationship is modulated by the vulnerability (size) and exposure (climate zone) of the company.*

2.2 | Rainfall

Since the 1950s, several regions of the world have seen an increase in the intensity of rainfall. Currently, more people are living in areas where the maximum annual rainfall has increased compared to those living in areas where it has decreased (IPCC 2022). In the coming years, rainfall is expected to increase in the tropics and regions located at higher latitudes but will decrease in dry areas (Turral et al. 2011). According to

WMO (2022), rainfall between May and September in the Sahel and northern Europe is expected to be higher in the period 2022–2026 than the average for the period 1991–2020, while between November and March, more rain is expected in the tropics and less rainfall in the subtropics.

Rainfall is a source of water of great relevance in the irrigation of agricultural production, although depending on its frequency and intensity, it can be beneficial or, in some cases, destructive. An adequate amount of rainfall is essential for a good harvest, both in the initial growth stage of plants and in the reproduction phase. Nguyen and Scrimgeour (2022) conclude that increased rainfall during the summer and autumn seasons is favourable for agricultural productivity. In South Africa, during the period 2017–2018, a 47% decrease in wheat production was recorded due to below-average rainfall and low soil moisture, which further affected the state of crops (Archer et al. 2019). In addition, Shi and Tao (2014) analyse a set of countries in Africa in the period 1961–2010 and conclude that decreased rainfall resulted in a reduction in maize crop yields. Regarding the effect of rainfall on firm performance, Thai et al. (2023) analyze listed companies in Vietnam in the period 2015–2019 and conclude that rain has a positive effect on the profitability of agricultural companies. This effect is attributed to precipitation creating favourable conditions for rice cultivation in wetland areas, fostering intensive farming, and promoting crop diversification.

Since increased rainfall benefits agricultural productivity, while decreasing rainfall has a negative effect on crop yields by not providing conditions conducive to agricultural development, which will have an impact on profitability, the following hypothesis is proposed in its alternative form:

H2. *There is a positive relationship between rainfall and the profitability of agricultural companies. This relationship is modulated by the vulnerability (size) and exposure (climate zone) of the company.*

2.3 | Natural Disasters

According to data provided by the WMO, in the last 50 years, natural water-related phenomena such as droughts, storms, and floods have been the most devastating in terms of economic losses (WMO 2021). In 2020, around 100 million people were affected by natural disasters, causing economic losses of $190 billion (Jones et al. 2022). Petteri Taalas, WMO Secretary-General, said:

> The impacts of climate change are often felt through water with more intense and frequent droughts, more extreme flooding, more erratic seasonal rainfall and accelerated melting of glaciers. All of this has cascading effects on economies, ecosystems, and all aspects of our daily lives. (Personal communication, 29 November 2022).[1]

Two of the natural disasters that most affect the agricultural sector are droughts and floods (FAO 2021, 2023a, 2023b). In addition to the intensity, the frequency of these phenomena has also been increasing. While 59 floods were recorded globally in 1990, a total of 141 floods were documented in 2024, representing an increase of 139% over a 34-year period (see Figure 2).

Droughts represent a clear physical risk to agriculture, as their occurrence reduces the amount of water available for irrigation, decreases soil fertility, increases erosion, and favours the presence of salinity, generating an impact on crops (Potopová et al. 2016). Between 2008 and 2018, droughts were the most destructive extreme events for the agricultural sector, causing $37 billion in production losses (FAO 2021).

Lin and Sheng (2023) examine the impact of drought on the productivity of agriculture-related firms in China and conclude that this climatic phenomenon significantly reduces total factor productivity. This adverse effect is explained, among other factors, by the increase in operating costs, highlighting the sector's vulnerability to extreme climatic variations. Water deficit during dry spells can lead to a significant reduction in yield and even total crop loss, affecting not only production but also crop quality (Hlavinka et al. 2009). Guo et al. (2025) analyse the impact of climate risk on corporate financial performance, finding that economic losses caused by meteorological disasters such as floods and droughts negatively affect firms' return on assets (ROA), particularly in smaller companies. The study highlights that business diversification and greater managerial attention to climate risk help mitigate these adverse effects.

Since agricultural companies will see their crops affected by the physical risk inherent in weather conditions that affect business operations, these will have an impact on the harvest that will affect the level of income and costs, thereby reducing profits, particularly for smaller and less diversified firms. Based on this evidence, the following hypothesis is proposed in its alternative form:

H3. *Droughts have a negative effect on the profitability of agricultural companies. This relationship is modulated by the vulnerability (size).*

Like droughts, floods also have a negative effect on agricultural production, constituting the second most extreme event affecting this sector. Between 2008 and 2018, low- and middle-income countries experienced economic losses of around $21 billion due to this phenomenon (FAO 2021). These data show that floods have a detrimental impact on agriculture due to various factors, such as erosion damage to fertile soil and the close connection between flooding and the emergence of pests, as they promote the spread of diseases and create suitable breeding habitats (FAO 2017, 2021). Flooding can also cause significant damage to irrigation infrastructure, affecting canals and waterways (Ashraf et al. 2013). All these factors have an impact on crop development, which can result in a loss of production and an increase in costs.

Several studies assess the impact of flooding on the agricultural sector. Posthumus et al. (2009) conclude that in England in 2007, the agricultural sector was affected by flooding

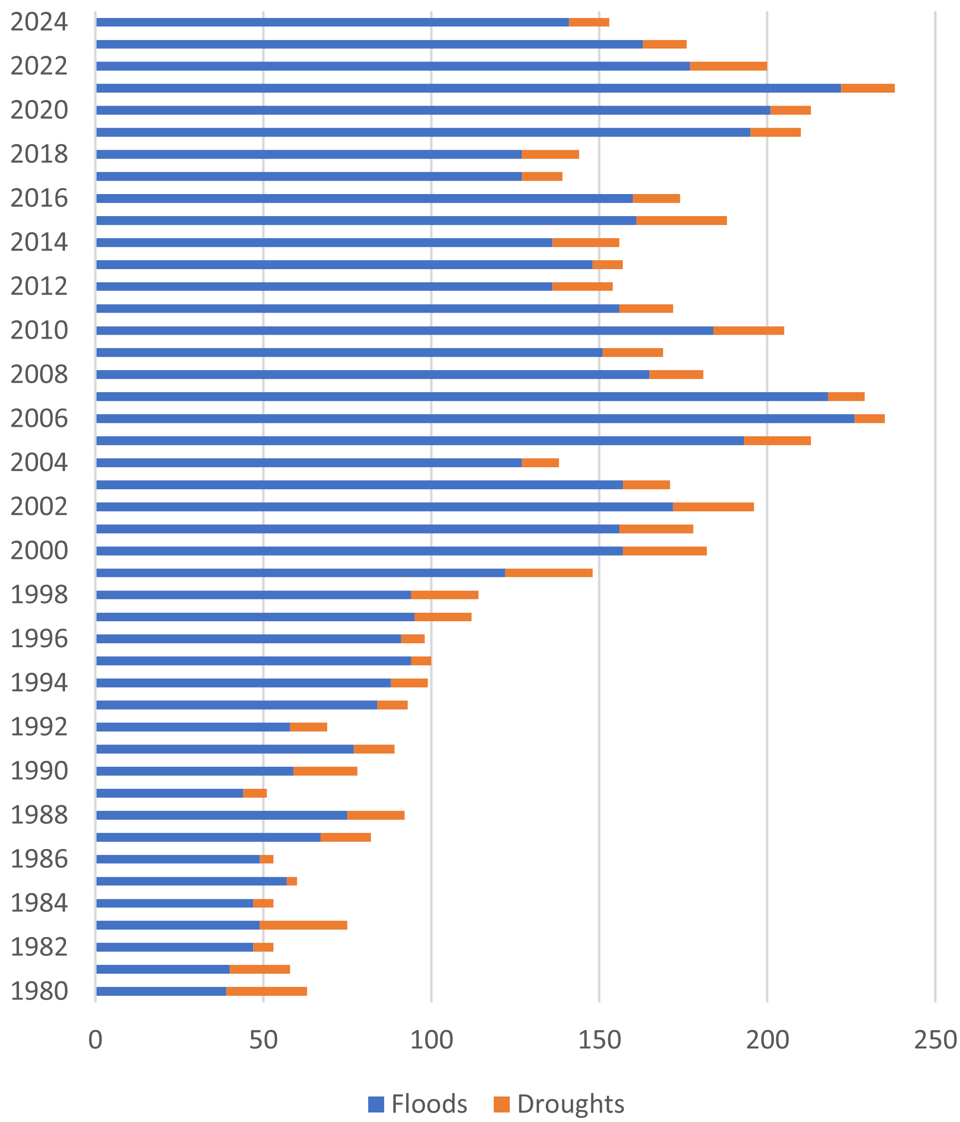

FIGURE 2 | Number of floods and droughts worldwide. *Source:* EM-DAT and CRED.

due to the long duration of the event, and several crops are sensitive to excess water, which can lead to a reduction in production that will vary according to the tolerance of the plant. Venkatappa and Sasaki (2021) found similar results in Southeast Asia in the 2015–2019 period, where the reduction in agricultural production ranged from 16.6% to 33.3% depending on the intensity of the flood. Similarly, Xiao (2011) examines the economic impacts of the 1993 flooding of the Midwest in the United States and finds that year saw a decline in farm incomes. Therefore, the occurrence of floods poses a physical risk to companies since the consequences can range from the loss of assets, such as agricultural infrastructure and machinery, to the interruption of operations due to impacts on crops, which will have a negative impact on companies' results especially on smaller ones with fewer resources to adapt. From the above, the following hypothesis is proposed in its alternative form:

H4. *Floods have a negative effect on the profitability of agricultural companies. This relationship is modulated by the vulnerability (size).*

3 | Data and Methodology

3.1 | Description of Variables

In order to test the hypotheses stated and analyse the impact of meteorological and climatic phenomena on the operational performance of companies, the study has been designed based on three types of variables. To measure the performance of agricultural firms, we employ ROA and return on sales (ROS) ratios. Regarding climate variables, we select temperature and precipitation (which are measures used as a surrogate for chronic physical risk) and droughts and floods (surrogates for acute physical risk). Finally, to ensure the robustness of the analysis, control variables related to both firm and country characteristics, previously associated in the literature with the performance measures, have been introduced, which helps to validate the model framework and improve its robustness (Buallay 2021; Cevik and Miryugin 2022; Lanzalonga et al. 2025; Liu and Xu 2021; Scafarto et al. 2016; Thai et al. 2023). Table 1 presents the description of the variables and the sources of information.

TABLE 1 | Description of the variables.

Variable	Calculation	Source
Performance variables		
ROA	Earnings before interest and taxes/total assets	Orbis
ROS	Earnings before interest and taxes/operating income	Orbis
Climatic variables		
TEMP	Average annual temperature in degrees Celsius	World Bank
PREC	Average annual precipitation in millimetres	World Bank
DROUGHT	A dichotomous variable that takes the value of 1 if a drought occurs, or 0 otherwise	EM-DAT/CRED
FLOOD	Number of floods recorded in the year	EM-DAT/CRED
Company-specific control variables		
SIZE	Natural logarithm of total assets	Orbis
LEV	Financial debt/(Equity + Financial debt)	Orbis
Macroeconomic control variables		
GDP	Annual change in Gross Domestic Product (GDP)	World Bank
API	Average annual change in agricultural price index	FAOSTAT

Note: The EM-DAT (Emergency Events Database of the Centre for Research in Disaster Epidemiology, CRED) database registers a drought or flood as a natural disaster if it meets at least one of the following criteria: 10 deaths, 100 people affected, a declaration of a state of emergency, or a call for international aid.

Five sources of information were used to obtain the information for the development of the study: the ORBIS database for accounting and financial data of agricultural companies; the World Bank's Climate Change Knowledge Portal for Development Practitioners and Policymakers for annual rainfall and temperatures; the Emergency Events Database (EM-DAT 2021) of the Centre for Research on the Epidemiology of Disasters (CRED) for natural phenomena (floods and droughts); the World Bank in relation to the rate of change of the Gross Domestic Product (GDP) and, finally, the Food and Agriculture Organization of the United Nations (FAOSTAT) statistical database on the agricultural price index (API). Given the available information, the data collected on climatic variables correspond to the country in which the parent company is located.

In this study, we use country-level climate data due to data availability and the format in which company data is reported. While regional or subnational climate data could provide more granular insights, their use is limited for two main reasons. First, the firm-level data set includes only the location of the company's headquarters or legal registration, not the actual location of the farms. As a result, attempting to link regional climate data to firms based solely on their registered address could lead to spatial misclassification and compromise the accuracy of the analysis. Second, long-term regional climate data are often limited or unavailable in some countries, particularly in developing economies. By using country-level data, we ensure consistency in both time and geographic coverage, reducing biases introduced by missing or uneven regional coverage.

3.2 | Sample

Companies active and linked to the agriculture, livestock, hunting, and services sectors have been selected from the Orbis database, using their NACE code (01), specifically non-perennial crops (011) and perennial crops (012), identifying a total of 3,398,623 companies.

Subsequently, only active companies with total assets, operating income and equity of at least $1 were included in the study.[2]

Given the scarcity of information to obtain the ratios, data up to 2012 have been eliminated, and observations for the period 2013–2021 have been taken, both included. Subsequently, a process of elimination of outliers from accounting variables has been carried out, identifying those values that were outside the interval of three times the standard deviation (SD) of the mean to establish the upper and lower limits of total assets, leverage, ROA and ROS and eliminate the observations located outside these limits.

In addition, companies containing fewer than three observations in the period under review have been removed from the sample to ensure that the sample adequately represents the agricultural sector and that they reflect some robustness to play a meaningful role in the sector. Finally, companies from countries that did not have information on floods or droughts were eliminated from the sample. Once all the criteria had been applied, a sample of 19,929 companies and 141,473 company-year observations were obtained. The companies analysed are located in 69 countries from five continents, as shown in Figure 3.

Table 2 shows the distribution of the sample according to geographic region (Panel A) and climate type (Panel B).[3] Micro and small companies have a significant presence in the total sample, representing 84.66% of the total observations, with most companies concentrated in European countries. Furthermore, based on Köppen's climate classification, which divides the climate into five groups (continental, temperate, tropical, dry and polar), the companies analysed in this study are predominantly situated in continental and temperate climate areas.

3.3 | Methodology

We conduct a panel data analysis in two steps to examine the effects of climatic conditions on the performance of agricultural companies globally. Following Anton (2021), we first study whether climate variables that have gradually changed over time influence the performance of companies. Thus, temperature and precipitation are taken as surrogates for chronic physical risk in Model (1), where we also control for firm and macroeconomic factors.

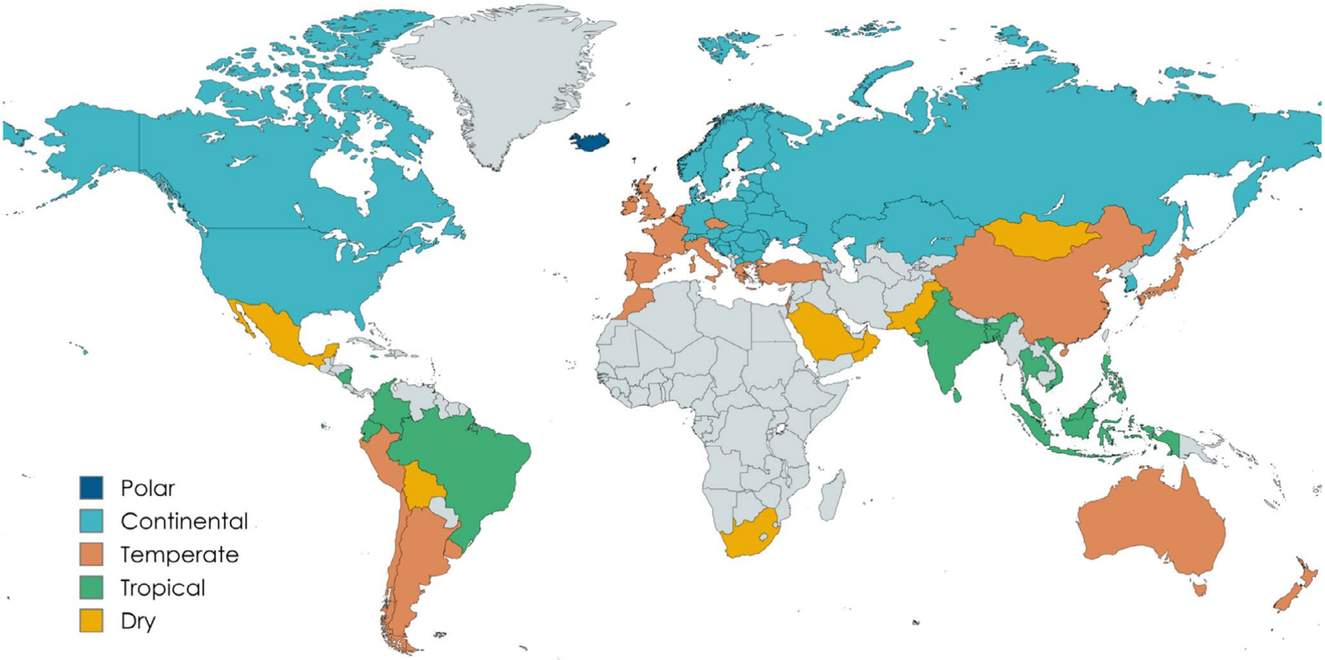

FIGURE 3 | Location of companies (shaded countries). *Note:* Several climates can be found in a country, according to the Köppen climate classification. To represent the countries, it has been decided to identify and highlight the climate that prevails in each of them.

TABLE 2 | Distribution of the sample by continent and type of climate.

	Total	Micro	Small	Medium	Large
Panel A: Continents					
America	3651	577	1972	773	329
Asia	8997	2705	3622	1773	897
Africa	280	115	93	47	25
Europe	128,208	46,401	64,215	15,034	2558
Oceania	337	18	50	153	116
Total	**141,473**	**49,816**	**69,952**	**17,780**	**3925**
Panel B: Type of climate					
Continental	96,979	38,499	48,165	8944	1371
Temperate	35,686	9697	17,711	6704	1574
Tropical	8675	1604	4040	2125	906
Dry	101	8	12	7	74
Polar	32	8	24	0	0
Total	**141,473**	**49,816**	**69,952**	**17,780**	**3925**

Note: The Köppen climate classification has been used, which divides the climate into five groups: continental, temperate, tropical, dry and polar.

TABLE 3 | Descriptive statistics.

Variable	Firm-year observations	Mean	SD	Min.	25th percentile	50th percentile	75th percentile	Max.
ROA	141,473	0.0887	0.0989	−0.5992	0.0224	0.0659	0.1373	0.6616
ROS	141,473	0.1379	0.1533	−0.8571	0.0345	0.1081	0.2266	0.8966
TEMP	141,473	9.69	7.33	−4.67	8.96	11.21	13.19	28.17
PREC	141,473	750.98	439.968	27.20	504.99	632.75	760.61	3297.34
DROUGHT	141,473	0.0238	0.1525	0	0	0	0	1
FLOOD	141,473	1.2985	1.6225	0	0	1	2	14
SIZE	141,473	76.9417	194.841	0.00187	15.6068	28.7808	62.8612	3505.67
LEV	141,473	0.2202	0.2539	−0.1925	0.0010	0.1201	0.3629	0.9997
GDP	141,473	1.7994	3.3407	−11.3254	0.4832	2.3686	3.4884	24.3705
API	141,473	112.67	32.83	56.96	100.60	106.01	117.12	507.22

Abbreviations: API, average annual change in agricultural price index; DROUGHT, dichotomous variable that takes the value of 1 if a drought occurs, or 0 otherwise; FLOOD, number of floods recorded in the year; GDP, annual change in gross domestic product; LEV, financial debt divided by the sum of equity plus financial debt; PREC, average annual precipitation in millimetres; ROA, earnings before interest and taxes divided by total assets; ROS, earnings before interest and taxes divided by operating income; SIZE, total assets expressed in hundreds of thousands of dollars; TEMP, average annual temperature in degrees Celsius.

$$R_{ijt} = \alpha + \beta_1 TEMP_{jt} + \beta_2 PREC_{jt} + \beta_3 SIZE_{ijt} + \beta_4 LEV_{ijt} + \beta_5 GDP_{jt} + \beta_6 API_{jt} + \mu_{it} \quad (1)$$

where R_{ijt} is the profitability of company i located in country j in year t. ROA has been used to measure this performance. We also employ ROS as a robustness analysis. The independent variables of interest are the climatic and meteorological variables $TEMP_{jt}$ and $PREC_{jt}$, which represent the average annual temperature and rainfall of country j in year t, respectively. In addition, previous evidence shows that the profitability of agricultural firms is related to firm-level variables such as size (SIZE) and financial structure (LEV), as well as by macroeconomic variables such as the annual change in Gross Domestic Product (GDP) or the API (Anton 2021; Cevik and Miryugin 2022; Liu and Xu 2021). $SIZE_{ijt}$ and LEV_{ijt} represent, respectively, the company size, measured by the natural logarithm of total assets, and leverage, measured as the ratio of financial debt divided by the sum of equity and debt, for company i located in country j in year t. GDP_{jt} and API_{jt} are calculated for each country j and each year t as the annual variation in gross domestic product and the average annual change in the sales prices received by farmers at the first point of sale, respectively. For the variable API_{jt}, the base period corresponds to the average prices observed during the years 2014, 2015 and 2016 (FAO 2022).

In order to broaden the scope of the analysis and examine the impact of acute physical risks associated with extreme natural events on firm performance, we incorporate to Model (1) the occurrence of both floods and droughts. To address this analysis, the Model (2) is used.

$$R_{ijt} = \alpha + \beta_1 TEMP_{jt} + \beta_2 PREC_{jt} + \beta_3 DROUGHT_{jt} + \beta_4 FLOOD_{jt} + \beta_5 DROUGHT_{jt-1} + \beta_6 FLOOD_{jt-1} + \beta_7 SIZE_{ijt} + \beta_8 LEV_{ijt} + \beta_9 GDP_{jt} + \beta_{10} API_{jt} + \mu_{it} \quad (2)$$

where $DROUGHT_{jt}$ is a dichotomous variable that takes the value of 1 if country j has experienced a drought in year t and 0 otherwise, and $FLOOD_{jt}$ refers to the number of floods reported in year t in country j. In order to capture the likely lagged effects of extreme events on firm performance, we also include these variables with a 1-year lag.

In order to consider vulnerability, Models (1) and (2) are estimated for the complete sample and four sub-samples corresponding to the classification of companies in the European Union (2022) according to Annex I of Regulation (EU) No. 651/2014 of the European Commission:

- Micro-company: Assets not exceeding €2 million.
- Small company: Assets between €2 million and €10 million.
- Medium company: Assets between €10 million and €43 million.
- Large company: Assets over €43 million.

In addition, to identify whether temperature and precipitation have a differential effect on profitability according to the climatic zone in which companies are located (exposure), Model (1) is estimated by dividing the observations into five subgroups according to the Köppen climate classification: continental, temperate, tropical, dry and polar. Since there can be different climates within a country, it has been decided to identify each country by its predominant climate.[4]

4 | Results

Table 3 shows the descriptive statistics of the dependent and independent variables, calculated for the entire sample in the study period. Companies had a mean ROA (ROS) of 8.87% (13.79%) in the period 2013–2021, with a SD of 9.89% (15.33%). Regarding climatic variables, we highlight the large SD found for temperature and precipitation, which is due to the differences between climatic characteristics in each geographical region.

Table 4 shows Pearson's correlation coefficients between each pair of variables. As a first approximation, we find that all climate variables are negatively correlated with ROA. Although a similar trend is observed for ROS, there is a positive correlation with flooding. Regarding the control variables at the firm level, size and leverage are negatively correlated with ROA, while ROS has a positive correlation with size and a negative correlation with leverage. In addition, both economic growth and the agricultural production index are positively correlated with both performance variables.

Since there is a significant correlation between the climatic variables, the variance inflation factor (VIF), shown in Table 5, has been calculated to evaluate the possible presence of collinearity between the explanatory variables. Since the mean VIF is 3.79, we conclude that there are no multicollinearity problems between the explanatory variables in this study.

We estimated Models (1) and (2) using panel data methodology. For the full sample, Hausman's test yielded a chi-square of 1488.16 for the first model and 1352.87 for the second, both with a p value of 0.000. Therefore, the fixed effects model is the most appropriate for the analysis. Similarly, when analysing the subsamples by firm size, the fixed effects model also proves to be the most suitable. However, when the analysis is conducted by climate zone, the fixed effects model is appropriate for the continental, temperate, and tropical subsamples, while for the dry and polar zones, the random effects approach provides a better fit.

Table 6 reports the results of the estimation of Model (1) for the full sample and the four subsamples by size. The results of the full sample support H1, which posits that there is a negative relationship between temperature and ROA, noting that for every 1°C increase in average annual temperature, the ROA falls by 1.27%. The decline in profitability reflects that the physical risks are associated with losses on agricultural assets because of some stress to the plant that would alter its ability to grow or affect the development of the reproductive organs (FAO 2023a, 2023b), which, in turn, would impact their ability to produce fruits and ultimately production. These results support the conclusions reached by Hugon and Law (2019) in the United States and Traore and Foltz (2018) in Côte d'Ivoire, who conclude that there is an inverse relationship between temperature and performance in agricultural companies.

Regarding rainfall, there is a positive and significant relationship at 1% that suggests that a lower level of rainfall has an adverse effect on production and, therefore, on the profitability of agricultural companies. We found that a reduction of 10 mm in average annual rainfall implies a reduction of 0.06% in profitability, which in turn supports H2. One possible explanation is that a low amount of rainfall affects crop productivity, which translates into a lower quantity and quality of the harvest, concluding that a reduction in the level of rainfall poses a threat or risk to the agricultural companies analysed in this study.

When splitting the sample by the size of the firms, we find that temperature has a negative and significant impact on the profitability of micro, small and medium-sized companies, but not on the large ones. In particular, the most affected are microcompanies, which experience a reduction in profitability of

TABLE 4 | Correlation matrix.

Variables	ROA	ROS	TEMP	PREC	DROUGHT	FLOOD	SIZE	LEV	GDP	API
ROA	1									
ROS	0.7719***	1								
TEMP	−0.1737***	−0.1954***	1							
PREC	−0.1041***	−0.0865***	0.6119***	1						
DROUGHT	−0.0594***	−0.0500***	0.1516***	0.0699***	1					
FLOOD	−0.0128***	0.0100***	0.0996***	0.3370***	0.1527***	1				
SIZE	−0.1411***	0.0517***	0.0553***	0.1475***	0.0794***	0.1630***	1			
LEV	−0.2185***	−0.1702***	0.0942***	0.0823***	0.0436***	0.0270***	0.0801***	1		
GDP	0.0349***	0.0276***	0.0878***	0.0906***	0.1072***	0.1426***	−0.0153***	−0.0243***	1	
API	0.0781***	0.0820***	0.1364***	0.2265***	−0.0402***	0.1781***	0.0518***	−0.0934***	−0.0126***	1

Note: *** significant at 1%.
Abbreviations: API, average annual change in agricultural price index; DROUGHT, dichotomous variable that takes the value of 1 if a drought occurs, or 0 otherwise; FLOOD, number of floods recorded in the year; GDP, annual change in gross domestic product; LEV, financial debt divided by the sum of equity plus financial debt; PREC, average annual precipitation in millimetres; ROA, earnings before interest and taxes divided by total assets; ROS, earnings before interest and taxes divided by operating income; SIZE, natural logarithm of total assets expressed in hundreds of thousands of dollars; TEMP, average annual temperature in degrees Celsius.

−1.54% when the average annual temperature increases by 1°C. On the other hand, small and medium-sized companies experienced a reduction of −1.04% and −0.65%, respectively, showing that the larger the size of the company, the lower the impact of temperature, thus smaller companies bear a greater physical risk. As in Addoum et al. (2020), these results suggest that larger companies are less vulnerable, as they have more resources to cope with climate fluctuations, and thus the impact on their operations is lower. In addition, large companies may have their crops distributed in several regions of the world. In relation to rainfall, there is evidence of a significant and positive relationship with profitability in all the subsamples analysed, highlighting that the impact is greater in the case of micro companies.

TABLE 5 | Variance inflation factor (VIF).

Variable	VIF	1/VIF
TEMP	4.64	0.2154
PREC	7.44	0.1345
DROUGHT	1.11	0.9024
DROUGHT ($t-1$)	1.16	0.8639
FLOOD	2.43	0.4107
FLOOD ($t-1$)	2.16	0.4623
SIZE	7.80	0.1282
LEV	1.75	0.5721
GDP	1.34	0.7453
API	8.07	0.1239
Mean	**3.79**	**0.45593**

Since physical risks are linked to exposure, which refers to the geographic location of agricultural companies likely to be impacted by climatic events, Table 7 presents the results of Model (1) by splitting the sample into climatic zones. Note that the number of observations in the subsamples for the polar and dry climate zones are very small; hence, the results should be interpreted with caution. The results show that temperature has a negative impact only on the profitability of companies located in continental and temperate climate zones, being more severe in the continental area, since a 1°C increase in temperature generates a reduction in profitability of −1.49%, while in companies located in temperate zones, the reduction is only of −0.46%. Therefore, exposition is a driver of the intensity of physical risk. This may be due to the fact that species that develop in these types of climates require an appropriate

TABLE 6 | Multivariate analysis of the effect of temperature and precipitation (chronic risks) on firm performance (ROA) by company size (vulnerability).

	Micro-firms	Small-firms	Medium-firms	Large-firms	Full sample
TEMP	−0.01535***	−0.01036***	−0.00651***	−0.00267	−0.01267***
	[−12.300]	[−14.797]	[−5.698]	[−1.176]	[−23.177]
PREC	0.00007***	0.00005***	0.00003***	0.00003***	0.00006***
	[14.074]	[17.475]	[6.437]	[3.545]	[25.258]
SIZE	0.00732***	−0.00295*	−0.00779***	−0.01143*	−0.00014
	[3.711]	[−1.715]	[−2.654]	[−1.714]	[−0.144]
LEV	−0.11250***	−0.08152***	−0.07337***	−0.09809***	−0.08856***
	[−26.914]	[−25.532]	[−12.785]	[−5.523]	[−39.486]
GDP	0.00145***	0.00050***	0.00013	0.00052**	0.00073***
	[9.659]	[6.564]	[1.229]	[2.427]	[12.249]
API	0.00027***	0.00018***	0.00011***	0.00014***	0.00019***
	[9.386]	[12.275]	[6.165]	[4.431]	[17.831]
Constant	0.17356***	0.14851***	0.15469***	0.15434***	0.16276***
	[12.791]	[14.693]	[7.684]	[2.802]	[24.085]
Num. Obs.	49,816	69,952	17,780	3925	141,473
R^2	0.0422	0.0360	0.0353	0.0592	0.0388
X^2	606.55	644.67	117.75	32.80	1488.16
Prob > X^2	0.0000	0.0000	0.0000	0.0000	0.0000

Note: ***, ** and * significant at 1%, 5% and 10%, respectively. The *t* statistic is in parentheses.
Abbreviations: API, average annual change in agricultural price index; GDP, annual change in gross domestic product; LEV, financial debt divided by the sum of equity plus financial debt; PREC, average annual precipitation in millimetres; ROA, earnings before interest and taxes divided by total assets; SIZE, natural logarithm of total assets expressed in hundreds of thousands of dollars; TEMP, average annual temperature in degrees Celsius.

TABLE 7 | Multivariate analysis of the effect of temperature and precipitation (chronic risks) on firm performance (ROA) by climate zone (company exposure).

	Continental	Temperate	Tropical	Dry	Polar
TEMP	−0.01493***	−0.00464***	0.00504	−0.00084	0.08035**
	[−23.882]	[−4.538]	[1.196]	[−0.352]	[4.040]
PREC	0.00013***	−0.00000	0.00006***	0.00001	−0.00019
	[29.921]	[−1.389]	[9.426]	[0.226]	[−0.951]
SIZE	−0.00115	−0.00006	−0.00512	−0.00247	−0.04532*
	[−0.935]	[−0.032]	[−1.462]	[−0.316]	[−1.847]
LEV	−0.10542***	−0.05859***	−0.03302***	−0.05019***	−0.05718
	[−34.742]	[−18.264]	[−4.328]	[−3.213]	[−0.941]
GDP	0.00080***	0.00050***	0.00050***	0.00182	−0.00349*
	[7.569]	[6.681]	[3.086]	[1.113]	[−1.876]
API	0.00039***	−0.00004	0.00012***	0.00003	−0.00131
	[20.138]	[−0.528]	[9.524]	[0.065]	[−0.579]
Constant	0.10589***	0.14050***	−0.17298	0.09526	0.45785
	[15.708]	[8.476]	[−1.483]	[1.268]	[1.037]
Num. Obs.	96,979	35,686	8675	101	32
R^2	0.0516	0.0225	0.0558	0.0429	0.2590
X^2	1807.85	181.14	112.18	4.64	8.16
Prob > X^2	0.0000	0.0000	0.0000	0.5907	0.0858

Note: ***, ** and * significant at 1%, 5% and 10%, respectively. The *t* statistic is in parentheses.
Abbreviations: API, average annual change in agricultural price index; GDP, annual change in gross domestic product; LEV, financial debt divided by the sum of equity plus financial debt; PREC, average annual precipitation in millimetres; ROA, earnings before interest and taxes divided by total assets; SIZE, natural logarithm of total assets expressed in hundreds of thousands of dollars; TEMP, average annual temperature in degrees Celsius.

period of cold hours during their dormancy to flourish and grow properly. Thus, exposure to higher temperatures can affect the development of reproductive organs, impacting their production (FAO 2023a, 2023b).

On the other hand, a reduction in the level of rainfall leads to a decrease in profitability in companies located in continental and tropical climates.

Table 8 presents the results of Model (2), which incorporates extreme natural events such as droughts and floods, which are treated as surrogates for acute risks. The results of temperature and precipitation are consistent with those obtained with Model (1), supporting H1 and H2.

Concerning droughts, when analysing the complete sample, the results show that the occurrence of this event does not have a significant effect on the profitability of that year (DROUGHT) but generates an impact on the following year (DROUGHT-1). This can be explained by the fact that droughts decrease soil fertility, affecting the growth capacity of plants and consequently resulting in a significant reduction in crop yields and even crop losses, which impact the sales level in the year following the event. In particular, the impact is greater on micro-companies (−3.58%) compared to small (−0.9%) and medium-sized companies (−0.3%). However, there is no evidence of a significant impact on large companies, possibly for the same reasons mentioned earlier. These results support H3, highlighting that micro companies are the most vulnerable, bearing the greatest physical risk, as they generally lack access to adequate infrastructure to cope with the consequences of droughts, such as the absence of an advanced irrigation system. Since crops depend on water to develop, the scarcity of this resource can affect production and, consequently, the level of income, reducing the profit margins of companies.

Regarding floods, our results support H4, as a negative association is observed between the variable of interest (FLOOD) and profitability, except for the subsample of large companies. The occurrence of a flood has a negative and significant effect on the profitability of the year in which the event occurs. However, this impact does not extend over time as it does not translate into an effect on the profitability of the following year (FLOOD-1). The effects of floods on the profitability of agricultural companies can be attributed to several reasons. First, they can cause physical damage to plants, which can affect their ability to grow and create habitats conducive to the development of diseases and the proliferation of pests, as well as the deterioration of plant health. This can, in turn, impact production (FAO 2017, 2021). Second, flooding can have a significant impact on agricultural infrastructure, as machinery and irrigation systems can be damaged, leading to increased costs due to the replacement or repair of assets.

TABLE 8 | Multivariate analysis of the effect of the set of climate variables (chronic and acute risks) on firm performance (ROA) by company size (vulnerability).

	Micro-firms	Small-firms	Medium-firms	Large-firms	Full Sample
TEMP	−0.01560***	−0.01092***	−0.00635***	−0.00239	−0.01328***
	[−12.426]	[−15.521]	[−5.596]	[−1.034]	[−23.837]
PREC	0.00007***	0.00006***	0.00003***	0.00003***	0.00007***
	[13.765]	[18.411]	[6.859]	[3.504]	[25.792]
DROUGHT	−0.00845***	0.00216	0.00123	0.00155	0.00122
	[−2.969]	[1.571]	[0.638]	[0.446]	[1.161]
FLOOD	−0.00130***	−0.00184***	−0.00096**	0.00065	−0.00126***
	[−2.736]	[−6.910]	[−2.490]	[1.020]	[−6.429]
DROUGHT-1	−0.03576***	−0.00983***	−0.00364**	−0.00037	−0.01372***
	[−15.467]	[−8.711]	[−2.381]	[−0.146]	[−15.479]
FLOOD-1	0.00017	−0.00033	−0.00090**	−0.00001	−0.00013
	[0.369]	[−1.243]	[−2.193]	[−0.012]	[−0.667]
SIZE	0.00880***	−0.00195	−0.00802***	−0.01134*	0.00027
	[4.425]	[−1.128]	[−2.727]	[−1.702]	[0.271]
LEV	−0.11178***	−0.08044***	−0.07240***	−0.09848***	−0.08748***
	[−26.701]	[−25.301]	[−12.541]	[−5.559]	[−39.026]
GDP	0.00136***	0.00055***	0.00014	0.00047**	0.00073***
	[8.919]	[7.076]	[1.307]	[2.226]	[12.020]
API	0.00007**	0.00017***	0.00011***	0.00013***	0.00015***
	[2.393]	[10.726]	[6.353]	[4.191]	[13.733]
Constant	0.19651***	0.15036***	0.15409***	0.15041***	0.17082***
	[14.270]	[14.830]	[7.661]	[2.733]	[25.070]
Num. Obs.	49,816	69,952	17,780	3925	141,473
R^2	0.0489	0.0381	0.0366	0.0597	0.0410
X^2	922.37	742.87	215.59	33.32	1352.87
Prob > X^2	0.0000	0.0000	0.0000	0.0002	0.0000

Note: ***, ** and * significant at 1%, 5% and 10%, respectively. The *t* statistic is in parentheses.
Abbreviations: API, average annual change in agricultural price index; DROUGHT, dichotomous variable that takes the value of 1 if a drought occurs, or 0 otherwise; FLOOD, number of floods recorded in the year; GDP, annual change in gross domestic product; LEV, financial debt divided by the sum of equity plus financial debt; PREC, average annual precipitation in millimetres; ROA, earnings before interest and taxes divided by total assets; SIZE, natural logarithm of total assets expressed in hundreds of thousands of dollars; TEMP, average annual temperature in degrees Celsius.

In summary, our results show that micro and small companies are more vulnerable while large companies are not affected by temperature, droughts, or floods, although we find a minimal impact on their performance by the decrease in rainfall, which could be due to several reasons. First, they have more experience in the sector and have been able to analyse and evaluate which crops are more resistant to certain climatic variables in each region where they carry out their activity. Secondly, they have managed to outsource their production to other regions, allowing them to reduce costs and specialise according to the geographical area. This behaviour highlights its greater adaptability to reduce the risk of losses due to climatic factors. These results align with the findings of Hugon and Law (2019), who conclude that larger and more diversified firms significantly reduce the negative effects of climate, and with those from Addoum et al. (2020) and Thai et al. (2023) for listed firms.

Regarding the control variables, the financial structure of firms (LEV) and economic growth (GDP) have a significant negative and positive relationship, respectively. These results are consistent with previous literature (Buallay 2021; Liu and Xu 2021; Thai et al. 2023). Concerning the API, our evidence shows a positive and significant relationship with profitability. However, when analysing the size of the firm (SIZE), the results are not homogeneous, as a significant and positive effect is observed in the subsample of micro-companies, while it is negative in the case of medium and large companies.

5 | Robustness Analysis

In order to validate the robustness of the results, this section employs the ROS as a performance measure to capture the influence of climatic variables on sales. To achieve this, we replicate Table 7 but employ ROS as the dependent variable in the regressions. Table 9 reports the results obtained for the estimation of Model (1).

The results concerning temperature in the continental and temperate climatic zones align in terms of sign and significance with those presented in Table 7. An increase in temperature has a negative effect on the profitability of sales for companies located in these two zones, with the effect being more pronounced in the continental zone at 1%. However, in contrast to the results in Table 7, with ROS as the dependent variable, an increase of 1°C in tropical areas leads to a 2.09% increase in profitability.

Regarding precipitation, it is still observed that a decrease in precipitation leads to a reduction in profitability for companies in continental and tropical climates. However, this new analysis also shows a reduction in profitability when rainfall increases in temperate zones.

We also replicate Table 8 using ROS as the dependent variable. Table 10 presents the results obtained for the estimation of Model (2).

The results related to chronic physical risks, such as temperature and precipitation, are consistent with the main estimates and reinforce the results found above, obtaining a negative and significant 1% relationship between temperature and firm profitability in the agricultural sector, except for large companies. They also support the positive relationship between rainfall and company performance, which is also significant at 1%.

Regarding droughts, our results corroborate the conclusion that the risks derived from these extreme events have a negative and significant impact on micro-companies. Due to their size and limited resources, these businesses are often more vulnerable to adverse weather conditions. Similar to Table 8, droughts have an impact on profitability in the following period (DROUGHT-1), and their effect is greater in micro-companies (−4.56%), although no significant impact is observed in medium and large companies.

In contrast to the results of Model (2) with ROA as the dependent variable, floods do have an impact on profitability on sales for the following year (FLOOD-1) in the full sample, although it is very low (0.061% at 5%). These results corroborate that companies

TABLE 9 | Multivariate analysis of the effect of temperature and precipitation (chronic risks) on firm performance (ROS) by climate zone (company exposure).

	Continental	Temperate	Tropical	Dry	Polar
TEMP	−0.02254***	−0.00364**	0.02090***	−0.00186	0.09894***
	[−27.050]	[−2.234]	[2.991]	[−1.107]	[3.510]
PREC	0.00017***	−0.00001**	0.00012***	0.00001	−0.00007
	[31.144]	[−2.007]	[10.680]	[0.291]	[−0.246]
SIZE	0.03966***	0.02530***	0.01716***	0.00972	0.02834
	[22.627]	[9.150]	[3.474]	[1.081]	[1.022]
LEV	−0.11601***	−0.05768***	−0.04902***	−0.02993	−0.17569**
	[−28.373]	[−10.645]	[−3.667]	[−0.823]	[−2.231]
GDP	0.00165***	0.00138***	0.00078***	0.00457	−0.00559***
	[11.112]	[10.419]	[2.840]	[1.468]	[−2.965]
API	0.00063***	−0.00022***	0.00015***	0.00094	−0.00230
	[24.450]	[−3.065]	[8.764]	[1.381]	[−0.695]
Constant	0.01924**	0.09235***	−0.76561***	−0.04881	0.19009
	[2.185]	[3.578]	[−3.957]	[−0.503]	[0.273]
Num. Obs.	96,979	35,686	8675	101	32
R^2	0.0627	0.0137	0.0510	0.0478	0.2504
X^2	2194.23	118.30	46.07	11.58	7.64
Prob > X^2	0.0000	0.0000	0.0000	0.0720	0.1057

Note: ***, ** and * significant at 1%, 5% and 10%, respectively. The *t* statistic is in parentheses.
Abbreviations: API, average annual change in agricultural price index; GDP, annual change in gross domestic product; LEV, financial debt divided by the sum of equity plus financial debt; PREC, average annual precipitation in millimetres; ROS, earnings before interest and taxes divided by operating income; SIZE, natural logarithm of total assets expressed in hundreds of thousands of dollars; TEMP, average annual temperature in degrees Celsius.

TABLE 10 | Multivariate analysis of the effect of the set of climate variables (chronic and acute risks) on firm performance (ROS) by company size (vulnerability).

	Micro-firms	Small-firms	Medium-firms	Large-firms	Full sample
TEMP	−0.01935***	−0.01683***	−0.00898***	−0.00702	−0.01804***
	[−13.274]	[−15.706]	[−4.351]	[−1.596]	[−23.310]
PREC	0.00008***	0.00010***	0.00008***	0.00005***	0.00009***
	[13.851]	[16.388]	[6.370]	[2.759]	[23.440]
DROUGHT	−0.01102***	−0.00060	0.00370	−0.00052	−0.00064
	[−3.017]	[−0.215]	[0.805]	[−0.081]	[−0.338]
FLOOD	−0.00188***	−0.00259***	−0.00134	0.00190	−0.00176***
	[−3.528]	[−5.796]	[−1.613]	[1.489]	[−5.683]
DROUGHT-1	−0.04563***	−0.01997***	−0.00317	−0.00154	−0.02088***
	[−16.363]	[−10.516]	[−0.946]	[−0.286]	[−15.470]
FLOOD-1	0.00022	−0.00061	−0.00151*	0.00077	−0.00061**
	[0.397]	[−1.362]	[−1.836]	[0.538]	[−1.975]
SIZE	0.04047***	0.04836***	0.03526***	0.01837	0.03836***
	[18.123]	[18.290]	[6.046]	[1.496]	[26.842]
LEV	−0.09584***	−0.10115***	−0.09458***	−0.14160***	−0.09617***
	[−20.088]	[−19.110]	[−8.701]	[−5.284]	[−29.958]
GDP	0.00182***	0.00175***	0.00138***	0.00014	0.00167***
	[9.975]	[12.882]	[5.718]	[0.264]	[17.552]
API	0.00011***	0.00022***	0.00025***	0.00014**	0.00023***
	[3.520]	[10.908]	[5.494]	[2.438]	[15.310]
Constant	0.16183***	0.05630***	−0.01606	0.06157	0.10610***
	[10.280]	[3.721]	[−0.414]	[0.612]	[11.348]
Num. Obs.	49,816	69,952	17,780	3925	141,473
R^2	0.052	0.0395	0.0288	0.0295	0.0447
X^2	870.18	855.79	163.37	28.76	1497.83
Prob > X^2	0.0000	0.0000	0.0000	0.0014	0.0000

Note: ***, ** and * significant at 1%, 5% and 10%, respectively. The *t* statistic is in parentheses.
Abbreviations: API, average annual change in agricultural price index; DROUGHT, dichotomous variable that takes the value of 1 if a drought occurs, or 0 otherwise; FLOOD, number of floods recorded in the year; GDP, annual change in gross domestic product; LEV, financial debt divided by the sum of equity plus financial debt; PREC, average annual precipitation in millimetres; ROS, earnings before interest and taxes divided by operating income; SIZE, natural logarithm of total assets expressed in hundreds of thousands of dollars; TEMP, average annual temperature in degrees Celsius.

are indeed exposed to high acute physical risks, translating into lower revenues in that period and the subsequent period, as well as higher costs that have a negative impact on results. Therefore, the results in this analysis generally support the conclusions reported in Table 8, validating the findings on climate variables.

Regarding the control variables at the company level, there is evidence of a positive and significant relationship between size and profitability in all the subsamples analysed, except for the large one, as in Buallay (2021) and Liu and Xu (2021). A negative and significant relationship is also observed between the financial structure of the company (LEV) and its performance, similar to Buallay (2021), Liu and Xu (2021), Scafarto et al. (2016) and Thai et al. (2023). Concerning the macroeconomic control variables, the results show that the growth of the economy (GDP) and the API have a significant and positive relationship with profitability.

The results using ROS as an alternative measure of performance show slight differences compared to ROA, mainly due to the nature of each indicator. While ROA captures the long-term efficiency in the use of the assets, ROS is more sensitive to immediate changes in sales and profit margins. For instance, the lagged impact of floods on ROS indicates potential disruptions in sales and logistics that are not immediately reflected in asset-based measures. These findings emphasise the importance of using multiple indicators to fully capture the effects of climate on firm performance.

6 | Discussion and Conclusions

Despite various international agreements aimed at limiting the increase in temperature, the risks associated with climate change are becoming increasingly evident. Extreme weather phenomena, such as droughts, floods, or heatwaves, are becoming more frequent and intense, and their impacts on the economy, society, and the environment are significant. This includes the loss of biodiversity, degradation of ecosystems, economic losses in productive sectors, and a greater risk to food security.

Indeed, climatic variations have a substantial impact on the economy. Several authors conclude that rising temperatures affect the economic growth of countries, particularly those that are developing and heavily dependent on agriculture. This is mainly due to the fact that temperature increases affect production in various sectors. Previous evidence (Dell et al. 2012, 2014; Hsiang 2010; Jain et al. 2020) shows that companies are currently facing higher costs due to global warming, associated with the physical risks posed by the consequences of climate change on the economic activity of companies. Agriculture is arguably one of the most vulnerable sectors, as climatic variations affect productivity, crop quality, and business assets (IPCC 2022).

At the microeconomic level, although some previous research has examined how climate influences business performance, it has often focused on specific geographical areas (Addoum et al. 2020; Hugon and Law 2019). To contribute to the current literature on climate finance, we study the impact of climate variables on the financial performance of agricultural companies globally, focusing on two categories of climate risks: chronic physical risks, represented by two variables of gradual evolution (temperature and precipitation); and acute physical risks, related to extreme weather events, such as floods and droughts.

Regarding chronic physical risks, our results align with expectations and confirm that an increase in temperature has a negative impact on the profitability of agricultural companies. This effect is due to the fact that an increase in temperature raises the energy demands of plants to breathe, affecting their ability to grow and harming agricultural production. These results are consistent with previous research (Traore and Foltz 2018), further noting that micro companies are the most vulnerable, and as the size of firms increases, the impact of temperature on profitability gradually decreases.

The physical risks faced by agricultural companies are linked to the degree of exposure, related to their geographical location. The effects of temperature are concentrated in companies located in continental and temperate climate zones, with the most severe impact in the continental area, where temperature increases affect the lethargy process of crops, ultimately impacting their development. These results differ from those presented by Mendelsohn and Massetti (2017), Tan et al. (2021), and Griffin et al. (2024), who argue that temperature increases will be more unfavourable in countries located in warmer climates.

Additionally, we find that a decrease in the average annual rainfall is associated with a reduction in profitability for that period. Lower rainfall levels lead to lower agricultural productivity, with a greater effect on micro-companies. Concerning climatic zones, our results show that the performance of companies located in continental and tropical areas experiences a greater impact when there is a reduction in rainfall levels.

Regarding acute physical risks related to extreme natural events, our empirical evidence shows that droughts only affect the performance of micro companies in the year in which the event occurs. However, its consequences will impact the profitability of the following period in almost all companies except the large ones. In the same vein, floods also impact the profitability of companies, being greater in micro and small companies. These results suggest that extreme weather events affect agricultural production, impacting germination, growth, and reproduction phases, resulting in decreased agricultural yields and additional costs for companies.

In summary, the results presented corroborate that the physical risks associated with climate change have an impact on agricultural companies, with micro and small companies being the most vulnerable. These companies face higher costs associated with the physical risks resulting from climate change, impacting not only the company's operations in the year of its occurrence but also in the following period. Conversely, large companies do not see their profitability affected by physical risks, except for rainfall. This may be due to the fact that they have greater financial resources that allow them to implement irrigation systems to address water deficits in droughts and drainage systems to facilitate water flow during floods, mitigating challenges related to climate risks. Additionally, these companies may have outsourced their production to other countries, adapting to local conditions and managing to reduce costs.

This study is subject to certain limitations. First, the climate data employed correspond to the firm's legal registration, as noted above, which may not accurately reflect the actual geographic areas where agricultural operations are conducted. Given the climatic heterogeneity that can exist within a single country, this may lead to geographic misclassification. Second, the analysis does not distinguish between crop types, which may introduce some problems, as different crops exhibit distinct levels of sensitivity to climatic conditions, potentially affecting the observed relationship between climate variables and profitability.

As future lines of research, we consider it relevant to explore additional factors that may influence the resilience of agricultural firms. These include institutional and technological differences across regions, as well as varying levels of vulnerability and adaptive capacity to climate change. Moreover, it would be pertinent to examine the role of public policies, particularly those related to state support in response to losses caused by extreme climate events, as these elements can significantly impact business performance and sustainability. Also, as more granular climate data becomes available in the future, research should increasingly focus on analysing local-level effects. Finally, it would be of interest to investigate how the disclosure of climate-related risk information influences the stock price performance of publicly traded agricultural firms, shedding light on the financial implications of climate transparency in the agricultural sector.

7 | Practical Implications

Our findings have important practical implications for both policymakers and businesses, particularly regarding the challenges faced by small and micro enterprises. From a policy perspective, targeted actions are needed to ensure that small and micro agricultural firms have access to affordable financing (Wu et al. 2022). Compared to large enterprises, these firms face greater barriers to securing low-cost capital. To address this, governments should implement tailored financial programmes, such as special loan schemes, climate adaptation grants, or financial incentives that address their specific needs. Also, policymakers should promote the adoption of agricultural insurance and establish disaster relief funds. These mechanisms can help small firms recover from losses caused by extreme weather events, which pose significant threats to their financial stability. Moreover, capacity-building programmes and technical assistance should be expanded to support micro and small agricultural enterprises. Providing training on sustainable farming practices and risk management strategies will enhance their resilience and adaptive capacity.

At the same time, agricultural enterprises, particularly small- and medium-sized firms, must prioritise innovation and infrastructure investments to mitigate the impact of climate risks. Developing climate-resilient irrigation and drainage systems, diversifying crop production, and implementing soil conservation techniques are crucial strategies for ensuring long-term sustainability. In order to remain competitive, smaller firms should also explore collective approaches, such as forming cooperatives or strategic partnerships, which can improve access to resources, knowledge and markets. Furthermore, as an increasing number of regulatory frameworks require the inclusion of climate-related risks in sustainability reporting, integrating these standards into business operations becomes essential. This integration enhances transparency, improves access to financing, and fosters more rigorous and forward-looking planning to address climate-related challenges.

Finally, political arguments against adopting more drastic measures to address climate change often emphasise transition costs for agricultural companies. However, our findings indicate that smaller firms in this sector are already bearing the burden of physical risks resulting from climate change. These results highlight the importance of regulatory frameworks such as the Directive (EU) 2022/2464 requiring companies to include information on the climate risks they face in their sustainability reports, detailing how these risks affect their operations, assets and financial performance, as well as the opportunities that may arise. This transparency is crucial to support more informed decision-making in relation to corporate resilience.

Acknowledgements

The work was supported by the Agencia Estatal de Investigación (Spain): Research Project (grant number: PID2020-117792RA-I00).

Endnotes

[1] Available at: https://news.un.org/en/story/2022/11/1131132.

[2] To ensure the robustness of the analysis, additional regressions were conducted, considering exclusively firms with assets equal to or greater than $100,000. The results of this supplementary analysis reinforce and confirm the validity of the findings presented in the results section. Results are available upon request.

[3] See classification criteria in Section 3.3.

[4] We do not estimate Model (2) in the analysis by climate zones since, in our opinion, by grouping several countries into a single category, there may be greater uniformity in climatic conditions, which would reduce the effect of extreme events such as droughts and floods, decreasing the relevance of these variables.

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