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Rogue Waves: Climate Change and Firm Performance

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Rogue Waves: Climate Change and Firm Performance

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Abstract

Climate change is an existential threat to the global economy and financial markets. There is a large body of literature documenting potential macroeconomic consequences of climate change, but firm-level empirical research on how climate change affects the performance of firms remains scarce. This paper aims to close this gap by empirically investigating the impact of climate change vulnerability on corporate performance using a large panel dataset of more than 3.3 million nonfinancial firms from 24 developing countries over the period 1997–2019. We find that nonfinancial firms operating in countries with greater vulnerability to climate change tend to experience difficulty in access to debt financing even at higher interest rates, while being less productive and profitable relative to firms in countries with lower vulnerability to climate change. We confirm these findings with alternative measures of climate change vulnerability. Furthermore, partitioning the sample reveals that these effects are significantly greater for smaller firms, especially in high-risk sectors and countries and countries with weaker capacity to adapt to and mitigate the consequences of climate change.

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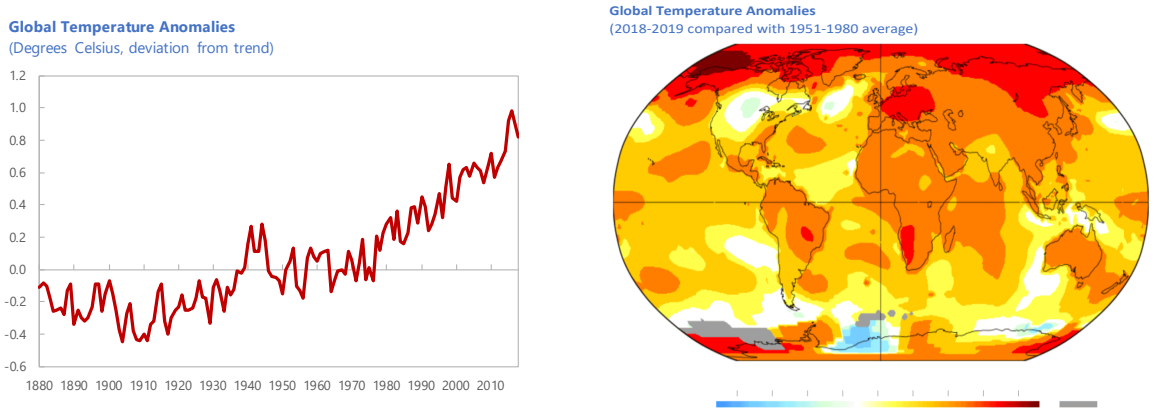
I. Introduction

Climate change already poses one of the most significant systemic risks to the global economy. With the global average surface temperature rising by 1.1 degrees Celsius (°C) compared to the preindustrial average, the frequency and severity of climate shocks have intensified across the world (Figure 1), and these extreme weather events are projected to worsen as the global annual mean temperatures increase by as much as 4°C over the next century (IPCC, 2007; IPCC, 2014; IPCC, 2021; Stern, 2007).[2] The socioeconomic consequences of climate change will be felt across the world, but potential vulnerability to weather anomalies depends on the size and composition of economies, the resilience of institutions and physical infrastructure, and the capacity for climate change mitigation and adaption.

There is growing evidence that climate-related shifts in the physical environment have significant macroeconomic consequences (Gallup, Sachs, and Mellinger, 1999; Nordhaus, 2006; Dell, Jones, and Olken, 2012), but research on the firm-level impact of climate change is scarce. Conceptually, there are multiple channels of transmission through which climate change can influence firm performance across different sectors and countries, including economic and financial effects of climate change, economic and financial consequences of climate change adaptation and mitigation policies, as well as effects on political stability. These transmission channels are not necessarily independent of each other, as the impact of climate change may amplify the transmission of risks across all channels. Furthermore, the extent of these effects varies from country to country, depending on the policies implemented—or not taken at all—for climate change adaptation and mitigation. This paper focuses on countries' exposure to physical risks that correspond to the potential macro-financial losses caused by climate change. However, it should be noted that transition risks related to the process of adjusting toward a low-carbon economy, such as stranded financial asset exposures, can also amount to a sizable burden.

Figure 1. Weather Anomalies Across the World



Source: NOAA.

[2] Climate refers to a distribution of weather outcomes for a given location, and climate change describes environmental shifts in the distribution of weather outcomes toward extremes.

This paper contributes to the literature by analyzing the effects of climate change vulnerability on firm performance in a large panel of more than 3.3 million nonfinancial companies from 24 countries during the period 1997–2019. We take advantage of a new dataset of climate change vulnerability developed by the Notre Dame Global Adaptation Institute (ND-GAIN), while taking into account a broad range of firm characteristics and macroeconomic factors. Empirical results show that climate change vulnerability has a statistically and economically significant impact on various measures of firm performance, including leverage, interest burden, profitability and total factor productivity (TFP). We find that nonfinancial firms operating in countries with greater vulnerability to climate change tend to experience difficulty in access to debt financing even at higher interest rates, while being less productive and profitable relative to firms in countries with lower vulnerability to climate change. We confirm these findings with alternative measures of climate change vulnerability. Furthermore, partitioning the sample reveals that these effects are significantly greater for smaller firms, especially in high-risk sectors and countries and countries with weaker capacity to adapt to and mitigate the consequences of climate change. The key policy takeaway from this paper is that while climate change is inevitable, policymakers can still strengthen structural and financial resilience to absorb shocks to economic activity and help reduce the financial burden on private firms and create growth opportunities. At the same time, however, it is important to acknowledge the private sector's critical role in building resilience against and adapting to climate change as well as in efforts aimed at climate change mitigation.

The remainder of this study is organized as follows. Section II provides an overview of the related literature. Section III describes the data used in the analysis. Section IV introduces the salient features of our econometric strategy and presents the empirical results, including a series of robustness checks. Finally, Section V offers concluding remarks with policy implications.

II. A Brief Overview of the Literature

This paper draws from two major threads of the literature—the macroeconomic impact of climate change and determinants of firm performance. First, there is a growing literature on the economic and financial effects of climate-related shifts in the physical environment.[3] Starting with Nordhaus (1991; 1992) and Cline (1992), aggregate damage functions have become a mainstay of analyzing the climate-economy nexus. Although identifying the macroeconomic impact of annual variation in climatic conditions remains a challenging empirical task, Gallup, Sachs, and Mellinger (1999), Nordhaus (2006), and Dell, Jones, and Olken (2012) find that higher temperatures result in a significant reduction in economic growth in developing countries. Burke, Hsiang, and Miguel (2015) confirm this finding and conclude that an increase in temperature would have a greater damage in countries that are concentrated in geographic areas with hotter climates. Using expanded datasets, Acevedo *et al*. (2018), Burke and Tanutama (2019) and Kahn *et al*. (2019) show that the long-term macroeconomic impact of weather anomalies is uneven across countries and that economic growth responds nonlinearly to temperature. In a related vein, it is widely documented that climate change by increasing the frequency and severity of natural disasters affects economic development (Loyaza *et al*., 2012; Noy, 2009; Raddatz, 2009;

[3] Tol (2018) provides a recent overview of this expanding literature.

Skidmore and Toya, 2002; Rasmussen, 2004), reduces the accumulation of human capital (Cuaresma, 2010) and worsens a country´s trade balance (Gassebner *et al*., 2010).

There is scarce, but growing research in terms quantity and intensity on how risks associated with climate change are priced in financial markets.[4] Bansal, Kiku, and Ochoa (2016) and IMF (2020) find that the risk of climate change—as proxied by temperature rises—has a negative effect on asset valuations, while Bernstein, Gustafson, and Lewis (2019) show that real estate exposed to the physical risk of sea level rise sell at a discount relative to otherwise similar unexposed properties. Similarly, focusing on the US, Painter (2019) find that counties more likely to be affected by climate change pay more in underwriting fees and initial yields to issue long-term municipal bonds compared to counties unlikely to be affected by climate change. Finally, from a cross-country perspective, Cevik and Jalles (2020; 2021; 2022) show that climate change vulnerability already has a statistically and economically significant impact on the cost of sovereign borrowing, credit ratings, and the risk of debt default, especially in developing countries.

Climate effects on firm earnings and performance are getting an increasing attention from researchers. Ginglinger and Moreau (2019) find that greater climate risk leads to lower leverage in the post-2015 period, i.e., after the Paris Agreement and show that the reduction in leverage related to climate risk is shared between a demand effect (the firm's optimal leverage decreases) and a supply effect (lenders increase the spreads when lending to firms with the greatest risk). Addoum *et al*. (2019) find that extreme temperatures significantly impact earnings in over 40 percent of industries in the U.S. and demonstrate bi-directional effects that harm some industries and bring benefits to others. On the global scale, Pankratz *et al*. (2019) find that an increasing exposure to extremely high temperatures has negative impact on firms' revenues and operating income. Focusing on a panel of 55 countries, Huang, Kerstein, and Wang (2018) find that climate risk at the country level is associated with lower corporate earnings and higher earnings volatility. In contrast, in this paper we focus on the developing economies, as these countries bear the most burden of the climate change, which is commonly accepted in the literature. Our paper is most closely related to Huang *et al*. (2018) and Kling *et al*. (2021) that explore the impact of climate risks on corporate performance and find that extreme weather events are associated with lower and more volatile earnings and cash flows.[5]

III. DATA OVERVIEW

We obtain harmonized firm-level financial data from the Orbis database in 24 countries for the period from 1997 to 2019, which provides a comparable coverage of both public (listed) and private (non-listed) firms including small and medium-sized enterprises. However, similar to any other large-scale micro dataset, the Orbis data require careful management to ensure consistency and comparability across firms and countries and over time. First, we select countries

[4] Giglio, Kelly, and Stroebel (2021) provide an overview of the recent literature studying interactions between climate change and financial markets.

[5] Both of these studies are based on smaller datasets over a shorter time periods.

with sufficient number of observations by setting a threshold of 10,000 annual observations per country. Second, following the data cleaning principles suggested by Gal (2013) and Kalemli-Özcan *et al*. (2015), we drop observations where total assets, tangible fixed assets, employment, operating revenue, sales and short-term loans and long-term debt in any given year are missing or negative, and where total assets do not equal to total liabilities and equity. Third, we winsorize the firm-level variables at the 1st and 99th percentile of the distribution in order to minimize the effect of possibly spurious outliers.[6] After these steps, we obtain an unbalanced panel of 3,357,471 firms with a total of 20,880,384 firm-year observations from 24 countries during the period 1997–2019.[7]

Appendix Table A1 and Appendix Table A2 display the distribution of nonfinancial firms across 24 countries and 11 nonfinancial sectors grouped according to the statistical classification of economic activities based on the *Nomenclature des Activités Économiques dans la Communauté Européenne* (NACE). The majority is concentrated in Russia, Hungary and Romania, accounting for 31.7, 11.3 and 11 percent of nonfinancial firms covered in our sample, respectively. It is important to note that the number of firms covered in the Orbis database varies from one year to another, increasing from less than half percent in 1997 to 10 percent in 2016 onwards (Appendix Table A3). In terms of sectoral coverage, the dataset is based on the NACE classification of economic activities and covers nonfinancial sectors excluding agriculture, public administration and defense, activities of extraterritorial organizations and bodies, and activities of households as employers and for own use. Most of the firms in the sample operate in the retail and wholesale trade sector, accounting for over a third of the sample size, followed by administrative and professional activities with 13.9 percent and manufacturing with 13.3 percent.

Descriptive statistics of all variables for the entire sample are presented in Appendix Table A4. Our firm-level dependent variables are (i) corporate leverage (measured by the ratio of total debt to total assets in the previous period), (ii) interest burden (measured by the ratio of interest payments in the current period scaled by total debt at the end of the previous year), (iii) profitability (measured by the ratio of profit before taxes to total assets in the preceding period), and (iv) TFP (estimated using the Levinsohn and Petrin (2003) approach). We include several key firm characteristics, such as firm age (measured by the log of years since establishment), firm size (measured as the logarithm of total assets), cash flow (measured by the ratio of cash flow to total assets), and asset tangibility (measured by tangible fixed assets to total assets).

The main explanatory variable of interest is climate change vulnerability as measured by the ND-GAIN index, which capture a country's overall susceptibility to climate-related disruptions.[8] To

[6] The estimation results remain robust if we winsorize 5 percent of observations on both tails of the distribution. These results are available upon request.

[7] The list of countries in our sample and firm-year observations per country and sector are provided Appendix Table A1 and Appendix Table A2. Countries are classified as advanced and developing according to the IMF's World Economic Outlook (WEO) database. Only developing economies are studied in this paper.

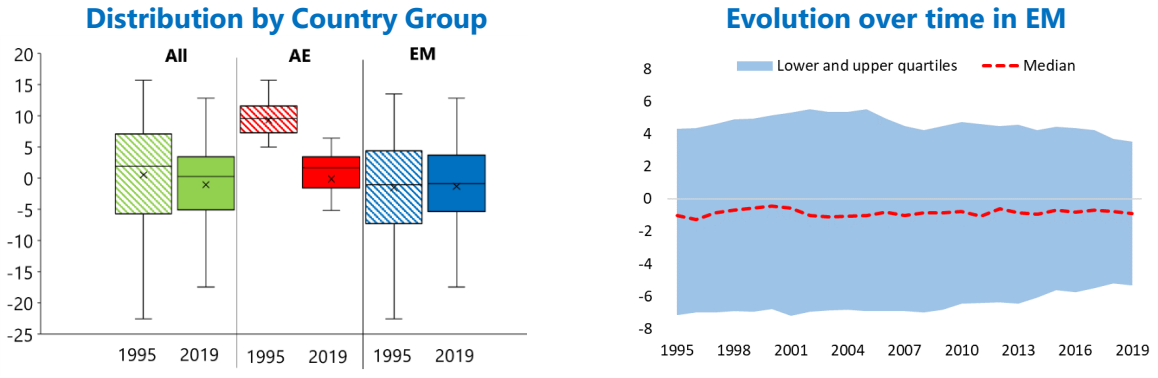
[8] Chen *et al*. (2015) provides a detailed presentation of the methodology and data sources for the ND-GAIN database, which is available at https://gain.nd.edu/.

assess a country's vulnerability to climate change, the ND-GAIN index takes into account six life-supporting sectors including food, water, health, ecosystem services, human habitat, and infrastructure. Within each sector, six indicators are evaluated from three components: the exposure of the sector to climate-related or climate-exacerbated hazards, the sensitivity of that sector to the impacts of the hazard, and the adaptive capacity of the sector to cope or adapt to these impacts. An important advantage of the ND-GAIN climate change vulnerability index is that it not only considers the physical factors of a country, such as geographic locations and physical climate impact that contribute to vulnerability externally, but also accounts for a country's degree of dependency on sectors that are climate sensitive, as well as the ability of the economy to mitigate potential damages during and after those negative climate shocks.

For each variable in ND-GAIN data, raw data are scaled into scores ranging from 0 to 1 to facilitate the comparison among countries. Scaling is based on reference points using a formula for the vulnerability indicator: the vulnerability score is then calculated by first taking the arithmetic mean of 6 constituent indicators for each sector, and then equally weighting across 6 sectors. Since the ND-GAIN climate change vulnerability index tends to be correlated with macroeconomic variables, such as real gross domestic product (GDP) or the human development index (HDI), we use a version of the climate change vulnerability index adjusted for the level of income. This version of the climate change vulnerability index is calculated by subtracting a country's measured climate change vulnerability from its expected value based on the regression of climate change vulnerability and real GDP. As a result, the correlation between the GDP-adjusted climate change vulnerability index and real GDP or the HDI becomes statistically insignificant.[9]

Figure 2 shows the time profile and box-whisker plots for the vulnerability index for the entire sample and income group, respectively. We can observe that vulnerability to climate change shocks has been declining, particularly since the early 2000s. It is also clear from the data that

Figure 2. Climate Change Vulnerability



Source: ND-GAIN; authors' calculations.

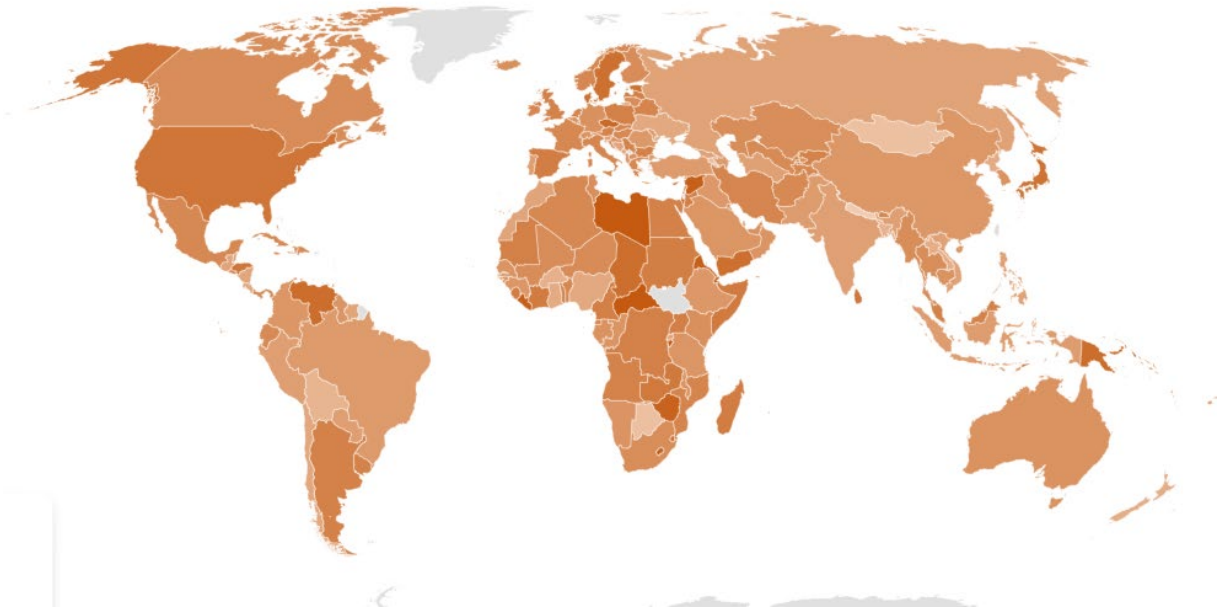
[9] In Appendix Table A5, we present the correlation matrix among all macroeconomic indicators used in the empirical analysis.

this decline is primarily driven by advanced economies that have been becoming less vulnerable to climate change over time. Developing countries have demonstrated limited improvement, and the median value of climate change vulnerability has slightly increased over the studied period.

Aggregate pictures, however, hide marked heterogeneity across countries that should not go unnoticed. Figure 3 compares the GDP-adjusted climate change vulnerability index in 1995 with that in 2019. We can see that the situation in North America, Europe Russia, Australia has improved, while South Asia and South America experienced an increase in vulnerability over the past two decades. Sub-Saharan Africa remained relatively unchanged over the studied period. It is important to highlight that the time-series variation in the ND-GAIN indices reflect the changes in countries' levels of vulnerability (which are not necessarily forward looking), not from the changes in the projected vulnerability to physical risks associated with climate change.

Firm-level data extend over a long period, covering economic booms and downturns. This coverage of different stages of the business cycle enriches the empirical analysis, but also necessitates the inclusion of country-specific information. Following the literature, we introduce a set of control variables, including the Human Development Index (HDI), real GDP growth, financial development as measured by domestic credit to the private sector as a share of GDP, trade openness as measured by the share of international trade in GDP, inflation as measured by the consumer price index (CPI), and average surface temperature in a given year. To better

Figure 3. Climate Change Vulnerability Across the World in 1995 vs. 2019
(Difference in the Vulnerability Index between 1995 and 2019)



Note: Values of the GDP-adjusted ND-GAIN climate change vulnerability index are plotted. Light colors correspond to improvement in the vulnerability index, darker – to its deterioration.
Source: ND-GAIN.

capture the level of economic development, we prefer the multidimensional HDI, which also includes per capita income in PPP-adjusted US dollars, instead of the commonly used standalone value of real GDP per capita.[10] These statistics are assembled from the World Bank's World Development Indicators (WDI) and the United Nations Development Program (UNDP) database.

There are large variations in firm performance—as measured by leverage, profitability, interest burden, and productivity—and key firm characteristics used in the analysis across sectors and type of firms, as well as in macroeconomic, financial and institutional conditions across countries and over time. It is therefore essential to analyze the time-series properties of the data to avoid spurious results by conducting panel unit root tests. We check the stationarity of all variables by applying the Im-Pesaran-Shin (2003) procedure, which is widely used in the empirical literature to conduct a panel unit root test. The results, available upon request, indicate that the variables used in the analysis are stationary after logarithmic transformation or upon first differencing.

IV. Empirical Strategy and Results

In our empirical analysis, we focus on the determinants of corporate performance according to the following specification:

$$y_{isct} = \alpha_1 vul_{ct} + \alpha_2 firm_{isct-1} + \alpha_3 macro_{ct} + \eta_i + \eta_{st} + \eta_{cs} + \varepsilon_{isct} \quad (1)$$

in which the subscripts *i*, *s*, *c*, and *t* denote firm, sector, country, and time, respectively. The dependent variable, y, is leverage, profitability, interest burden and productivity as defined in the previous section. vul is the measure of climate change vulnerability. vul denotes climate change vulnerability—the main variable of interest in our empirical analysis. The term *firm* is a vector of company-specific control variables, including total assets, cash flow, asset tangibility, and age. The term *macro* denotes a set of country-specific, including real GDP growth, the HDI, consumer price inflation, trade openness, and financial development.

The η_i coefficient denotes the firm-specific fixed effects capturing time-invariant unobservable factors. The η_{st} coefficient denotes the set of sector-year fixed effects capturing unobserved time-invariant heterogeneity among firms across sectors, and common shocks to firms belonging to the same sector in a given year. This helps control for aggregate and sectoral demand or policy-induced shocks, as well as cross-sectional dependence among firms in our sample. Furthermore, including sector-year fixed effects allows us to interpret the coefficient on, for example, the leverage ratio as the effect of higher indebtedness relative to a firm's sector peers at time *t*. This is an important consideration since some sectors are more highly leveraged than others, with differing investment patterns. The η_{cs} coefficient does the same for country-sector groups. As a result, without sector-country and sector-year fixed effects, the results would only reflect average investment patterns in more leveraged sectors. Finally, ε_{isct} is an idiosyncratic error term. Robust standard errors are clustered at the firm level to account for the fact that

[10] The results remain unchanged when real GDP per capita is used instead of the HDI.

observations pertaining to a firm are correlated and thus do not contain as much information as un-clustered errors.

We begin the empirical analysis with the standard fixed effects model, but endogeneity concerns arising from omitted variables and reverse causality prevent making causal statements. We address potential endogeneity concerns due to omitted variables by estimating panel models with firm, sector, country and time fixed effects and by controlling for a plethora of firm and country characteristics. Table 1 presents the results of our baseline estimations with corporate leverage, interest burden, profitability and total factor productivity. We estimate the equations using the standard fixed effects model and include the set of macroeconomic controls, such as HDI, real GDP growth, financial development, trade openness, inflation and average surface temperature in all specifications.

Table 1. Climate Change and Firm Performance —Baseline Estimations

	(1)	(2)	(3)	(4)
	Dependent variable			
Variables	**Leverage**	**Interest Burden**	**Profitability**	**Productivity**
Climate vulnerability	**-0.064*** **	**0.567*** **	**-0.718*** **	**-2.571*** **
	[0.010]	[0.134]	[0.017]	[0.173]
Firm-level				
Total assets	0.004***	-0.146***	-0.005***	0.103***
	[0.000]	[0.003]	[0.000]	[0.001]
Asset tangibility	0.032***	-0.164***	-0.037***	-0.347***
	[0.000]	[0.007]	[0.001]	[0.004]
Cash flow	-0.004***	0.006	0.029***	0.039***
	[0.000]	[0.004]	[0.000]	[0.002]
Age	-0.014***	0.011**	-0.016***	-0.085***
	[0.000]	[0.005]	[0.000]	[0.004]
Other controls				
HDI	-0.375***	0.454**	-1.066***	8.312***
	[0.013]	[0.223]	[0.025]	[0.155]
Real GDP growth	0.024***	0.231***	0.204***	0.873***
	[0.002]	[0.041]	[0.005]	[0.029]
Financial development	0.001	0.003	-0.025***	0.121***
	[0.001]	[0.013]	[0.002]	[0.022]
Trade openness	-0.062***	-0.005	-0.041***	0.276***
	[0.001]	[0.013]	[0.002]	[0.014]
Inflation	0.039***	-0.046***	0.018***	-0.235***
	[0.001]	[0.015]	[0.002]	[0.017]
Temperature	-0.000	-0.007***	-0.003***	0.047***
	[0.000]	[0.002]	[0.000]	[0.002]
Number of obs.	20,123,083	1,999,224	19,454,091	1,744,249
Number of firms	3,316,115	435,869	3,230,399	250,035
Adj R-squared	0.004	0.013	0.003	0.042

Note: Robust standard errors clustered at the firm level are reported in brackets. Firm as well sector-country and sector-year fixed effects are included in all specifications.
*** p<0.01, ** p<0.05, * p<0.1

Our baseline empirical findings show that the estimated coefficients on firm- and country-level control variables have the expected signs and are also statistically significant. With regards to the main variable of interest, we find that climate change vulnerability has a statistically significant, but economically small effect on corporate leverage, with an estimated coefficient of -0.064, after controlling for macroeconomic factors and average temperature. That means, an increase of 0.01 unit in the climate change vulnerability index is associated with a decline of about 0.06 percentage points in corporate leverage. This may be reflecting that nonfinancial firms in countries with greater vulnerability to climate change experience more constrained access to debt financing due to the reluctance of lenders to supply credit to firms exposed to climate-related risks, especially in sectors with greater vulnerability. Of course, such firms may also proactively limit debt accumulation that could become an operational burden, especially during adverse shocks, and rely more on internal resources and equity financing for new investment projects. This is

Table 2. Climate Change and Firm Performance—Vulnerable Sectors

Variables	(1) Leverage	(2) Interest burden	(3) Profitability	(4) Productivity
Climate vulnerability	**-0.158*** **	**1.137*** **	**-0.664*** **	**-1.347*** **
	[0.022]	[0.305]	[0.036]	[0.412]
Firm-level				
Total assets	0.002***	-0.163***	-0.009***	0.095***
	[0.000]	[0.006]	[0.000]	[0.003]
Asset tangibility	0.024***	-0.132***	-0.030***	-0.262***
	[0.001]	[0.014]	[0.002]	[0.009]
Cash flow	-0.002***	0.010	0.026***	0.037***
	[0.000]	[0.009]	[0.001]	[0.004]
Age	-0.008***	0.001	-0.015***	-0.074***
	[0.001]	[0.013]	[0.001]	[0.008]
Other controls				
HDI	-0.641***	0.683	-1.238***	1.681***
	[0.027]	[0.506]	[0.060]	[0.327]
Real GDP growth	-0.016***	0.762***	0.278***	-0.124*
	[0.005]	[0.095]	[0.011]	[0.066]
Financial development	-0.009***	-0.012	-0.010**	0.247***
	[0.003]	[0.031]	[0.004]	[0.051]
Trade openness	-0.089***	0.078**	0.002	0.288***
	[0.003]	[0.031]	[0.004]	[0.033]
Inflation	0.026***	-0.024	0.042***	-0.119***
	[0.002]	[0.025]	[0.003]	[0.014]
Temperature	-0.003***	-0.012**	-0.001**	0.005
	[0.000]	[0.005]	[0.001]	[0.005]
Number of obs.	3,687,484	445,710	3,576,489	344,001
Number of firms	642,190	93,817	626,125	53,013
Adj R-squared	0.003	0.013	0.003	0.025

Note: Robust standard errors clustered at the firm level are reported in brackets. Firm fixed effects are included in all regressions as well as sector-year and sector-country fixed effects.
*** p<0.01, ** p<0.05, * p<0.1

consistent with our estimations showing a statistically significant and economically large positive coefficient on the interest burden. An increase of 0.01 unit in the climate change vulnerability index is associated with an increase of about 0.57 percent in the cost of borrowing. Similar to findings for the impact of climate change vulnerability on sovereign bonds presented in Cevik and Jalles (2022), nonfinancial firms in countries with greater vulnerability to climate change are also subject to higher intertest rates on average. We also find strong evidence that climate change vulnerability is associated with a stifling effect on corporate profitability and firm-specific total factor productivity. An increase of 0.01 unit in the climate change vulnerability index is associated with a decline of approximately 0.7 percentage points in profitability and about 2.6 percentage points in productivity, which indicate that nonfinancial firms in countries with greater vulnerability to climate change are at a significant disadvantage compared to counties unlikely to be affected substantially by climate change.

To obtain a granular analysis, we split the sample into (i) small and large firms by classifying companies with total assets in the lowest quartile as small and those in the highest quartile as large, and (ii) young and old if its age falls into the bottom or top quarter of the age distribution of all firms operating in the same industry in that year. These results are presented in Appendix Table A8 and A9, respectively. First, with regard to size, we find that the impact of climate change vulnerability is greater on smaller nonfinancial firms than larger enterprises and relative to the baseline coefficient estimate. Second, with regards to age, the magnitude and size of coefficient on climate change vulnerability varies with measures of corporate performance, but younger firms appear to be more adaptive. Therefore, even though some of these specifications suffer from a significant reduction in the sample size due to limited availability, the impact of climate change vulnerability on firm performance is still clear across all specifications.

Some sectors are more exposed and vulnerable to climate change, mostly due to a greater risk of physical damage and severe disruptions to business operations. Following the literature, we define agriculture, mining, construction and transportation as climate vulnerable sectors (Fleming, Kirby, and Ostdiek, 2006; Hsiang, 2010; and Challinor *et al*., 2014, Huang, Kerstein, and Wang, 2018), and estimate the baseline regression models on a subset of firms operating in these sectors. The results, presented in Table 2, reveal an interesting pattern between climate change vulnerability and corporate performance as measured by leverage and interest burden. In these highly vulnerable sectors, an increase in climate change vulnerability is associated with significantly higher interest burden, even though firms appear to have lower levels of debt. This intriguing pattern, in our view, reflects fewer debt financing opportunities that may be available for firms operating in sectors with greater susceptibility to the threats associated with climate changes. The impact of climate change vulnerability on profitability and productivity, however, appears to be comparable to the benchmark results. We also estimate regressions separately for each sector and present these results in Appendix Table A6, which confirm significant heterogeneity in the effect of climate change vulnerability across nonfinancial sectors.

Following the approach used by Ginglinger and Moreau (2019), we introduce a post-2015 dummy in an effort to explore whether the Paris Climate Accord has reshaped firm behavior with regards to climate change vulnerability. These results, presented in Table 3, suggest that greater

climate change vulnerability results in lower corporate leverage after 2015, while the overall effect of climate vulnerability on leverage moves slightly below zero. This could reflect firms' anticipation of significant costs associated with technological innovations required to meet carbon emission targets and other environmental commitments. Higher levels of debt accumulation, caused by measures for climate change adaptation and mitigation, are likely to result in excessive interest payments in the future, as already indicated by a larger coefficient we find for the period after the Paris Agreement. This also implies that firms operating in more vulnerable countries may need to shift more resources away from production to deal with

Table 3. Climate Change and Firm Performance—After the Paris Agreement

Variables	(1) Leverage	(2) Interest burden	(3) Profitability	(4) Productivity
Climate vulnerability	0.008	**0.595*** **	**-0.282*** **	**-1.963*** **
	[0.012]	[0.135]	[0.016]	[0.177]
Climate vulnerability x post-2015 dummy	**-0.089*** **	**0.164** **	**-0.546*** **	**-1.045*** **
	[0.004]	[0.065]	[0.008]	[0.065]
Firm-level				
Total assets	0.004***	-0.146***	-0.006***	0.103***
	[0.000]	[0.003]	[0.000]	[0.001]
Asset tangibility	0.033***	-0.164***	-0.036***	-0.348***
	[0.000]	[0.007]	[0.001]	[0.004]
Cash flow	-0.004***	0.006	0.029***	0.039***
	[0.000]	[0.004]	[0.000]	[0.002]
Age	-0.014***	0.010**	-0.016***	-0.086***
	[0.000]	[0.005]	[0.000]	[0.004]
Other controls				
HDI	-0.343***	0.477**	-0.869***	8.621***
	[0.013]	[0.223]	[0.025]	[0.155]
Real GDP growth	0.018***	0.241***	0.169***	0.813***
	[0.002]	[0.042]	[0.005]	[0.029]
Financial development	-0.001	0.009	-0.035***	0.091***
	[0.001]	[0.014]	[0.002]	[0.022]
Trade openness	-0.065***	-0.006	-0.061***	0.272***
	[0.001]	[0.013]	[0.002]	[0.014]
Inflation	0.038***	-0.044***	0.010***	-0.230***
	[0.001]	[0.015]	[0.002]	[0.017]
Temperature	-0.000**	-0.007***	-0.004***	0.047***
	[0.000]	[0.002]	[0.000]	[0.002]
Number of obs.	20,123,083	1,999,224	19,454,091	1,744,249
Number of firms	3,316,115	435,869	3,230,399	250,035
Adj R-squared	0.004	0.013	0.003	0.042

Note: Robust standard errors clustered at the firm level are reported in brackets. Firm fixed effects are included in all regressions as well as sector-year and sector-country fixed effects.
*** p<0.01, ** p<0.05, * p<0.1

business disruptions caused by climate change and to undertake additional investments necessary for climate change mitigation. These changes, in turn, could lead to lower firm-level productivity and, combined with additional costs, in lower profitability.

We confirm the robustness of our empirical findings by using an alternative measure of climate vulnerability based on the INFORM Global Risk Index that identifies countries at risk of emergencies including climate-related natural disasters (De Groove, Poljansek, and Vernaccini, 2015; UN OCHA, 2020). These results, presented in Appendix Table A10, remain consistent with our baseline estimations and show that the climate risk is strongly related with various measures of firm performance. We estimate our models with the ND-GAIN climate change resilience index, which measures a country's capacity for climate change adaptation and covers three areas—economic, governance and social readiness—with nine indicators.[11] These results, presented in Appendix Table A11, confirm that climate change resilience is associated with measures of firm performance as expected. For example, an improvement in climate change resilience is found to have a positive effect on productivity and profitability at the firm level, while firms operating in more resilient countries have easier access to debt financing at lower interest rates. This is consistent with our findings using the climate change vulnerability index, which indicate constrained access to debt financing at a higher cost of borrowing in countries with greater vulnerability to climate change. Finally, we estimate the models excluding Russia, which accounts for about one-third of nonfinancial firms in the sample. These results, presented in Appendix Table A12, confirm that the baseline results remain unchanged.

V. CONCLUSION

Climate change already poses one of the most significant systemic risks to the global economy, and extreme weather events are projected to worsen as the global annual mean temperatures increase by as much as 4°C over the next century. There is growing evidence that climate-related shifts in the physical environment have significant macroeconomic consequences—from economic growth to sovereign bonds. This paper contributes to the literature by analyzing the effects of climate change vulnerability on firm-level performance in a large panel of more than 3.3 million nonfinancial companies from 24 countries during the period 1997–2019.

The empirical analysis shows that climate change vulnerability is strongly associated with constrained access to debt financing at a higher cost of borrowing and lower levels of productivity and profitability at the firm level. That is, nonfinancial firms operating in countries with greater vulnerability to climate change tend to experience difficulty in access to debt financing even at higher interest rates, while being less productive and profitable relative to firms in countries with lower vulnerability to climate change. We confirm these findings with alternative measures of climate change vulnerability. Furthermore, partitioning the sample reveals that these

[11] The ND-GAIN database refers to this series as "readiness" for climate change, which we use as a measure of resilience against climate change. While we use the GDP-adjusted version of the climate change resilience index, it is important to acknowledge that the ND-GAIN resilience score incorporates governance and social indicators that are not related to climate change. Thus, we present estimations including the climate change resilience index as a point of reference, not for causal inference.

effects are significantly greater for smaller firms, especially in high-risk sectors and countries with weaker capacity to adapt to and mitigate the consequences of climate change.

Econometric evidence presented in this paper has clear policy implications to better prepare for and cope with the consequences of climate change, especially in high-risk developing countries. Policymakers need to strengthen structural and financial resilience to absorb shocks to economic activity and help alleviate the financial burden of climate change adaptation and mitigation on private firms. At the same time, however, it is important to acknowledge the private sector's critical role in building resilience against and adapting to climate change as well as in efforts aimed at climate change mitigation. Accounting for 85 percent of all investments worldwide, private firms also have a significant control over most of the climate-related investment needs in adaptation (such as the location and design of buildings and infrastructure) and mitigation (such as the transition to clean energy and technological solutions for carbon emission reduction).

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APPENDICES

Appendix Table A1. Firm Distribution by Sector

Sector	Num. of firms	*Percent*	Num. of obs.	*Percent*
AGR	108,180	*3.22*	817,029	*3.91*
MIN	13,986	*0.42*	90,883	*0.44*
MFG	446,971	*13.31*	2,826,260	*13.54*
UTI	41,613	*1.24*	275,647	*1.32*
CON	332,966	*9.92*	1,968,130	*9.43*
IT	132,338	*3.94*	807,193	*3.87*
OTH	217,758	*6.49*	1,325,455	*6.35*
TRG	1,193,710	*35.55*	7,296,419	*34.94*
TRA	161,822	*4.82*	1,027,502	*4.92*
EST	241,736	*7.20*	1,593,848	*7.63*
ADM	466,391	*13.89*	2,852,018	*13.66*
Total	**3,357,471**	***100.00***	**20,880,384**	***100.00***

Note: AGR – Agribusiness, MIN – Mining, MFG – Manufacturing, UTI – Utilities, CON – Construction, IT – Information technology, OTH – Other service activities, households, extra territorial bodies, TRD – Wholesale and retail trade, accommodation, TRA – Transport and storage, EST – Real estate, ADM – Professional and administrative activities.

Appendix Table A2. Firm Distribution by Country

Country	Number of firms	Percent	Number of firms	Percent
Algeria	6,734	*0.20*	21,066	*0.10*
Bosnia and Herzegovina	15,419	*0.46*	135,839	*0.65*
Brazil	8,525	*0.25*	41,565	*0.20*
Bulgaria	263,221	*7.86*	1,401,354	*6.72*
China	215,473	*6.43*	621,918	*2.98*
Colombia	34,761	*1.04*	208,107	*1.00*
Croatia	137,546	*4.10*	1,069,906	*5.13*
Hungary	379,409	*11.32*	2,526,075	*12.11*
Kazakhstan	2,444	*0.07*	13,583	*0.07*
Malaysia	1,947	*0.06*	12,244	*0.06*
Mexico	1,457	*0.04*	6,643	*0.03*
Moldova	743	*0.02*	5,520	*0.03*
Montenegro	5,075	*0.15*	18,376	*0.09*
Morocco	75,913	*2.27*	298,719	*1.43*
North Macedonia	25,836	*0.77*	128,252	*0.61*
The Philippines	9,938	*0.30*	59,802	*0.29*
Poland	73,204	*2.18*	529,412	*2.54*
Romania	370,397	*11.05*	3,670,892	*17.60*
Russia	1,064,728	*31.78*	6,232,818	*29.88*
Serbia	66,006	*1.97*	462,543	*2.22*
Thailand	174,071	*5.20*	774,042	*3.71*
Turkey	17,921	*0.53*	82,286	*0.39*
Ukraine	252,897	*7.55*	2,033,651	*9.75*
Vietnam	153,806	*4.59*	525,771	*2.52*
Total	**3,357,471**	***100.00***	**20,880,384**	***100.00***

Appendix Table A3. Sample Breakdown by Year

Year	Number of obs.	*Percent*	Year	Number of obs.	*Percent*
1997	59,466	*0.28*	***2009***	777,700	*3.72*
1998	70,067	*0.34*	***2010***	829,972	*3.97*
1999	113,300	*0.54*	***2011***	907,837	*4.35*
2000	179,119	*0.86*	***2012***	980,361	*4.70*
2001	248,089	*1.19*	***2013***	1,232,259	*5.90*
2002	328,553	*1.57*	***2014***	1,509,760	*7.23*
2003	356,658	*1.71*	***2015***	1,858,020	*8.90*
2004	435,958	*2.09*	***2016***	2,156,690	*10.33*
2005	487,773	*2.34*	***2017***	2,221,602	*10.64*
2006	566,914	*2.72*	***2018***	2,269,854	*10.87*
2007	619,888	*2.97*	***2019***	2,003,180	*9.59*
2008	667,364	*3.20*			
Total	**Number of observations: 20,880,384**			***Percent: 100.00***	

Appendix Table A4. Definition of Variables

Variable	Definition	Source
Leverage	Ratio of long-term and short-term debt to lagged total assets	Orbis
Profitability	Ratio of profit before taxes to lagged total assets	Orbis
Interest burden	Ratio of interest payments to lagged total debt	Orbis
Productivity	Total factor productivity estimated with Levinsohn-Petrin approach	Orbis
Total assets	Log of total assets	Orbis
Asset tangibility	Ratio of tangible fixed assets to total assets	Orbis
Cash flow	Ratio of cash flow to total assets	Orbis
Age	Log of the difference between the current year and the year of establishment	Orbis
HDI	HDI is the geometric mean of normalized indices for each of the three dimensions: long and healthy life, knowledge, and a decent standard of living	UNDP
GDP growth	Annual percentage growth rate of GDP at market prices based on constant local currency	WDI
Trade openness	Ratio of the sum of exports and imports of goods and services to GDP	WDI
Financial development	Ratio of domestic credit to private sector to GDP	WDI
Inflation	Consumer price index (2010 = 100)	WDI
Climate vulnerability	Inverted "GDP-adjusted Vulnerability" – the distance of a country's measured vulnerability to the expected value for its GDP per capita	ND-GAIN
Temperature	Average surface temperature in °C	WB
INFORM vulnerability index	Index for Risk Management – an index that measured the susceptibility of communities to hazards	EC/UN
Climate resilience	An index that measures readiness by considering a country's ability to leverage investments to adaptation actions.	ND-GAIN

Appendix Table A5. Summary Statistics

Variables	Unit	Min	1st quartile	Median	3rd quartile	Max	Average	Std. dev.	Number of obs.
Firm characteristics									
Leverage	Ratio	0.00	0.00	0.00	0.01	2.14	0.09	0.23	20,880,384
Profitability	Ratio	-3.00	-0.01	0.03	0.15	1.54	0.05	0.35	20,212,810
Interest burden	Ratio	0.00	0.04	0.08	0.15	17.03	0.23	0.87	2,255,981
Productivity	Log	-7.25	5.12	5.58	6.09	16.01	5.64	0.94	1,861,107
Total assets	Log	0.00	9.87	11.45	13.11	33.86	11.50	2.61	20,880,384
Asset tangibility	Ratio	0.00	0.00	0.10	0.41	1.00	0.24	0.29	20,880,384
Cash flow	Ratio	-0.67	-0.04	0.00	0.05	3.04	0.05	0.33	20,880,384
Age	Log	0.00	1.61	2.20	2.64	4.61	2.15	0.71	20,880,384
Other controls									
HDI	Ratio	0.54	0.70	0.74	0.78	0.88	0.74	0.06	472
GDP growth	Ratio	-0.15	0.02	0.04	0.06	0.14	0.04	0.04	489
Trade openness	Ratio	0.16	0.57	0.81	1.07	2.20	0.86	0.41	489
Financial development	Ratio	0.07	0.30	0.47	0.67	1.65	0.55	0.36	420
Inflation	Ratio	-0.02	0.02	0.04	0.08	10.58	0.09	0.50	483
Climate vulnerability	Index	-0.03	0.03	0.06	0.08	0.13	0.06	0.03	489
Temperature	°C	-0.42	0.70	1.17	1.58	2.64	1.18	0.59	479
INFORM vulnerability index	Index	0.70	1.90	2.90	3.70	6.10	2.90	1.26	166
Climate resilience	Index	0.27	0.37	0.41	0.47	0.62	0.42	0.07	489

Appendix Table A6. Correlation among Macroeconomic Indicators

	Real GDP growth	Trade openness	Private credit	Inflation	HDI	Climate vulnerability
Real GDP growth	1	0	0	0	0	0
Trade openness	0.19	1	0	0	0	0
Private credit	0.04	0.43	1	0	0	0
Inflation	-0.24	-0.11	-0.05	1	0	0
HDI	-0.20	-0.13	0.16	-0.06	1	0
Climate vulnerability	0.06	0.11	0.14	-0.09	-0.22	1

Appendix Table A7. Climate Change and Firm Performance—By Sector

Variables	(1) AGR^{v}	(2) MIN	(3) MFG	(4) UTI	(5) CON^{v}	(6) IT	(7) OTH	(8) TRD	(9) TRA^{v}	(10) EST	(11) ADM
Dependent variable: Leverage											
Climate vulnerability	**-0.551***** [0.053]	**0.280*** [0.167]	**-0.082***** [0.027]	0.052 [0.080]	**-0.192***** [0.029]	**0.148***** [0.052]	**-0.138***** [0.042]	**-0.291***** [0.018]	-0.007 [0.048]	**0.337***** [0.041]	-0.024 [0.028]
Num. of obs.	755,212	84,786	2,659,889	258,188	1,864,239	769,286	1,269,043	6,958,851	972,610	1,508,320	2,726,236
Num. of firms	110,850	14,578	461,552	43,685	350,244	140,670	233,217	1,210,702	171,254	264,084	494,592
Adj R-squared	0.007	0.002	0.004	0.003	0.003	0.001	0.003	0.003	0.003	0.004	0.002
Dependent variable: Interest Burden											
Climate vulnerability	**2.366***** [0.469]	1.522 [2.028]	**-0.594**** [0.259]	-0.751 [0.920]	0.761 [0.534]	1.483 [1.085]	**1.599*** [0.866]	**0.423*** [0.230]	**-1.257**** [0.627]	-0.202 [0.480]	0.354 [0.658]
Num. of obs.	165,025	18,518	438,593	42,430	158,556	41,882	48,780	680,354	103,242	151,900	134,781
Num. of firms	27,542	3,634	87,404	8,286	39,436	10,343	12,031	158,143	23,288	33,971	34,681
Adj R-squared	0.019	0.015	0.013	0.012	0.010	0.005	0.015	0.015	0.013	0.030	0.014
Dependent variable: Profitability											
Climate vulnerability	**-0.356***** [0.064]	-0.180 [0.183]	0.030 [0.036]	**-0.417***** [0.105]	**-0.481***** [0.053]	**-0.422***** [0.111]	**-1.418***** [0.089]	**-1.018***** [0.028]	**-0.902***** [0.080]	**-0.642***** [0.054]	**-0.970***** [0.058]
Num. of obs.	739,471	82,431	2,598,225	252,103	1,804,435	732,147	1,198,892	6,761,299	939,962	1,456,405	2,601,546
Num. of firms	108,519	14,159	451,522	42,617	341,072	135,156	220,474	1,182,103	166,771	256,949	476,394
Adj R-squared	0.005	0.004	0.003	0.001	0.004	0.005	0.004	0.004	0.005	0.002	0.005
Dependent variable: Productivity											
Climate vulnerability	**-5.713***** [0.963]	2.372 [3.258]	**-2.560***** [0.315]	**6.115***** [1.538]	0.243 [0.608]	**2.724***** [0.933]	**5.819***** [0.790]	**-6.862***** [0.271]	**-2.115***** [0.699]	1.590 [2.181]	**1.746***** [0.515]
Num. of obs.	57,977	5,465	284,077	21,457	152,213	69,669	85,644	639,261	128,143	51,618	242,700
Num. of firms	8,640	732	37,782	2,999	22,597	10,453	13,696	90,927	21,148	7,966	36,176
Adj R-squared	0.031	0.018	0.033	0.035	0.023	0.031	0.020	0.085	0.030	0.017	0.023

Note: Robust standard errors clustered at the firm level are reported in brackets. Firm fixed effects as well as year and country fixed effects are included in all regressions.
Firm-level and other controls used in the baseline specification are included but not reported for ease of exposition. AGR – Agribusiness, MIN – Mining, MFG – Manufacturing, UTI – Utilities, CON – Construction, IT – Information technology, OTH – Other service activities, households, extra territorial bodies, TRD – Wholesale and retail trade, accommodation, TRA – Transport and storage, EST – Real estate, ADM – Professional and administrative activities. ^{v} indicates a vulnerable sector.
*** p<0.01, ** p<0.05, * p<0.1

Appendix Table A8. Climate Change and Firm Performance—By Size

	(1) Small	(2) Large	(3) Small	(4) Large	(5) Small	(6) Large	(7) Small	(8) Large
	Dependent variable							
Variables	Leverage		Interest Burden		Profitability		Productivity	
Climate vulnerability	**0.211*** **	**-0.070*** **	**2.542***	**0.918*** **	**-1.799*** **	**-0.190*** **	**-2.314*** **	**-1.308*** **
	[0.025]	[0.021]	[2.538]	[0.150]	[0.064]	[0.017]	[0.713]	[0.316]
Firm-level								
Total assets (lag)	0.000***	0.016***	-0.159***	-0.089***	-0.028***	-0.007***	0.046***	0.104***
	[0.000]	[0.000]	[0.030]	[0.003]	[0.000]	[0.000]	[0.003]	[0.003]
Asset tangibility (lag)	0.010***	0.045***	-0.330***	-0.114***	-0.055***	-0.021***	-0.142***	-0.470***
	[0.001]	[0.001]	[0.095]	[0.008]	[0.002]	[0.001]	[0.009]	[0.011]
Cash flow (lag)	-0.002***	-0.007***	-0.008	0.012*	0.024***	0.025***	0.017***	0.068***
	[0.000]	[0.000]	[0.029]	[0.006]	[0.001]	[0.001]	[0.004]	[0.006]
Age	-0.010***	-0.012***	0.144*	0.007	-0.001	-0.007***	0.016	-0.099***
	[0.000]	[0.001]	[0.076]	[0.006]	[0.001]	[0.001]	[0.010]	[0.008]
Other controls								
HDI	0.174***	-0.462***	1.522	-0.166	-1.385***	-0.230***	9.112***	6.809***
	[0.031]	[0.029]	[7.029]	[0.248]	[0.101]	[0.025]	[0.750]	[0.261]
Real GDP growth	0.003	0.008	-0.171	0.187***	0.158***	0.248***	0.465***	1.291***
	[0.004]	[0.007]	[1.080]	[0.045]	[0.018]	[0.006]	[0.108]	[0.053]
Financial development	-0.002	-0.016***	-1.086*	0.023	-0.092***	0.000	0.813***	0.055*
	[0.002]	[0.003]	[0.635]	[0.015]	[0.007]	[0.002]	[0.114]	[0.032]
Trade openness	-0.004	-0.064***	-0.011	0.012	-0.141***	-0.011***	0.039	0.257***
	[0.003]	[0.002]	[0.597]	[0.014]	[0.007]	[0.002]	[0.070]	[0.022]
Inflation	0.014***	0.076***	-0.030	-0.048***	-0.004	0.062***	-0.408***	-0.146***
	[0.001]	[0.005]	[0.022]	[0.016]	[0.004]	[0.004]	[0.146]	[0.021]
Temperature	0.001***	-0.001***	0.049	-0.010***	-0.011***	0.001***	0.085***	0.019***
	[0.000]	[0.000]	[0.039]	[0.002]	[0.001]	[0.000]	[0.009]	[0.003]
Num. of obs.	4,676,725	4,895,924	17,054	1,350,202	4,260,471	4,838,531	194,530	532,406
Num. of firms	1,050,235	886,811	6,968	272,042	978,536	875,766	51,390	76,973
Adj R-squared	0.001	0.006	-0.008	0.003	0.004	0.004	0.010	0.031

Note: Robust standard errors clustered at the firm level are reported in brackets. Firm fixed effects are included in all regressions as well as sector-year and sector-country fixed effects. Negative adjusted R-squared is a result of low number of observations and a large number of explanatory variables, including the fixed effects.
*** p<0.01, ** p<0.05, * p<0.1

Appendix Table A9. Climate Change and Firm Performance—By Age

	(1) Young	(2) Old	(3) Young	(4) Old	(5) Young	(6) Old	(7) Young	(8) Old
	Dependent variable							
Variables	**Leverage**		**Interest Burden**		**Profitability**		**Productivity**	
Climate vulnerability	**-0.142*** **	**0.077*** **	-0.654	**0.485** **	**-0.587*** **	**-0.798*** **	**2.315*** **	-0.451
	[0.025]	[0.019]	[0.564]	[0.226]	[0.052]	[0.028]	[0.570]	[0.298]
Firm-level								
Total assets (lag)	0.001***	0.003***	-0.257***	-0.147***	-0.019***	-0.010***	0.021***	0.109***
	[0.000]	[0.000]	[0.008]	[0.005]	[0.000]	[0.000]	[0.002]	[0.003]
Tangibility (lag)	0.018***	0.028***	-0.251***	-0.164***	0.012***	-0.016***	-0.086***	-0.278***
	[0.001]	[0.001]	[0.023]	[0.013]	[0.002]	[0.001]	[0.008]	[0.009]
Cash flow (lag)	-0.002***	-0.003***	0.009	0.003	0.009***	0.024***	0.023***	0.035***
	[0.000]	[0.000]	[0.008]	[0.010]	[0.001]	[0.001]	[0.003]	[0.005]
Age	-0.003***	-0.005*	0.010	0.112***	-0.029***	-0.060***	-0.050***	-0.503***
	[0.000]	[0.003]	[0.019]	[0.027]	[0.001]	[0.003]	[0.009]	[0.048]
Other controls								
HDI	0.096***	0.034	2.098*	0.012	-0.531***	-0.717***	6.959***	3.273***
	[0.034]	[0.026]	[1.071]	[0.375]	[0.081]	[0.041]	[0.437]	[0.289]
Real GDP growth	-0.014***	0.017***	0.258*	0.196***	0.137***	0.208***	0.643***	1.065***
	[0.005]	[0.004]	[0.150]	[0.065]	[0.013]	[0.008]	[0.067]	[0.056]
Financial development	-0.049***	0.013***	-0.305***	0.050**	-0.050***	-0.030***	0.972***	0.481***
	[0.004]	[0.002]	[0.083]	[0.022]	[0.008]	[0.003]	[0.064]	[0.037]
Trade openness	-0.063***	-0.047***	0.176***	0.004	0.016***	0.006**	0.413***	0.057***
	[0.003]	[0.002]	[0.058]	[0.023]	[0.006]	[0.003]	[0.043]	[0.022]
Inflation	0.021***	0.023***	0.004	-0.083***	0.006**	0.051***	-0.110***	-0.081***
	[0.002]	[0.002]	[0.017]	[0.026]	[0.003]	[0.003]	[0.025]	[0.015]
Temperature	0.001***	-0.002***	-0.003	-0.005	0.000	0.003***	0.034***	0.037***
	[0.000]	[0.000]	[0.007]	[0.003]	[0.001]	[0.000]	[0.005]	[0.004]
Num. of obs.	4,997,206	5,723,103	329,354	707,444	4,805,231	5,556,796	434,529	503,299
Num. of firms	1,691,591	1,003,679	128,461	147,554	1,635,223	977,296	144,712	75,206
Adj R-squared	0.001	0.002	0.032	0.008	0.004	0.002	0.004	0.023

Note: Robust standard errors clustered at the firm level are reported in brackets. Firm fixed effects are included in all regressions as well as sector-year and sector-country fixed effects.

*** p<0.01, ** p<0.05, * p<0.1

Appendix Table A10. Climate Change and Firm Performance—Alternative Indicators

Variables	(1) Leverage	(2) Interest burden	(3) Profitability	(4) Productivity
INFORM vulnerability score	**-0.003*** **	**0.006*** **	**-0.010*** **	**-0.045*** **
	[0.000]	[0.004]	[0.000]	[0.004]
Firm-level				
Total assets	0.002***	-0.174***	-0.018***	0.040***
	[0.000]	[0.004]	[0.000]	[0.002]
Tangibility	0.032***	-0.201***	-0.006***	-0.190***
	[0.001]	[0.010]	[0.001]	[0.007]
Cash flow	-0.002***	0.012**	0.020***	0.028***
	[0.000]	[0.005]	[0.000]	[0.003]
Age	-0.010***	-0.002	-0.012***	-0.062***
	[0.000]	[0.008]	[0.001]	[0.006]
Other controls				
HDI	0.752***	2.246***	0.271***	-5.072***
	[0.029]	[0.366]	[0.045]	[0.530]
Real GDP growth	0.011***	0.414***	0.121***	-4.792***
	[0.004]	[0.121]	[0.011]	[0.073]
Financial development	-0.106***	-0.089**	-0.161***	-0.373***
	[0.002]	[0.039]	[0.004]	[0.047]
Trade openness	-0.061***	-0.069**	0.087***	-0.136***
	[0.002]	[0.029]	[0.003]	[0.030]
Inflation	0.067***	0.049	0.083***	-6.054***
	[0.002]	[0.039]	[0.004]	[0.156]
Temperature	0.002***	0.001	0.006***	0.085***
	[0.000]	[0.003]	[0.000]	[0.004]
Number of obs.	13,127,595	1,192,478	12,654,628	690,273
Number of firms	2,971,733	322,123	2,888,557	145,815
Adj R-squared	0.003	0.015	0.004	0.029

Note: Robust standard errors clustered at the firm level are reported in brackets. Firm fixed effects are included in all regressions as well as sector-year and sector-country fixed effects.
*** p<0.01, ** p<0.05, * p<0.1

Appendix Table A11. Climate Change and Firm Performance—Alternative Indicators

Variables	(1) Leverage	(2) Interest burden	(3) Profitability	(4) Productivity
Climate resilience	**0.095*** **	**0.180*** **	**0.134*** **	**2.056*** **
	[0.002]	[0.029]	[0.004]	[0.064]
Firm-level				
Total assets	0.004***	-0.146***	-0.005***	0.104***
	[0.000]	[0.003]	[0.000]	[0.001]
Tangibility	0.033***	-0.164***	-0.036***	-0.351***
	[0.000]	[0.007]	[0.001]	[0.004]
Cash flow	-0.004***	0.006	0.029***	0.038***
	[0.000]	[0.004]	[0.000]	[0.002]
Age	-0.014***	0.013**	-0.016***	-0.082***
	[0.000]	[0.005]	[0.000]	[0.004]
Other controls				
HDI	-0.422***	0.297	-0.981***	5.095***
	[0.013]	[0.223]	[0.025]	[0.191]
Real GDP growth	0.017***	0.149***	0.210***	0.910***
	[0.002]	[0.042]	[0.005]	[0.029]
Financial development	0.014***	0.017	-0.008***	-0.264***
	[0.001]	[0.014]	[0.002]	[0.023]
Trade openness	-0.058***	-0.010	-0.027***	0.361***
	[0.001]	[0.013]	[0.002]	[0.014]
Inflation	0.038***	-0.047***	0.018***	-0.247***
	[0.001]	[0.015]	[0.002]	[0.018]
Temperature	0.000***	-0.006***	-0.004***	0.050***
	[0.000]	[0.002]	[0.000]	[0.002]
Number of obs.	20,123,083	1,999,224	19,454,091	1,744,249
Number of firms	3,316,115	435,869	3,230,399	250,035
Adj R-squared	0.004	0.013	0.003	0.042

Note: Robust standard errors clustered at the firm level are reported in brackets. Firm fixed effects are included in all regressions as well as sector-year and sector-country fixed effects.
*** p<0.01, ** p<0.05, * p<0.1

Appendix Table A12. Climate Change and Firm Performance—Excluding Russia

Variables	(1) Leverage	(2) Interest burden	(3) Profitability	(4) Productivity
Climate resilience	**-0.109*** [0.016]**	**0.628*** [0.214]**	**-0.359*** [0.025]**	**-2.568*** [0.173]**
Firm-level				
Total assets	0.004*** [0.000]	-0.122*** [0.003]	-0.003*** [0.000]	0.103*** [0.001]
Tangibility	0.020*** [0.000]	-0.191*** [0.009]	-0.047*** [0.001]	-0.347*** [0.004]
Cash flow	-0.002*** [0.000]	0.006 [0.005]	0.036*** [0.000]	0.039*** [0.002]
Age	0.000** [0.000]	0.039*** [0.007]	-0.009*** [0.001]	-0.085*** [0.004]
Other controls				
HDI	-0.219*** [0.015]	-0.157 [0.239]	-0.968*** [0.026]	8.309*** [0.155]
Real GDP growth	0.009*** [0.002]	0.200*** [0.051]	0.214*** [0.005]	0.873*** [0.029]
Financial development	0.005*** [0.001]	0.077*** [0.014]	-0.004** [0.002]	0.121*** [0.022]
Trade openness	-0.053*** [0.001]	-0.033** [0.015]	0.002 [0.002]	0.276*** [0.014]
Inflation	0.037*** [0.001]	-0.059*** [0.016]	0.008*** [0.002]	-0.235*** [0.017]
Temperature	-0.001*** [0.000]	-0.016*** [0.003]	-0.002*** [0.000]	0.047*** [0.002]
Number of obs.	13,909,772	1,252,912	13,424,496	1,743,316
Number of firms	2,251,750	275,926	2,188,634	249,821
Adj R-squared	0.004	0.008	0.003	0.042

Note: Robust standard errors clustered at the firm level are reported in brackets. Firm fixed effects are included in all regressions as well as sector-year and sector-country fixed effects.
*** p<0.01, ** p<0.05, * p<0.1