# The Financial Impacts of Climate Risk

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# Abstract

Drawing on state-level data on temperature anomalies, the dissertation contributes to the growing literature on the financial impacts of climate change on US-headquartered firms. Benchmarking long-term climate change, the first two chapters are empirical corporate finance papers examining the impacts of statewide climate change risks on corporate payout policy and the value of firms' financial flexibility. The third chapter is an asset-pricing paper that predicts corporate climate sensitivity of firms' stocks to state-level climate change as a new systematic risk factor.

The first chapter shows that long-term climate change adversely affects corporate dividend payout policy. With state-level temperature anomalies (SLTA), the impacts of climate change on corporate payout are severely persistent when firms are exposed to abnormally warmer temperatures. Cash holdings, trade credit, and market leverage present statistically significant mediating roles in the impacts of long-term climate change on corporate payout policy. The impacts of SLTA on corporate payout are pronounced for firms with higher vulnerability to climate transition risk (e.g., polluting firms) since the Paris Agreement (COP21). Smaller and younger firms and firms with higher tangibility are sensitive to the long-term impacts of climate change across US states. The contributions of the study to related literature are threefold. First, the study shows that the consequences of climate change on firms are chronically severe. With the persistent predicted decrease in dividend policy, climate change affects firms' growth prospects, with its geographical complexity, escalating earnings uncertainty for firms. Second, the long-term systematic risks of climate change imposed on firms are multifaceted, with high geographical divergence, for which firms might face great challenges in opting for flexible and

reliable financing choices in the long-term period. The impacts of SLTA on corporate dividends are persistently robust when the study controls the mediating effects of corporate financial policies and the moderating effects of other climate risk factors.

The geographical complexity of long-term climate change impacts on firms is investigated in the second chapter through the lens of corporate financial flexibility. The second chapter shows that long-term climate change is adversely associated with the value of corporate financial flexibility (VOFF). Using the forward-looking and market-based measure, the predicted decrease in VOFF supports evidence from the first chapter by showing that long-term climate change systematically affects firms' growth opportunities across the US states. The impact of SLTA on firms' VOFF is persistent for firms with higher market-to-book values and larger firms. The impacts of long-term climate change on the VOFF are robust when the study controls the mediating effects of financial policies and the joint effects of other climate-related externalities.

The third chapter estimates the state-level corporate climate sensitivity (SL-CCS) to temperature anomalies. Using the predicted SL-CCS for each firm's stock, the study examines whether the financial market is pricing the SL-CCS betas as a new systematic risk factor. The broad findings show that the pricing of financial markets to the SL-CCS betas is conditional on the levels of global warming across the US states. Investors demand a premium when firms' stocks are exposed to abnormally warmer temperatures; otherwise, there is a negative association between SL-CCS betas and firms' stock returns (RET). The varying associations between SL-CCS betas and RET are aligned with our predictions when the study tests for other endogenous and exogenous climate-related risk factors.

## Introduction

Scholars, stakeholders, and policymakers have been increasingly paying attention to the impacts of climate change risks on corporate behaviors, performance, and financial policies. Human activities for economic growth induce escalating emissions that pollute the environment, leading to climate change as the ultimate challenge for economics Nordhaus (2019b). Earth's climate has changed since the middle of the 20th century due to human activity, especially the burning of fossil fuels, which raises the amount of heat-trapping greenhouse gases in the atmosphere and raises the planet's average surface temperature[1]. Climate change can also be caused by natural processes that have been overtaken by human activity. These include external forcings like volcanic activity, changes in the Sun's energy output, and variations in Earth's orbit, as well as internal variability like cyclical ocean variations like El Niño, La Niña, and the Pacific Decadal Oscillation. Scientists track and investigate past, current, and future climate change using the key indicators of climate change, including rising sea levels, ice loss at the poles and in mountain glaciers, changes in the frequency and intensity of extreme weather events like hurricanes, heat waves, wildfires, droughts, floods, and precipitation, as well as changes in cloud and vegetation cover. The terms "global warming" and "climate change" are sometimes used synonymously, but they have different meanings. Similarly, despite referring to occurrences with widely disparate spatial and temporal ranges, the terms "weather" and "climate" are occasionally used interchangeably throughout the dissertation. How do we benchmark climate change risks? The question is crucial to reflect the financial impacts of climate risk on firms and the pricing of financial markets. Being unable to benchmark climate change risks leads to conflicting findings

[1] What Is Climate Change? - NASA Science

of the financial impacts of climate risks in corporate finance (Ginglinger & Moreau, 2023; Huang et al., 2018) and asset pricing literature (Aswani et al., 2023a, 2023b; Bolton & Kacperczyk, 2021; Patrick Bolton & Marcin Kacperczyk, 2023a, 2023b). Given the growing literature, we could agree that prior studies fail to benchmark long-term climate change risk, leading to consequential heterogeneous findings. Therefore, benchmarking climate change risk and quantifying its financial impacts on firms and corporate sensitivity to local climate factors are the fundamental critical novelties of this doctoral dissertation.

In climate science, temperature anomalies are more significant than absolute temperature for the following fundamental reasons[2]. A temperature anomaly is a deviation from the baseline or average temperature. The average of 30 years or more of temperature data is usually used to calculate the baseline temperature. The temperature that was measured was warmer than the baseline when the anomaly was positive, and cooler than the baseline when it was negative. Urban regions tend to be warmer than rural areas, while higher elevations tend to be cooler than lower elevations. These factors, together with station placement, will affect the data when determining an average of absolute temperatures. For instance, a region's summer months may be colder than usual in both a neighboring valley and a mountaintop, yet the two places' absolute temperatures will differ significantly. When stations are added, withdrawn, or disappear from the monitoring network, using anomalies also helps to reduce these issues.

[2] Did You Know? | Anomalies vs. Temperature | National Centers for Environmental Information (NCEI)

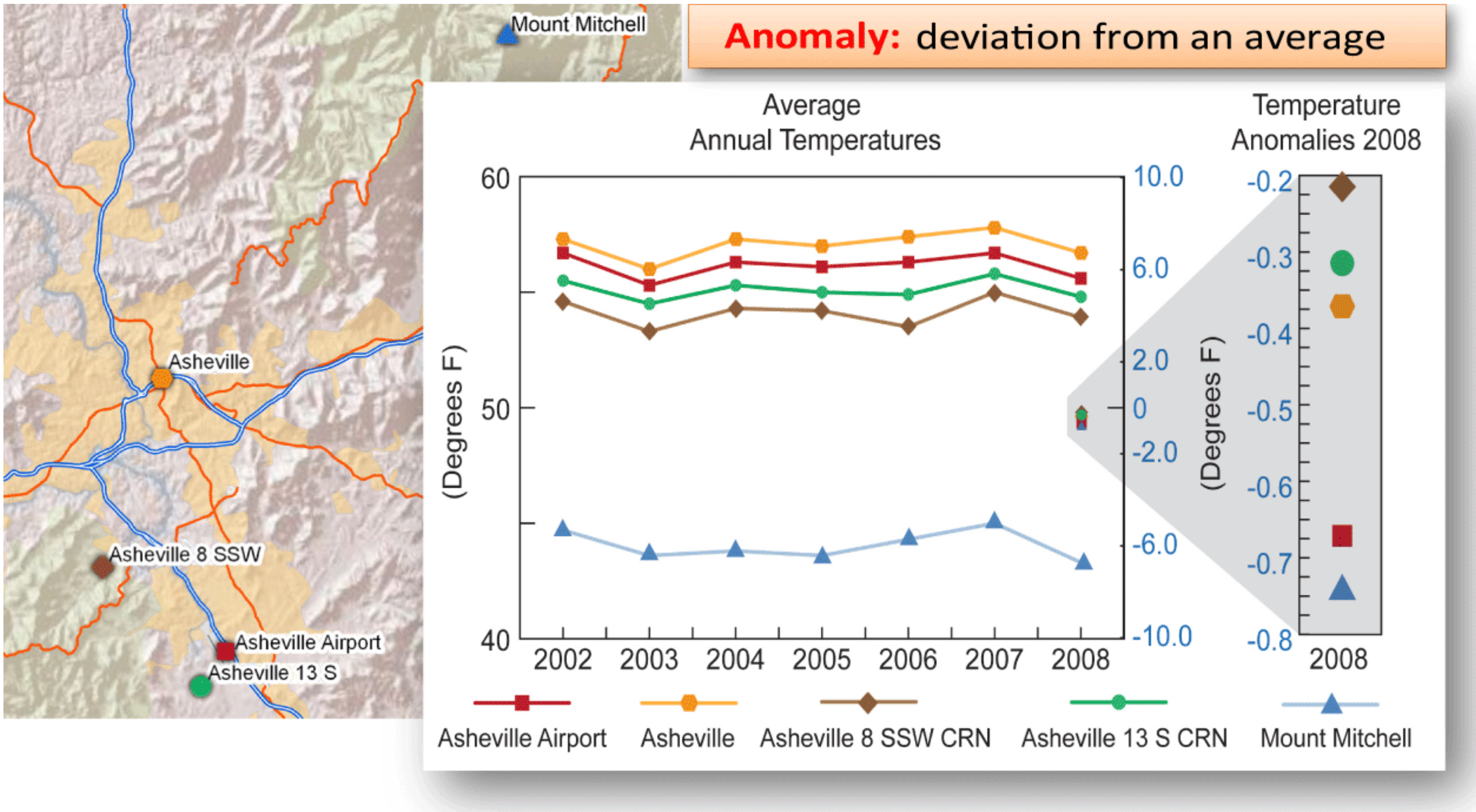


**Diagram 1**: Temperature anomaly, deviation from an average temperature value. Source: Adapted from NCEI-NOAA (2025)[3].

[3] Adapted as of November 2025 that can be accessed at Did You Know? | Anomalies vs. Temperature | National Centers for Environmental Information (NCEI)

Adapted from NCEI-NOAA (2025), absolute temperatures (lines) for five nearby sites are displayed in the diagram above, with the 2008 anomalies serving as symbols. Observe how, concerning the absolute temperatures, all the anomalies fall into a very small range. The total average temperature could vary greatly depending on which station dropped out of the record, but the average anomaly would not change much even if one station were removed, see a recent meta-analysis by Tol (2024). Employing data from state-level temperature anomalies [SLTA], the dissertation investigates the financial impacts of climate risk on corporate dividend payout policy (Chapter One) and the value of financial flexibility (VOFF) using a predicted forward-looking and market-based measure (Chapter Two). While the first two chapters quantify the impacts of long-term climate change on listed firms and corporate policies, the third chapter contributes to asset pricing literature by estimating corporate sensitivity to the long-term climate change risk, namely state-level corporate climate sensitivity (SL-CCS) betas. The study then examines whether the predicted SL-CCS betas are being priced by the equity markets as a newly priced systematic risk factor for firms' stocks located across the US states.

Benchmarking long-term climate change with its geographical divergence, the dissertation contributes to the growing literature on corporate climate finance and asset pricing quantifying different types of climate risks (Bolton & Kacperczyk, 2021; PATRICK BOLTON & MARCIN KACPERCZYK, 2023b; Ginglinger & Moreau, 2023; Huang et al., 2018; Pankratz et al., 2023; Shaojun Zhang, 2024). The dissertation is dedicated to firms located in the US for the following reasons. The average surface temperature in the contiguous 48 states has increased by 0.17°F per decade since 1901[4]. Since the late 1970s, average temperatures have increased at a faster rate (0.32 to 0.51°F per decade since 1979). The two warmest years on record for the contiguous

[4] Climate Change Indicators: U.S. and Global Temperature | US EPA

United States were 2012 and 2016, while nine of the ten warmest years on record have happened since 1998. Climate change is geographically divergent, and some US states have experienced more warming than others. For this dissertation, state-level temperature anomalies, or abnormal temperature values compared to the average normal temperature values for the US states between 1901 and 2000 are used for empirical works. Monthly anomalies were calculated using daily temperature readings at each site, and an annual temperature anomaly for each year was then determined by averaging the monthly anomalies. To determine anomalies for the contiguous 48 states and Alaska, average anomalies for regions within each state have been calculated using topography, station density, and interpolation. Using state-level climate change data extracted from NCEI-NOAA[5], the dissertation comprehensively investigates the financial impacts of climate change on firms' stocks headquartered across the US states over recent decades.

The doctoral dissertation aims to investigate the financial impacts of long-term climate change. The dissertation consists of three chapters. The first two chapters are empirical corporate finance papers examining the impacts of long-term climate change on corporate payout policies and the value of corporate financial flexibility. The third chapter is an asset pricing paper predicting firm-level sensitivity to statewide climate change risks and investigating the pricing of equity markets.

The first chapter examines the impacts of state-level temperature anomaly on corporate dividend payout. The findings show that abnormally warmer temperatures are adversely associated with corporate dividends paid to shareholders. In other words, long-term climate change captured by statewide global warming induces firms to decrease dividend payouts. Chronic climate-induced

[5] National Centers for Environmental Information (NCEI)

decreases in dividends are persistent when the study controls for the joint effects of firms' cash reserves. Trade credit and market leverage are reliable channels for firms coping with climate change and the presence of global warming across US states. The adverse direct effects of temperature anomalies on corporate dividends are persistently controlling for the Paris Agreement (e.g., international climate transition risk), the long-term proneness to natural disasters (e.g., physical risks), and corporate vulnerability (e.g., polluting firms) to climate transition risk. The impact of state-level temperature anomalies on corporate dividends is highly sensitive to younger and smaller firms and firms with higher tangibility. The findings imply the systematic risks of long-term climate change imposed on firms leading to earnings uncertainty and escalated volatility of firms' growth prospects. The findings of the 1st chapter directly complement the recent study of Yuyuan Chang et al. (2024) showing that long-term climate change imposes unfavorable consequences on corporate payout policy. Distinguished from short-term physical risks used in Yuyuan Chang et al. (2024), the study implies that long-term climate change imposes more severe systematic risks on firms' growth prospects. While prior studies suggest that firms could prefer shares repurchasing over dividends (Yuyuan Chang et al., 2024) or hoarding cash to hedge temporary climate risks (Dimitrios Gounopoulos & Yu Zhang, 2024; Siamak Javadi et al., 2023), benchmarking climate change risks, the impacts of state-level global warming on corporate dividends are persistently controlling for endogenous and exogenous factors, presented in this study.

The empirical findings imply chronic severity and systematic risks of climate change imposed on firms across the US states. In the context of long-term climate change, the findings of the 1st chapter motivate research questions about the value of corporate financial flexibility to be examined in the second chapter of the dissertation. The value of financing flexibility is dependent on external financing costs, personal and corporate tax payments that result in an effective cost of a firm's cash holdings, potential firm growth, corporate maturity, and capital reversibility (GAMBA & TRIANTIS, 2008). Under a predicted decrease in dividend payouts under the impacts of state-level climate change risk, leading to stringent growth prospects of firms, firms face climate-induced financing frictions with potential lending and borrowing practices. Financing frictions are closely related to the natural dynamics of debt and cash policies and the value of financial flexibility. Mimicking Rapp et al. (2014), financial flexibility could shape corporate financial policy, for which shareholders consider financial flexibility with its higher value than dividend payouts. Under climate risks, firms may prefer share repurchases to dividends (Yuyuan Chang et al., 2024), exhibiting lower leverage ratios to ample financial flexibility (Ginglinger & Moreau, 2023) and hoarding cash (Dimitrios Gounopoulos & Yu Zhang, 2024; Siamak Javadi et al., 2023). Therefore, understanding the impacts of long-term climate change on the value of financial flexibility is critical to listed firms shaping financial policies.

Based on the theoretical framework of GAMBA and TRIANTIS (2008) that defines the value of corporate financial flexibility (VOFF) as a firm's ability to access financing sources with possible restructuring at a low cost, Chapter 2 examines the impacts of state-level temperature anomalies on corporate financial flexibility by constructing the market-based and forward-looking measure of VOFF. The empirical findings show that state-level climate change (SLCC), measured by temperature anomalies, is adversely associated with firms' VOFF. The adverse impacts of SLCC on VOFF are pronounced for larger firms and those having a higher market-to-book value. The findings imply that long-term climate change imposes systematic risks on growth opportunities, leading to a consequentially predicted decrease in VOFF. The direct and adverse impact of SLCC on VOFF is persistent, controlling corporate dividend payout (e.g., dividend-paying firms). The findings present the negative and statistically significant joint effects of SLCC and market leverage (SLCC x MKT_LEV) on VOFF. Controlling for cash balance, the adverse impacts of SLCC on VOFF remain negative but statistically significant. Under the impacts of SLCC, the predicted decrease in VOFF is pronounced for firms located in disaster-prone states with a statistically significant joint effect (SLCC x DPS). The impact of SLCC on VOFF remains marginal and statistically significant for firms located in US states with state-led adaptation plans finalized (SAPF). The effects of SLCC on VOFF remain negative but statistically insignificant when the study controls the joint effect of the Paris Agreement (POST 2015). In general, the empirical findings present negative and robust impacts of SLCC on VOFF, implying the long-term systematic risks imposed on firms due to climate change across the US states. For firms' contemporary responses, prior literature documents that firms might hedge against climate risks by adjusting financial policies (Dimitrios Gounopoulos & Yu Zhang, 2024; Huang et al., 2018; Siamak Javadi et al., 2023); however, the VOFF is diminishing under the long-term systematic consequences of climate change. Regarding Ginglinger and Moreau (2023), this chapter benchmarks long-term climate change by using state-level temperature anomalies and shows that, with the deceased VOFF, firms might chronically face greater challenges given the supply and demand-side effects of climate risks. The findings are robust when the study controls for a battery of endogenous firm-level financial policies and exogenous climate-related risk factors. While prior literature documents firms' responsive financial policies to temporarily cope with climate risks, this study shows that long-term climate change has led to a predicted decrease in VOFF of firms over the last decades.

The first two chapters have investigated the impacts of climate risks on corporate policies with a predicted decrease in dividend payout and the value of financial flexibility. With decreased growth prospects, under the long-term climate change exposure, shareholders could have found that firms could face a great challenge to secure ample financial flexibility in the longer term. Given the concerns about global warming due to rising carbon dioxide (CO2) concentration, temperature anomalies lead to a rationale that corporate climate sensitivity to climate change represents a systematic risk that could be presented in stock returns and investment portfolios for investors. Among climate risk drivers, a recent study by Shaojun Zhang (2024) shows that carbon premiums vary across countries with their levels of policy stringency for our climate action. Prior studies have debated whether material risks (e.g., corporate carbon emissions) are associated with stock returns (Aswani et al., 2023a, 2023b; Patrick Bolton & Marcin Kacperczyk, 2023a). The foremost goal of the Paris Climate Agreement, signed by 196 Parties, is to limit global warming below 2 °C above pre-industrial levels. There has been increasing engagement of non-government organizations joining global action (Ilhan et al., 2023; Krueger et al., 2020). Therefore, the pricing of financial markets to climate risks could be dependent on how sensitive stocks are to local long-term climate factors, namely the levels at which firms are exposed to global warming across US states with consequential climate risk drivers. This research gap is investigated in the third essay of the dissertation.

Using state-level climate change data, Chapter 3 estimates corporate climate sensitivity for firms located across the US states. Using the predicted state-level corporate climate sensitivity (SL-CCS) measure, the study examines the pricing of financial markets to SL-CCS betas as a new systematic risk factor. Employing multidecade data on firms' stocks, the empirical findings show that SL-CCS betas are negatively associated with stock returns (RET), and the association between SL-CCS betas and RET becomes positive and statistically significant when the study tests for abnormal positive temperature anomalies across US states. The findings are robust when the study controls for firm fundamentals before and after the COVID-19 period with(out) penny stocks. While the predicted SL-CCS betas with their associations with RET are robustly conditional on state-level temperature anomalies, the study finds no significant evidence on the pricing of financial markets to polluting (carbon intensive firms) stocks. Equity markets price the SL-CCS betas for firms' stocks located in disaster-prone states (DPS). Compared to the long-term proneness to climate disasters (DPS as the long-term climate physical risks), the pricing of equity markets to SL-CCS is still persistently robust with the levels of state-wide temperature anomalies.  For climate transition risks, the pricing of equity markets to SL-CC remains for US states with state-led adaptation plans finalized (SAPF), and the joint effects of SAPF with SL-CCS on RET become positive with stronger statistically significant levels under positive abnormal temperature anomalies.

The findings imply the outperformance of state-level climate change in the long-term period in explaining the pricing of financial markets to climate risk factors. For this study, the 3rd chapter proves that the associations between climate-related risk factors and stock returns are conditional on long-term climate change, with the predicted SL-CCE betas based on statewide temperature anomalies, the benchmarking measures for climate change risks. With the predicted SL-CCE betas tested on RET, the chapters explain escalating debates of asset pricing literature on the correct relations between climate-related risk factors and stock returns (Aswani et al., 2023a, 2023b; Patrick Bolton & Marcin Kacperczyk, 2023a) and the pricing of financial markets to climate risks (Huynh & Xia, 2021; Huynh & Xia, 2023). The SL-CCS betas predicted by this chapter could be highly applicable to emerging literature on climate corporate finance and asset pricing in tracking firm-level climate sensitivity for predicted corporate behaviors and other risk factors.

The next parts of the dissertation present the first, second, and third chapters, respectively. Related tables of results and appendices are inserted at the bottom of each chapter. A list of references is inserted at the bottom of the dissertation, automatically generated with the EndNote program.[6].

# **Chapter One**: State-Level Climate Change and Corporate Payout Policy

## Introduction

Climate change as a public bad is ultimately challenging the global economy (Nordhaus, 2019b). On the bright side, exposing firms to climate risks incentivizes them to invest more in research and development (R&D) to develop climate change mitigation technology (Li et al., 2021). On the downside, climate risks induce firms to reserve more cash to hedge potential illiquidity (Dimitrios Gounopoulos & Yu Zhang, 2024; Siamak Javadi et al., 2023) and higher cost of funding or equity capital (Huynh et al., 2020), leading to lower financial leverage (Ginglinger & Moreau, 2023; Nguyen & Phan, 2020; Nguyen et al., 2022). Arguably, the impacts of climate change on corporate behaviors and adaptive policies are complex given both the demand and supply effects on corporate financial policies with the involvement of stakeholders. On the demand side, investors demand compensation when firms are exposed to transition risk (e.g., carbon returns, etc.) (Bolton & Kacperczyk, 2021; P. Bolton & M. Kacperczyk, 2023). Based on a survey of perceptions of climate risks, Krueger et al. (2020) document that institutional

[6] Using a licensed account offered by Massey University, Palmerston North 4442 New Zealand

investors believe in the financial implications of climate-related regulatory risks in investment portfolios. Many larger, long-term, and ESG-driven investors consider risk engagement and management as their approaches to dealing with climate risks. Using holdings data, Ilhan et al. (2023) provide empirical evidence of the positive association between climate-sensitive institutional ownership and increased climate risk disclosures by firms. On the supply side, financial systems (e.g., banks) have become more sensitive to climate risks (Beirne et al., 2024; Cai & Li, 2024; Nguyen & Wilson, 2020; Noth & Schüwer, 2023; Uesugi et al., 2025; Zhang et al., 2024), leading to the potential volatility of firms' access to credit. Given climate-induced volatility to corporate liquidity, firms might be incentivized to adjust their corporate payout policies to be more flexible in paying back to shareholders. For instance, with evidence from contemporary physical-related risks (e.g., storms, hurricanes, flooding, etc.), Chang et al (2024) show that firms prefer share repurchases over dividend payouts when firms are exposed to weather-related events[7].

In climate science, temperature anomaly is a benchmarking measure for capturing long-term climate change, indicating global warming worldwide. The reason is that climatic conditions are abnormally changing after decades of global warming, leading to frequent physical risks. In other words, temperature anomaly captures long-term climate change that imposes climate-related risks on firms, as recently employed by the literature (Y. Chang et al., 2024; Huang et al., 2018). For the US, climatic conditions and climate patterns are heterogeneous and geographically divergent across US states. Therefore, understanding the impacts of state-level

[7] The authors employ the global climate risk index (GCRI) that investigates, to what extent, our countries and and associated regions have been affected by weather-related events (e.g., storm, floods, heat waves, etc.). See details at https://www.germanwatch.org/en/cri

temperature anomaly (e.g., SLTA) is critical to firms' financial policies dealing with long-term climate-induced risks[8].

For this study, we examine the financial impacts of SLTA on corporate payout policies with state-level evidence for firms located across the US states. The rationale is that payout policies reflect firms' growth prospects and are closely linked to other corporate decisions (e.g., investments, financing choices, etc.). As posited, understanding the impacts of SLTA on corporate payout policies is crucial for leading financial markets like the US, given its statewide climate divergence. Furthermore, corporate dividend payout is important to investors and managers (Agarwal & Chakraverty, 2023; Bae et al., 2021; Chay & Suh, 2009; DeAngelo et al., 2006; HAIL et al., 2014; Kahle & Stulz, 2021). As mentioned earlier, in a recent study by Y. Chang et al. (2024), the authors argue that firms in countries with higher climate risk exposure substitute dividends with share repurchases to hedge physical and transition risks. Our focus is on one specific component of climate change – temperature anomaly. The complexity of how climate change, especially abnormal temperature changes, affects dividend payout is even more crucial and worth examining for economies like the United States (U.S.), where climatic conditions across the US states due to temperature anomalies affect dividend payout.

One limitation of Y. Chang et al. (2024) is that it cannot capture the impact of within-country climatic variation on firms' identifying locations of firms. By utilizing the location of the headquarters of the firms in the U.S., which is the most developed capital market in the world, and where the highest number of firms are listed publicly, we explore the relationship between the temperature anomaly and cash dividends. The temperature anomaly is the difference between

[8] Climate-related risks are acknowledged as the number-one long-term global risks, see Global Risks Report 2024 | World Economic Forum | World Economic Forum

the current state-level temperature in which the firm is located, and its baseline/average temperature estimated by averaging 30 or more years of temperature data by NCEI-NOAA.

The study employs US state-level data matched with firms' locations (headquarters) on temperature anomaly to quantify the impacts of climate change on dividend payout for the following reasons. For climate science, temperature anomalies play a more important role than an absolute temperature value. Temperature anomaly captures the difference from a baseline average temperature estimated with at least thirty years (or more) of temperature data on average. A positive value of temperature anomaly indicates that the observed temperature is warmer than the historical baseline value. In contrast, a negative value of temperature anomaly indicates that the observed temperature is cooler than the historical baseline value. Using US state-level temperature anomalies matched with the locations of US firms would mitigate potential issues caused by the geographical divergence of temperature trends. Furthermore, temperature change is a benchmarking measure for climate change as it causes severe consequent climatic conditions, such as drought risks, and also other physical climate risks that are used by recent studies (Adrian et al., 2023; Do et al., 2021; Ginglinger & Moreau, 2023; Hong et al., 2019; Huang et al., 2018; Huynh et al., 2020; Siamak Javadi et al., 2023; Nguyen et al., 2022). Even though modern literature employs firm-level climate exposure measures to convey soft information on multifaceted climate risks (Sautner et al., 2023), temperature anomalies purely reflect acute and chronic climate change in the US states[9]. To examine the impacts of temperature anomalies on payout, the study tracks firms across US states back to

[9] We acknowledge that different measures convey specific information about the nature of climate-related risk drivers and are unique with their own nature. For empirical studies, it could be fruitfully to the literature when we employ diverse sets of measures to examine the impacts of climate risk on corporate policies (e.g., dividend policy in this study). No single measure might be perfect to covey all the information needed to quantify the effects of climate risks.

1971 as the earliest corporate payout data available. Our firm-level data extracted from the COMPUSTAT annual file is comparable to related literature on corporate payout (Kahle & Stulz, 2021) for US firms. We consequently match COMPUSTAT data with yearly average climate data with temperature anomalies extracted from NCEI-NOAA based on the US states where firms are located. Our merged data includes 220,658 state-firm-year observations between 1971 and 2020 for a total of forty-nine US states for empirical works.

Our broad findings show that long-term state-level climate change induces firms to decrease dividends paid to their shareholders. Our findings are robust when we test alternative measures of dividend payouts, share repurchases, and payout flexibility.  We do not observe any evidence of firms favoring share repurchases over dividends to increase payout flexibility in the context of climate change, measured by state-level temperature anomalies [SLTA]. Our study contributes directly to Y. Chang et al. (2024) by showing that the proneness to physical risks could even induce firms to maintain positive dividends paid to their shareholders for mitigating agency problems with positive signals about firms' growth prospects (Allen & Michaely, 2003; Brav et al., 2005; Brockman & Unlu, 2009; Chay & Suh, 2009; Easterbrook, 1984; Farre-Mensa et al., 2014; La Porta et al., 2000). Regarding life-cycle theory (Chay & Suh, 2009; DeAngelo et al., 2006; Faff et al., 2016; Kuo et al., 2013), large firms with higher asset tangibility are highly vulnerable to climate change. In other words, firms in their later cycle stages with fixed assets located across US states become more prone when physical risks emerge, compared to younger firms with lower tangibility, and are unlikely to make payouts with less profitability. Trade credit acts as an alternative financing choice; firms with progressive credit policies maintain positive dividend payouts to their shareholders. Firms with a proactive average increase in financing their operating needs could maintain positive payouts to their shareholders. Overall, our evidence from state-level climate change [SLCC] shows that long-term climate risks impose severe impacts on firms' payout policies with a persistent predicted decrease in dividends paid to shareholders. The proneness to climate disasters could motivate suitable risk management for positive equity payouts to mitigate agency problems with positive signaling to shareholders about their growth prospects. Payout choices are related to other corporate policies, financial flexibility, and firm characteristics (Allen & Michaely, 2003; Bonaimé et al., 2013; Brav et al., 2005; Chay & Suh, 2009; Denis, 2011; Farre-Mensa et al., 2014; Jagannathan et al., 2000; Kahle & Stulz, 2021; Kumar & Vergara-Alert, 2020; Kuo et al., 2013; La Porta et al., 2000; Erik Lie, 2005; Michaely & Moin, 2022; Rapp et al., 2014; Zhou & Ruland, 2006) with (dis)appearing dividends.

The study contributes to related literature with the following critical contributions. This study offers critical contributions to the systematic effects of US state-level temperature anomaly dividend payout. For the US context, Dimitrios Gounopoulos and Yu Zhang (2024) employ data on county-level measures of temperature values, which are temporary climatic phenomena that firms could diversify those temporary risks with cash holdings and payout flexibility choices, as documented by Y. Chang et al. (2024). For the current study, we employ statewide temperature anomaly measures. The current study contributes to the extant literature by investigating the long-term systematic risk of climate change that firms may be unable to diversify its effects.

While temperature values capture current trends of climate change, temperature anomaly captures the deviation of current trends compared to the 30-year or more average temperature values. The measures used for the current study capture the systematic risk of long-term climate change rather than the current trends of temporary climatic phenomena. For the US state level, our study empirically shows that temperature anomaly benchmarks the effects of climate change over the recent decades back to the early 1970s. Global warming has appeared since the late 1900s and induced systematic adverse effects on corporate dividend policy for the US firms[10]. Due to potential climate-induced liquidity shortfalls, firms that are exposed to global warming reserve more cash, consequently paying less dividends to shareholders. This study contributes to the related literature, which attempts to quantify the impacts of climate-related risks ranging from drought risks (Adrian et al., 2023; Do et al., 2021; Huynh et al., 2020; Nguyen et al., 2022), temporary heating trends (Dimitrios Gounopoulos & Yu Zhang, 2024) to other physical climate risks (Ginglinger & Moreau, 2023; Huang et al., 2018).

As elaborated throughout the study, our findings complement the prior literature by suggesting that firms may face a significant challenge in diversifying long-term climate change risk. In other words, theoretically, systematic risk caused by temperature anomaly is undiversifiable by firms with their financing policies, as increasingly documented in emerging literature (Yuyuan Chang et al., 2024; Huang et al., 2018; S. Javadi et al., 2023; C.-C. Lee et al., 2023; Sang Ho Lee et al., 2023). Our evidence on the systematic risk of long-term climate change offers critical implications to established finance literature on corporate risk management and financial decisions (Arena & Julio, 2023; Bonaimé et al., 2013). Our findings offer critical findings to future literature on theoretical predictions for corporate risk management when firms are exposed to long-term systematic risks, compared to other risk factors (Dittmar, 2000; Grullon et al., 2002; Guay & Harford, 2000; Michaely & Moin, 2022).

The remaining parts of the study are structured as follows. Section 2 reviews the related literature and develops the hypothesis. Section 3 represents data, variables, and methodologies. Section 4

[10] Climate Change Indicators: U.S. and Global Temperature | US EPA

presents findings and related discussions. Section 5 concludes the main findings and implications.

## Literature Review and Hypotheses

### Literature Review

#### *Climate change and risk drivers.*

The theory of public goods acknowledges climate change as a negative externality (Nordhaus, 2019). The thorniness of climate change is reflected by its global consequences (Goulder & Pizer, 2006). Global externalities are defined as those whose impacts are indivisibly spreading worldwide and dissimilar from national or local public goods because of their resistance to the control of national governments and markets. Due to climate change, global warming is now the most noticeable environmental externality that threatens our planet. Between 1980 and 2018, losses from worldwide natural disasters amounted to around $ 270 billion as of 2022, with roughly 55% uninsured (Munich-RE, 2024).

The physical and transition risks are two channels through which climate change affects financial sectors. The physical risks raised by damage to infrastructure, land, and properties, and the transition risks caused by climate policies, technologies, and the sentiment of consumers and markets during the transition to a lower-carbon economy. Climate exposure varies across income groups and regions, where the high vulnerability of lower- and middle-income economies is typically due to physical risks (Grippa et al., 2019 ).

Physical risks can be directly exposed to financial institutions through their impacts on households, corporations, and countries that incur extreme climate events or through indirect channels through the impacts of climate change on the wider economy, with feedback effects within financial systems Grippa et al. (2019 ). The magnification of climate risks is presented through loan portfolios' increased default risk and decrease in asset values. Climate change also puts corporate credit portfolios at risk. For instance, the Wall Street Journal (Gold, 2019)[11] identified the first "climate-change bankruptcy" with California's largest utility company, Pacific Gas and Electric (PG&E), which put $5.4 billion in cash plus 22.19 percent of its stock into a trust for victims after the wildfires caused by the utility's equipment[12]. Prolonged droughts caused by rapid climatic changes that consequently increase the risk of fires from the operations of PG&E in California, leading to tighter financial conditions on bank lending, particularly in times of climate events, posing severe impacts on many institutions. For insurance sectors, physical risks are more crucial to the asset side for insurers and reinsurers. However, risks may also emerge from the liability side as claims from insurance policies can be generated at a higher frequency and with more severe consequences than normal. Evidence of increasing losses from natural disasters has already been defined, making insurance more expensive and unavailable in areas with higher climate risk exposure worldwide. Physical risks such as droughts and floods due to the increased likelihood of severe climatic events are previously considered uncorrelated, leading to decreased diversification in insurers, reinsurers, and banks due to climate change.

Transition risk drivers are societal shifts resulting from transitioning to a low-carbon economy. They can occur as a result of changes in public sector policies, innovation, and changes in the affordability of current technologies (for example, making renewable energies cheaper or allowing for the removal of atmospheric GHG emissions) or investor and consumer sentiment

[11] PG&E: The First Climate-Change Bankruptcy, Probably Not the Last - WSJ
[12] PG&E, Troubled California Utility, Emerges from Bankruptcy - The New York Times (nytimes.com)

toward a cleaner environment (BIS, 2021). While banks have been impacted by, and hence closely monitored by, these types of changes, the expected scale and simultaneous nature of transition-related developments have the potential to magnify the impact far more than previously thought[13]. Transition risks are important to the asset side of financial institutions that could experience losses due to climate change, to firms with business models not built around the economics of climate change, and toward a low-carbon economy. According to Bank of England Governor Mark Carney, if the estimate is approximately correct, it would induce those relying on being stranded or "literally unburnable" for fossil fuel firms in a world transitioning toward a low-carbon economy. Fossil fuel firms could experience a decline in earnings, disruption in businesses, and an increase in funding costs due to changes in climate policies, technologies, and the sentiment (demand) of consumers and investors for alignment with environmental policies to cope with climate risks. Not just fossil fuel firms, coal producers must deal with new climate policies to cope with global warming, and several large banks have committed to not deliver financing for new facilities for coal producers. So, how the mining industry can respond to the impact of climate change and the new environmental policies for decarbonization has increasingly been a discussion topic for every mining CEO over the past decade (Delevingne et al., 2020).

### *Climate change and global warming*

According to the Intergovernmental Panel on Climate Change reported by IPCC (2018), there has been an increase of 0.87 °C in the Earth's measured mean surface temperature since 1900. It is anticipated that the increasing rate of global warming will persist and lead to changes that will

[13] Climate policy success depends on transition risk mitigation | World Economic Forum (weforum.org)

affect all economies. Based on scientific evidence, it is highly likely that the primary cause of global warming is a rise in greenhouse gas concentrations in the atmosphere (IPCC, 2014). Moreover, if nothing is done to mitigate them, the warming brought on by human emissions will last for years to millennia (IPCC, 2018). Therefore, scientists advise economies to cut GHG emissions by transitioning to a "low-carbon" economy to lessen global warming and the severity of future climate change consequences (IPCC, 2014).

Global warming will increase if human emissions of GHGs persist. There will probably be more extreme precipitation occurrences and extreme temperatures around the mean.  (IPCC, 2014). Over long horizons, these physical hazards would continue to develop. They would include rising sea levels, more variable precipitation (Allen & Ingram, 2002; Solomon et al., 2009), more frequent wildfires (Abatzoglou et al., 2019), and recurrent and increasingly severe floods and increased frequency of extreme temperatures. Regarding BIS (2021), banks and the banking system are vulnerable to climate change via macroeconomic and microeconomic transmission channels, resulting from physical and transition risk drivers.

Global temperature increases can generate acute climate changes through repeated heat waves and wildfires (Abatzoglou et al., 2019; Jones et al., 2021) and the spread of forest fires (Abatzoglou & Williams, 2016), causing damage to fauna and to local economies. A warmer atmosphere can hold more moisture, which is expected with high confidence to increase heavy and concentrated precipitation in several regions (c). The increase in the severity of rainfall and its concentration over relatively short periods is expected to produce acute climate events, such as destructive flash floods that give rise to physical damage to properties, infrastructure, and agriculture. When associated with heatwaves, concentrated rainfall may increasingly result in periods of severe drought followed by periods of flooding in certain regions. This type of climate impact has the potential to generate, and in some cases has generated, significant and recurring financial losses.

Ocean acidification, average temperature increases, and rising sea levels are usually regarded as chronic physical threats. Prolonged temperature increases can potentially exacerbate long-term climate events like desertification. Likewise, prolonged elevated mean temperatures could also affect the ecosystem, namely the agricultural sector. Heatwaves claimed the lives of over 166,000 people between 1998 and 2017, with over 70,000 deaths occurring in Europe during the 2003 heatwave. There is a global trend towards an increase in the frequency, length, and size of extreme temperature events. There was an approximate 125 million increase in the number of people exposed to heatwaves between 2000 and 2016. Additionally, the IPCC issued a warning stating that rising temperatures will hasten the melting of glaciers and ice sheets, increasing sea levels (IPCC, 2019). IPCC estimates a carbon budget limiting global temperature rises to 2 degrees above pre-industrial levels, ranging from $1/5^{th}$ to $1/3^{rd}$ of the world's oil, gas, and coal reserves[14].

### *Climatic conditions and temperature anomalies in the United States*

Climatic conditions are diverse in the United States. For instance, South Florida and Hawaii have tropical conditions, while the Rocky Mountains and Alaska have alpine and arctic conditions. Temperatures present a strong gradient in the United States across seasons and regions. While the southern coastal states are hot, with very high temperatures that could exceed 21°C, the

[14] The IPCC provides the budgets predicted for future emissions that are dependent on proven assumptions about other drivers of climate change and the risk levels of temperatures increasing by more than 2 degrees that society is likely to accept. Visit Table 2.2 in the IPCC (2014), setting these in the context of current reserves of fossil fuel resources including oil, gas, and coal, at AR5 Synthesis Report: Climate Change 2014 (ipcc.ch).

northern states along the Canadian border have cooler conditions, with a great divergence between annual temperatures from 10 °C up to 50 °C in the winter and summer of the northern Great Plains. Similarly, precipitation is different by season and across the US states. Precipitation is measured at more than 127 cm annually along the Gulf of Mexico, while precipitation could be less than 30 cm in the Southwest and Intermountain West regions. The seasons for peak rainfall are extremely variable across the US. For instance, several regions in the Midwest and Great Plains have late-spring rainfall peaks, while the US states on the West Coast experience a distinct rainy season in winter. Many coastal Atlantic and Gulf regions have summertime peaks, and the North American monsoon in the summer affects the Desert Southwest. The United States is sensitive to many kinds of extreme weather, such as hurricanes and thunderstorms, that induce landfall along the Atlantic and Gulf coasts every decade. For any specific time, the United States could experience drought conditions affecting up to 20% of the country[15].

Also, climatic conditions in the United States present historical variations across the economy. According to NOAA[16], the US presents diverse microclimates and climates. For instance, the southern states, namely Arizona (AZ), California (CA), Texas (TX), Florida (FL), and California (CA) have annual average temperatures of at least 70 degrees. The rainfall amounts are also divergent, from just 10 inches or less in the Southwest region to more than 50 inches for the rainfall amount in Florida. North Dakota and South Dakota regions present yearly droughts comparable to New Mexico (NM). Parts of the mountains, including isolated ridges and plateaus, are wetter than their neighboring lowlands. The most extreme wet conditions are shown in Washington (WA) and Oregon (OR), where the Cascade Ranges and Coast in the west are eight

[15] United States - Climatology | Climate Change Knowledge Portal (worldbank.org)
[16] New maps of annual average temperature and precipitation from the U.S. Climate Normals | NOAA Climate.gov

times wetter than parts of the Columbia River Plateau to the east. By contrast, the local areas of the Appalachian Mountains, ranging from the North to the South in the East, show less dramatic contrasts, including New Hampshire's White Mountains, West Virginia's Alleghenies, and the intersection areas of North Carolina (NC), South Carolina (SC), and Georgia (GA).

The rich divergence of climatic conditions is present across the US states and is volatile over time, in the era of global warming, in particular[17]. The annual average temperatures have changed in the contiguous 48 US states since 1901. EPA records that the average surface temperature for the US contiguous 48 states has increased at a mean rate of 0.17°F per decade since 1901[18]. The average temperatures have increased faster since the late 1970s (from 0.32 to 0.55 °F per decade since 1979). Nine of the ten recorded warmest years have occurred since 1998 across the contiguous 48 states; 2012 and 2016 were the two warmest recorded years. Compared to the temperature worldwide, the United States has warmed faster than the global rate since the late 1970s. Furthermore, some parts of the United States have experienced even more warming than others. States, including the North, the West, and Alaska, have exhibited the most temperature increases, while the Southeast, with its parts, has experienced little change in temperature.

### *Climate risks and corporate policies*

Emerging literature has documented the links between climate risks and corporate policies. Severe climatic conditions, such as heat waves, flooding, storms, etc., adversely affect corporate

[17] Global Warming (nationalgeographic.org)
[18] Climate Change Indicators: U.S. and Global Temperature | US EPA with the surface data extracted from the stations for land-based weather. The measurements of the satellite cover the lower troposphere, the lowest level of the Earth's atmosphere. "UAH" and "RSS" represent two different analytical approaches for the measurement of the original satellite. Regarding EPA, this graph uses the 1901–2000 average temperature as a baseline for depicting change and selecting another baseline period would not make a difference in the shape of the data over time.

retained earnings and cash flows. Using the country climate risk index, firms located in countries with more frequent, severe climatic conditions are more likely to hold cash to attain corporate resilience with potential financial slack due to higher climate risk exposure.  (Huang et al., 2018). Those firms likely have more long-term debt than short-term debt and are unlikely to make dividend payouts in cash. Extreme weather is less severe in some specific industries, leading to lower climate risk exposure than high-climate-sensitive industries, including energy (mining and oil extraction), agriculture, healthcare, communications, food products, transportation, and business services. The effects of climate physical risk on corporate capital structure in the US, leading to a decrease in leverage (Ginglinger & Moreau, 2023). The Kyoto Protocol ratification in Australia impedes corporate leverage, and polluting firms suffer from financial distress risk (Nguyen & Phan, 2020). The ratification of the Kyoto Protocol also leads to lower financial performance for carbon-intensive firms.

Firms' carbon risk exposure has received increasing attention in business. The Carbon Disclosure Project (dividend payout) survey reports that firms may experience an increase in the cost of debt if they, especially carbon-intensive firms, are unwilling or fail to respond to the dividend payout survey (Jung et al., 2018). Not just associated with higher debt financing costs, carbon risk adversely affects corporate investment, and more extreme impacts are exposed to higher carbon-intensive firms, leading to changes in financial constraints, including firm size, age, and dividend payout (Phan et al., 2022). Consequently, the emissions trading scheme (ETS) puts a price on greenhouse gases for eco-friendly behavior. For example, Australia introduced the National Greenhouse and Energy Reporting Act 2007 (NGER Act) to disseminate and report information related to greenhouse gas projects, emission intensity, energy consumption, production, etc.[19], in which banks consider carbon risk in their lending decisions. Modern banking needs to be extended for additional considerations on issues such as the corporate social responsibility (CSR) reputation of banks on lending practices (Herbohn et al., 2019). The study highlights the value of banks as financial intermediaries in the context of asymmetric information about firms' carbon risk exposure.

Furthermore, the literature highlights that high carbon emissions may induce a decrease in firms' market value (Clarkson et al., 2015; Griffin et al., 2017; Matsumura et al., 2014). CSR is positively associated with firm value, lowering the cost of equity, and increasing earnings persistence (Gregory et al., 2014). Overall, it is inevitable that climate risks pose threats to financial markets. However, on the bright side, we could acknowledge that such threats provide institutions and economies to pursue a more sustainable path for economic development. Giglio, Kelly, et al. (2021) elaborate on diverse approaches in microfinance models incorporating climate change risks in the asset pricing context with various asset classes such as equities, fixed-income securities, and real estate, and show how investors structure their investment portfolios to hedge climate risks.

### Hypotheses

The sensitivity to climate change makes corporate earnings volatile and, consequently, causes potential liquidity shortfalls and divergent financing choices. (Ginglinger & Moreau, 2023; Huang et al., 2018; Nguyen, 2018; Nguyen & Phan, 2020). Extreme climate conditions, such as drought risks, induce firms to incur a higher cost of equity capital due to their drought duration and intensity (Huynh et al., 2020). Under such severe climate-induced risks, firms reinvest more

[19] National Greenhouse and Energy Reporting Act 2007 (legislation.gov.au)

cash and increase their corporate diversification to attenuate the impacts of drought risks. Such climatic conditions also adversely affect corporate leverage and the speed of leverage adjustment in the US (Nguyen et al., 2022), highlighting the roles of cash holdings in coping with environmental externalities.

Many studies show the importance of corporate payout policy, such as dividends (as well as share repurchases), which represent substantial cash outflows from firms to shareholders (Allen & Michaely, 2003; DeAngelo & DeAngelo, 2007; Farre-Mensa et al., 2014; Kahle & Stulz, 2021). The explanations for dividend policy range from the agency theory of Jensen (1986) to the signaling hypothesis (JOHN & WILLIAMS, 1985; MILLER & ROCK, 1985), clientele (Allen et al., 2000; Shefrin & Statman, 1984), catering (Baker & Wurgler, 2004; Desai & Jin, 2011), and life cycle (DeAngelo et al., 2006; Faff et al., 2016; Zhou & Ruland, 2006). Like any other climate-related D. Gounopoulos and Y. Zhang (2024)incidences, anomalies in temperature are more likely to increase the financial risk that firms face. The physical and transition risks related to such anomalies are more likely to affect firms' strategies and operations, resulting in extra costs and further reducing profitability and earnings. Increased cash holdings are the mechanisms for firms to safeguard against potential liquidity shocks due to climate risks (Dimitrios Gounopoulos & Yu Zhang, 2024; Siamak Javadi et al., 2023). Such financial risks may lead to the distribution of earnings to shareholders in the form of dividends. Yuyuan Chang et al. (2024), using a large sample of 45 countries, show that firms reduce their cash dividends by substituting dividends with repurchases in response to higher climate risk. D. Gounopoulos and Y. Zhang (2024) use local temperature trends by county in the U.S. as a proxy for climate uncertainty and find that firms increase their cash holdings in response to such risks. While dividend policy is a mechanism to mitigate agency problems, the effects of climate change on dividend payout might be costly for firms exposed to climate risk, inducing a higher cost of equity (Huynh et al., 2020). Due to such systemic effects of climate change on firm performance and cash holdings to hedge against potential earnings uncertainty, we propose the following hypotheses:

**H1:** Increased temperature anomaly is associated with decreased corporate dividend payout in the US states.

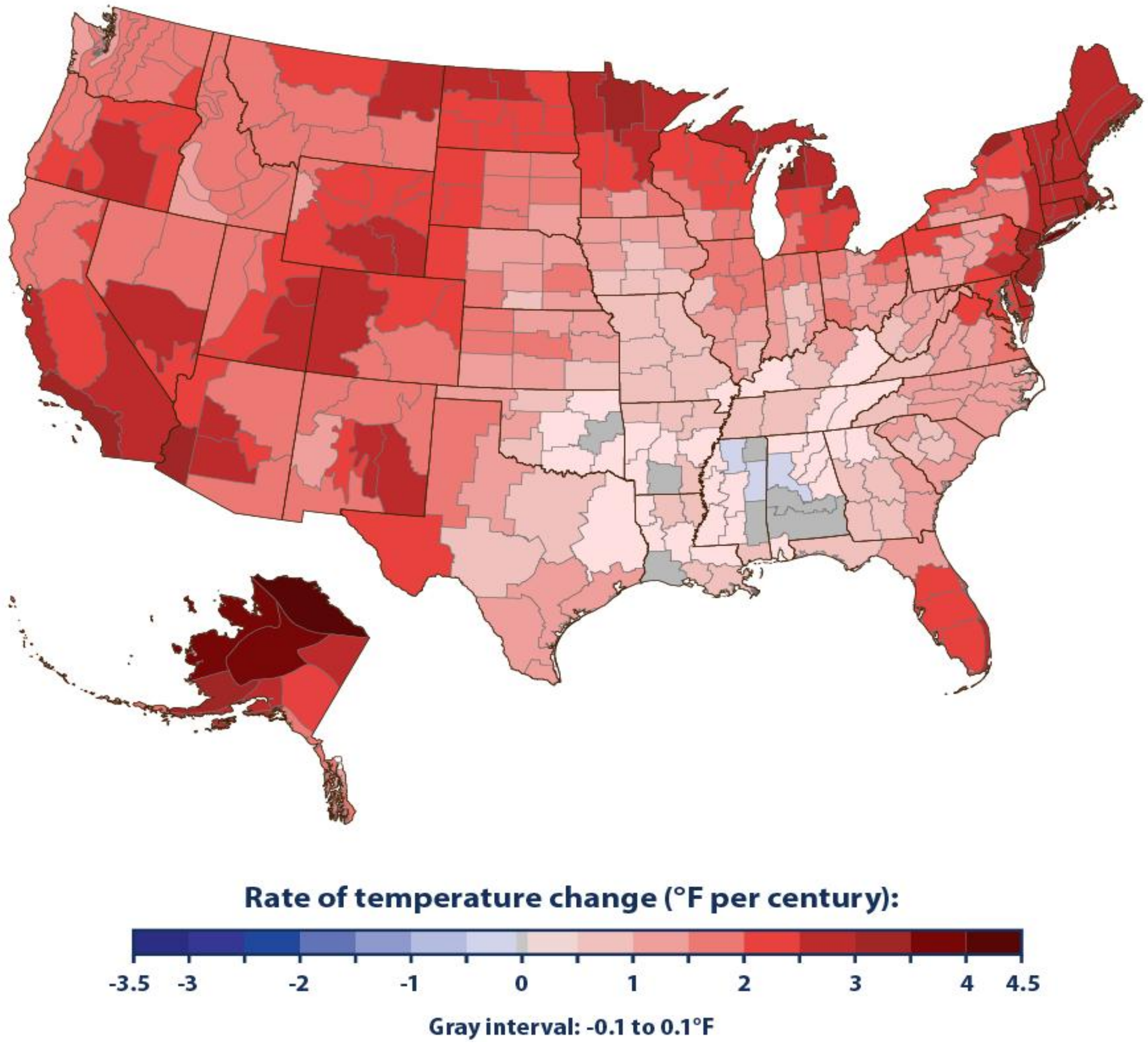


**Figure 1:** US state-level temperature change rate. Source: Adapted from NOAA, 2022[20].

Corporate liquidity is critical to firms under climate risk exposure (D. Gounopoulos & Y. Zhang, 2024; S. Javadi et al., 2023; Li & Wan, 2024). Since the Stern review, an exogenous shock to a firm's climate change awareness, firms with higher exposure to transition risk are likely to hoard cash (S. Javadi et al., 2023). Regarding the precautionary motive, the study suggests that cash reserves are critical to firms in safeguarding them from the adverse impacts of climate change that lead to financial constraints. For temperature trends, hoarding cash is empirically exhibited to be a hedging policy for firms exposed to heatwaves (D. Gounopoulos & Y. Zhang, 2024). The study shows that environmental enforcement and physical risk are the two channels to explain firms' cash management given temperature trends. The roles of cash holdings are evident from Emission Trading Schemes (ETS) (Sakariyahu et al., 2023). The study argues that ETS-member firms hoard cash to mitigate financial climate-induced risks with possible investment opportunities while meeting regulatory costs. Increasing cash reserves under climate change exposure could be a rational decision under the potential impacts of climate risk drivers for the following reasons. External financing choices could be even more costly under climate change exposure (S. Javadi & A. A. Masum, 2021), and climate risks could deteriorate bank liquidity creation  (Xu et al., 2024). Therefore, climate change could indirectly affect firms' access to credit, and cash holdings might serve as a possible solution. Also, deleveraging is a reliable choice for firms to secure their ample financial flexibility because financial leverage could be challenging for firms to reconcile (DeAngelo et al., 2017). Consequently, cash holdings and leverage adjustments could be a reliable choice for firms to deal with climate change impacts, hedging demand and supply effects. Trade credit is an alternative financing decision for firms. Firms could rely more on trade credit when banking crises emerge, causing reduced credit lines with weak creditors (Li et al., 2024). Firms with quality-disclosed CSR practices could improve financing capacity through trade credit (Cai & Huang, 2024). Trade credit could play a crucial role in the impacts of fiscal policy uncertainty on corporate financial leverage (Bhatia et al., 2024). Under climate change uncertainty, firms could significantly limit trade credit provision (Cao et al., 2024). The study posits that a firm's adjustment to its trade credit policy is due to the managerial prediction of associated costs caused by physical damage instead of regulatory costs. Carbon assurance supports firms with increasing trade credit from suppliers with reduced risk and asymmetric information (Safiullah & Nguyen, 2024). As payout policies are closely linked to other financing decisions (Allen & Michaely, 2003; Brav et al., 2005; DeAngelo et al., 2008), our second hypothesis is below.

**H2:** The impacts of climate risk on dividend policy are mediated by corporate cash holdings, trade credit, and market leverage policies.

Since the Paris Agreement, for the US and global equity markets, investors have cared more about firms' environmental performance (Bolton & Kacperczyk, 2021; P. Bolton & M. Kacperczyk, 2023). The studies show that investors demand a premium for carbon-intensive firms. Polluting firms are subject to lower financial leverage (Nguyen & Phan, 2020). Employing Australia's Kyoto Protocol ratification, Nguyen and Phan (2020) show that climate policy reduces carbon-intensive firms ' access to credit with decreased financial leverage. With decreased leverage, climate policy could induce corporate financial constraints and distress risk to polluting firms. Since the Paris Agreement, Ginglinger and Moreau (2023) show that firms' deleveraging is caused by both the demand side (optimal capital structure) and the supply side (higher lending spreads), leading to costly operations and financial distress. Transition risk (e.g., environmental policy stringency) does matter to corporate leverage adjustment (Lee et al., 2024). The effects could be prominent for firms with higher financial constraints and located in places with significantly higher climate change exposure. In the US, there are states where firms are located experiencing long-term proneness to natural disasters (e.g., disaster-prone states, abbreviated as DPS), and such physical risks induce distress costs to firms (Ginglinger & Moreau, 2023). Corporate payout choices are adjustable to maintain financial flexibility based on corporate operating performance  (E. Lie, 2005). While corporate liquidity is critical to firms when they are prone to climate risks (D. Gounopoulos & Y. Zhang, 2024; S. Javadi et al., 2023; S. H. Lee et al., 2023), investors could specialize in firms with excessive cash, problematic ESG reputation, and no payouts (Wong & Zhang, 2024). Therefore, payout policies could play influential roles in mitigating the antipathy of shareholders to firms with excessive cash for reliable reasons (e.g., firms maintain higher liquidity to hedge climate risks, etc.). Instead of paying dividends, firms might repurchase more shares for flexible payout choices under climate risks (Yuyuan Chang et al., 2024), and payout policy is critical to firms' risk management and financial flexibility (Bonaimé et al., 2013; Denis, 2011). Given that firms are increasingly vulnerable to climate change impacts, based on the related literature discussed, our third hypothesis is as follows.

**H3:** The Paris Agreement, proneness to disasters, and corporate vulnerability moderate the impacts of SLTA on corporate dividend policy.

Aligned with prior literature, the Paris Agreement (COP21) is a timed dummy variable that is set equal to 1 for the years after COP21 was adopted in 2015; otherwise, it is set equal to 0. COP21 is critical to test, regardless of the complex commitment of the US to our global climate action[21]. Carbon premium has been increasingly demanded by investors since the COP21 (Bolton &

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[21] Climate change: US formally withdraws from Paris agreement; The United States Officially Rejoins the Paris Agreement - United States Department of State

Kacperczyk, 2021; P. Bolton & M. Kacperczyk, 2023). Also, payout policy conveys signals about a firm's growth prospects to investors (Allen & Michaely, 2003; Brav et al., 2005). Therefore, COP21 could present a possible moderation to the impacts of SLTA on corporate payout policy.

The study follows the US News and World Report to identify US states that are chronically prone to climate disaster risks[22]. The study classifies disaster-prone states (DPS) and sets our DPS dummy equal to 1 if a firm is headquartered in a US state that is prone to natural disasters; otherwise, it is set equal to 0.  The US's most disaster-prone states include 1) Texas, 2) California, 3) Oklahoma, 4) Washington, 5) Florida, 6) Oregon, 7) New York, 8) New Mexico, 9) Arizona, 10) Colorado, and Nevada (tie). While Yuyuan Chang et al. (2024) examine the temporary impacts of climate-related events with disaster events, we control for the long-term proneness of firms to state-level natural disasters. Our tests for DPS aim to provide the following complementarities, plus added novelties. First, the payout policy is critical to mitigating agency problems (Allen & Michaely, 2003; Brav et al., 2005). Hence, firms located in DPS could have more well-prepared risk management to maintain possible payouts to shareholders. Second, assuming that a firm is in a chronic disaster-prone state, should the firm ignore payouts all?  The first possible answer is that it depends on diverse determinants of corporate payouts in the literature. The second possible rationale is that it should not always be the case, as no payouts could raise agency problems with signaling effects on firms' growth prospects related to the literature on (dis)appearing dividends (Fama & French, 2001; Fatemi & Bildik, 2012; Kuo et al., 2013; Michaely & Moin, 2022). Therefore, controlling for DPS provides insightful empirical

[22] See, the US News and World Report The Most Disaster-Prone States in the U.S.[22]

findings to mitigate biased interpretations caused by endogeneity, reflecting the long-term nature of climate change risks for this study.

Consistent with related literature (Nguyen & Phan, 2020), the study defines the vulnerability of firms to carbon transitional risk by employing a dummy variable that is set equal to 1 for firms that are polluting; otherwise, we set our dummy variable equal to 0. Vulnerable firms (i.e., polluting firms) are not just carbon-intensive with great vulnerability to climate risks, but are also prone to biodiversity risks (Giglio et al., 2023). Regarding prior literature (Ginglinger & Moreau, 2023; Sautner et al., 2023), corporate vulnerability (e.g., polluting firms, etc.) is sensitive to climate risk drivers with expected moderation to dividend payout under SLTA where firms are located. Therefore, potential moderations are hypothesized to provide in-depth investigations and serve as an additional robustness check for the association between STLA and corporate dividend policy. Based on GIC sectors [GSECTOR code in CUMPUSTAT]. Firms belonging to the following sectors are classified as vulnerable firms (Vulnerability): 1) Energy (GIC code = 10), 2) Materials (GIC code = 15), Industrials (GIC code = 20), and 4) Utilities (GIC code = 55)[23]. It is critical to examine the potential moderation of corporate vulnerability for the following reasons. While carbon-intensive firms might attract higher awareness of stakeholders to their environmental performance (Bolton & Kacperczyk, 2021; P. Bolton & M. Kacperczyk, 2023) with possible decreased leverage under stringent climate policies (Lee et al., 2024), payout policies are adjustably conditional on corporate operating performance (E. Lie, 2005). In the context of Australia, polluting firms have exhibited lower leverage since the Kyoto Protocol (Nguyen & Phan, 2020); however, polluting firms contribute a large fraction of the

[23] GICS® - Global Industry Classification Standard - MSCI; The Global Industry Classification Standard (GICS) - Classification.Codes; GICS®: Global Industry Classification Standard | S&P Dow Jones Indices

country's gross domestic product (GDP) to economic growth[24]. Consequently, the rationale is questionable that the lower leverage of polluting firms is driven by either stringent climate policies or financial flexibility, or both. While the polluting levels of firms are subject to transition risks (e.g., investors, policies, etc.), climate physical risks impose widespread impacts on firms and the wider economy worldwide. Therefore, we test corporate vulnerability to i) provide more insightful findings with mitigated endogeneity issues and ii) robustly check the impacts of SLTA on corporate payout policy with a possible moderation of corporate vulnerability. Overall, we aim to highlight the long-term consequences of SLTA benchmarking climate change risks across the US states.

## Data and Methodology

### Data

We extract data from multiple sources. We first extract data on statewide monthly temperature series from the National Centers for Environmental Information of the National Oceanic and Atmospheric Administration (NCEI-NOAA)[25]. The webpage provides monthly statewide time series for temperature values and anomalies within the US states from 1985 onward. The temperature data are available for 49 states across the US. We extract firm-level financial accounting data from COMPUSTAT - Capital IQ, offered by Wharton Research Data Services (WRDS)[26]. Consistent with the literature on corporate payouts and data availability, we collect a

[24] See Composition of the Australian Economy Snapshot | Education | RBA
[25] National Centers for Environmental Information (NCEI) (noaa.gov)
[26] We use the licensed account for PhD candidate/Doctoral Researcher offered by the School of Economics and Finance, Massey University, Private Bag 11 222 Palmerston North, 4442, New Zealand.

comprehensive coverage of US firms from 1971 to 2020[27]. We exclude financial and utility firms with SICs between 6000-6999 and 4000-4949, respectively. We further exclude firms with missing data on dividend payout (DV), total assets (AT), and market capitalization (CSHO and PRCC_F). Our unbalanced panel data includes 20,144 listed firms for the US, with data on state locations (STATE) available for the sample firms. Given the data available on monthly statewide time series for temperature anomaly, our final merged panel data includes 49 US states with 220,658 state-firm-year observations for the US between 1971 and 2020.

## Methodology

We investigate the association between US state-level temperature anomalies and corporate dividend payout (dividend payout) by proposing the following linear regression model:

$$DIVIDEND_{i,j,t} = \alpha + \beta_1 TEMPERATURE\_ANOMALY_{i,j,t-1} + \beta_k \sum_{i=0}^{n} X_{i,j,t-1} + \emptyset + \partial + \varepsilon_{i,j,t} \quad (1)$$

$DIVIDEND_{i,j,t}$ is the total amount of dividends as a fraction of the total assets of firm $i$ from state $j$ at year $t$. Following related literature (Chay & Suh, 2009; HAIL et al., 2014; Hossain et al., 2023; Zhou & Ruland, 2006), the study uses alternative dividend policy measures, including dividends as a fraction of common shares outstanding (CSHO), dividends to Sales, and the logarithm of one plus dividends. $TEMPERATURE\_ANOMALY_{i,j,t-1}$ is the temperature anomaly

[27] We stop our sample period at 2020 to mitigate the unexpected impacts of the post Covid-19 period on corporate payouts/ Please find WHO Coronavirus (COVID-19) Dashboard | WHO Coronavirus (COVID-19) Dashboard With Vaccination Data

by state *j* where the firm *i* is in year *t-1*, defined as the difference between the state-level temperature in which the firm is located and a baseline/average temperature following NCEI-NOAA. The baseline temperature is normally estimated by an average of 30 or more years of temperature data. A positive anomaly implies a warmer temperature relative to the baseline, while a negative anomaly represents a cooler temperature relative to the baseline within the US states[28].

The study follows the related literature on corporate payout (Chay & Suh, 2009; DeAngelo et al., 2006; Kahle & Stulz, 2021) to include a comprehensive set of control variables $X_{i,j,t-1}$. The control variables include firm size (log of assets total), tangibility, operating income to assets, net income to assets total, capital expenditures to assets total, acquisitions to assets total, research and development expenditure to assets total, selling, the general and administrative expense to sales, advertising expenses to sales, Tobin's Q, cash holdings, book and market leverage ratios, operating cash flow to assets total, interest and related expense to assets total, income taxes to assets, free cash flow to assets total, change in debt to assets total and change in cash to assets total (Kahle & Stulz, 2021). We control the fixed effects for time (year), industry (SIC codes), and firms' location (STATE) levels. The standard errors are clustered by firm. Regarding related finance panel regressions, the study follows a common practice of adjusting standard errors for possible correlation across firms (Ginglinger & Moreau, 2023; Huynh et al., 2020; Nguyen & Phan, 2020; Nguyen et al., 2022; Thompson, 2011). The study presents detailed variables, descriptions, and sources in the Appendix (Table A1).

[28] Anomalies vs. Temperature | Did You Know? | National Centers for Environmental Information (NCEI) (noaa.gov)

## Empirical results

### Summary statistics

Table 1 reports descriptive statistics of the variables. Our full sample includes 147,836 state-firm-year observations. State-Level Temperature Anomaly [SLTA] presents a mean value of 0.9029, ranging from -1.9167 for the minimum value to 4.2500 for the maximum value, with a standard deviation of 1.3094. The median value of SLTA is 0.7500. Our findings show that our sample firms have experienced global warming over the recent decades. Statistically speaking, on a state-level average, our sample firms experience an abnormally warmer temperature of 0.9029 Fahrenheit - °F, compared to their 1901-2000 baseline temperature. Over the sample period from 1971 onward, our sample firms experienced the coolest abnormal temperature of -1.9167°F and abnormally hottest abnormal temperature of 4.2500°F. With a median abnormal temperature of 0.7500, overall, our sample firms experience global warming where their headquarters are located across the US states, with a standard deviation of 1.3094. While prior studies look at temporary climate change along with its short-term climatic outcomes (Dimitrios Gounopoulos & Yu Zhang, 2024; Huang et al., 2018), our current study shows abnormal temperature values that benchmark long-term climate change, showing the divergence between current temperature values and their baseline 30-year average temperature values. Such anomalies have led to more severe physical risks with higher frequency in recent decades, with diverse kinds of natural disasters (Adrian et al., 2023; Blanco et al., 2024; Gu & Hale, 2023; Huang et al., 2018; Jha et al., 2021; Keerthiratne & Tol, 2017; Klomp, 2014; Mallucci, 2022; Munich-RE, 2024). The very first and substantial difference that the current study brings to prior studies is that we employ more benchmarked measures for capturing long-term climate change, which is geographically divergent to firms located across the US states, see NCEI-NOAA

(2024a, 2024b); Stern (2008); Tol (2024). Furthermore, global warming with abnormally high temperatures induces abnormal drought risks that have been recently used in related literature (Adrian et al., 2023; Do et al., 2021; Huynh et al., 2020; S. Javadi & A.-A. Masum, 2021; Nguyen et al., 2022). Drought risks, biodiversity issues, and our ecosystems are shaped by temperature (NCEI-NOAA, 2024a, 2024b); therefore, temperature anomalies benchmark climate change in a multidimensional manner[29].

[Table 1 Inserted Here]

In the context of SLTA, which indicates widespread global warming in the US, our sample firms exhibit a mean value of common ordinary dividends to assets of 0.0077 with a standard deviation of 0.0151, ranging from 0.0000 for the minimum value to 0.0851 for the maximum value. With the median value [p50] of 0.0000, it seems our sample firms' dividends are disappearing. Disappearing dividends remain a case for our sample firms when we take the fraction of dividends to firms' common shares outstanding, sales, and the logarithm value of dividends commonly paid to shareholders. Share repurchases to assets total exhibit a mean value of 0.0100 with a standard deviation of 0.0293, ranging from 0.0000 for the minimum value to 0.1886 for the maximum value. The median value of share repurchases to assets is 0.0000. For payout flexibility, where firms' share repurchases are divided by their total payouts, presents a mean value of 0.4085, ranging from 0.0000 for the minimum value to 1.0000 for the maximum value, with a standard deviation of 0.4404. While prior literature argues that disappearing dividends are strongly correlated with firm characteristics, corporate life cycle, and volatile earnings (Fama &

[29] To some extent, we could acknowledge the cofounding effects of diverse kinds of climate risks with timely market responses. Abnormal temperature leans our focus to the long-term systematic consequences of climate change. Regarding the Paris Agreement, our goal is to limit the increase in our global temperature to 1.5°C and mitigate global warming by the end of this century. See, The Paris Agreement | UNFCCC

French, 2001; Fatemi & Bildik, 2012; Kuo et al., 2013; Michaely & Moin, 2022). So, what causes such correlations? Our initial findings imply the contribution of climate change, SLTA more specifically, for this current to be a possible important determinant of corporate payout policy, which is interactive with other corporate policies. The study provides trend plots for US statewide temperature anomaly, as presented in Figures 1-5.

### Regression results

Table 2 reports the results of the baseline ordinary least-squares linear (OLS) regression in equation (1), where corporate dividend payout is defined as cash dividend/assets (DIVIDEND) is regressed on the US state-level temperature anomaly (TEMPERATURE ANOMALY) along with a comprehensive set of firm characteristics. All control variables, including the temperature anomaly, are lagged by one year. We include year, industry, and state-level fixed effects. The standard errors are clustered around firms. As lagged variables represent historical values, the inclusion is a common practice in related finance literature on quantifying dynamic relationships in which current outcomes of our dependent variable of interest are influenced by historical values of explanatory variables.

Columns 1 and 2 report the coefficient estimates of temperature anomaly without and with the control variables, respectively. Irrespective of the inclusion of the control variables, the coefficient of temperature anomaly is -0.0001 and highly statistically significant, which means a one-degree increase in temperature anomaly induces firms to decrease dividend payout by approximately -0.01%. This effect is also economically significant: a one standard deviation change in temperature anomaly implies a decrease equal to 1.63% [(0.0001×1.307)/0.008] of the mean dividend payout or a 0.007 [(0.0001×1.307)/0.018] standard deviation decrease in dividends[30].

Under state-level climate change exposure [SLCCE], we consistently follow the literature with a set of control variables included for the study including Firm Size, Book to Market, Tobin's Q, capital expenditure (Capex), Research and Development Expenditure to Assets (R&D to Assets), Leverage, Operating Cash Flow; Selling, General and Administrative (Sga to Sales), and Advertising Expense to Sales (Xad to Sales) and additional literature-based control variables (Brav et al., 2005; Farre-Mensa et al., 2014; Hanlon & Hoopes, 2014; Huynh et al., 2020; Kahle & Stulz, 2021). Changes in dividends convey a signal about the current and potential prospects of firms. Miller and Modigliani (1961) provide a detailed discussion on factors influencing firms' dividend payouts that signal information about dividends paid to shareholders. Dividend policy also conveys reasons that investors might interpret as a proxy for changes in the management boards' points of view about firms' prospects. Such signaling information conveyed by firms' dividend policy changes is formalized as dividend signaling models (JOHN & WILLIAMS, 1985; MILLER & ROCK, 1985). In the context of SLCCE, our baseline regressions show that firms with larger book assets and higher book-to-market [BM] ratios become conservative in their dividends paid to shareholders. Given changes in state-level temperature anomalies [SLTA], the conservativeness of increasing dividends by larger firms with higher BM ratios remains constant when we test for warmer and abnormal cooler temperature anomalies.

[30] As the study investigates the long-term systematic risk caused by statewide temperature anomaly measures, our predicted findings may imply that firms may not respond significantly to long-term climate change risk compared to extreme climate events in the literature.

Our baseline findings convey managerial optimism about the prospects of our sample firms for being sensitive to climate change across the US states. Given the consciousness of firms to SLTA, firms with promising investment opportunities, higher investments in corporate innovation [R&D], higher leverage, higher operating cash flow, and higher selling, general, and administrative expenses are likely to decrease dividends. Our baseline findings imply that SLCCE affects firms' managerial optimism about their prospects, leading to a predicted decrease in dividends. In other words, when firms are exposed to SLTA, climate risks with predicted decreases in dividends induce firms 'managers to expect unsound firm performance in the future. With signaling models discussed earlier, the findings imply a long-term climate-induced deterioration in the growth prospects of our sample firms with their subsequent dividend reduction.

Regarding FAMA and FRENCH (1995) with a rational pricing model, a higher BM ratio conveys poor, persistent earnings. Such forecasts about substandard earnings by firms could be explained further by firms' subsequent dividend reductions given a unit increase in SLTA that embarks on climate change across the US states. With a lower propensity to pay dividends when firm characteristics are changing (Fama & French, 2001), the findings are aligned with prior literature by showing a fall in corporate dividends when publicly listed firms have been increasingly exposed to SLCC over the recent decades. In the context of SLTA, climate change could induce firms with low profitability and retained growth opportunities to ignore dividend payouts. Given the sample period starting from the late 1970s, regardless of whether firms' characteristics are changing, our evidence from SLCCE supports Fama and French (2001) by showing that listed firms have a low motivation to make dividend payouts.

[Table 2 Inserted Here]

Regarding the life-cycle theory, DeAngelo et al. (2006) argue that the proportion of publicly listed firms with dividends paid is only high when their retained earnings cover a large portion of equity and total assets. The fraction of dividends paid by firms to their shareholders decreases toward zero when their equity is distributed rather than earned. While dividend payouts could follow a firm's life cycle, in the context of climate change, dividend omissions could be a case for firms for the following reasons. On the supply side, climate risks induce higher volatility in a firm's retained earnings. Therefore, even large firms would become conservative in the amounts of dividends paid to shareholders (Huang et al., 2018). For locations that are prone to natural disasters due to climate risks, such consequences could induce the volatility of retained earnings of firms even more severely, leading to a lower propensity to pay dividends[31]. For different levels of earned/distributed capital mix, such physical risks might impose expected losses on larger firms with higher tangibility. Given the vulnerability of corporate tangibility, which firms might use to support more borrowings and further investments (Almeida & Campello, 2007), the investment-cash flow nexus could be more sensitive when firms' asset tangibility is exposed to severe climate change. in other words, larger firms might face a greater challenge in using tangible assets as a credit multiplier. With increasing awareness of investors about climate risks, costly external finance could demotivate firms to borrow more (Chava, 2014; Ginglinger & Moreau, 2023; S. Javadi & A.-A. Masum, 2021). Our evidence on SLCCE could support prior literature by documenting the long-term consequences of climate change on the effects of asset tangibility on firms' investment–cash flow sensitivity (Moshirian et al., 2017).  Dividends are disappearing; our findings complement prior literature with empirical novelties added, showing

[31] See Billion-Dollar Weather and Climate Disasters | United States Summary | National Centers for Environmental Information (NCEI) (noaa.gov)

that the impacts of SLCC on corporate payout policy are significant for firms at the later stages of their life cycle.

The findings show that large firms are highly sensitive to climate risks. Given volatile retained earnings due to climate risks (Huang et al., 2018), paying fewer dividends to optimize corporate liquidity seems a reliable choice for firms in dealing with SLTA, see Yuyuan Chang et al. (2024); Denis (2011); Dimitrios Gounopoulos and Yu Zhang (2024); Siamak Javadi et al. (2023). Regarding DeAngelo et al. (2006); Fama and French (2001); Grullon et al. (2002), our baseline findings initially explain the impacts of SLCC on corporate dividend policy, with their consequences becoming even severe and larger in more mature firms in later stages of the life cycle. Not just younger firms with higher growth opportunities, the impacts of climate change, SLTA, here in our case, could impose significant risks on larger firms with more constant retained earnings to become conservative in their dividend payouts. Our baseline findings imply widespread and long-term consequences of climate change for firms to deal with in the form of their payout policies to be more resilient.

Since our temperature is calculated as the difference from the 30-year temperature average, the (negative) positive values imply the (cooler) hotter temperature average. We investigate the impacts of positive and abnormal temperatures (Abnormal warmer and abnormal cooler) on dividend payout. Results reported in columns (3) and (4) show that abnormal warmer temperature anomalies are negatively associated with dividend payout as the coefficient estimates are -0.0002 and 0.0002, respectively, with statistical significance at the 1% level. A positive coefficient estimate of the abnormal cooler is because the values of this variable are all negative. Our results indicate that an increase in abnormal temperature, irrespective of abnormal warming or cooling, induces farms to pay less dividends.

## Robustness Check

In this section, we check the robustness of our baseline findings with alternative measures of dividend payout, additional controls, economic conditions across states, and alternative payout methods like share repurchases.

### Alternative measures of dividends

The study is comparable to recent literature on corporate dividend policy (Hossain et al., 2023). The study employs the measures of Dividend to Shares, Dividend to Sales, and Log of Dividend as alternative measures to Dividend to Assets for our dependent variable of interest. Regarding the literature, we use these three alternative measures to quantify firms' dividend policies because they are related to the magnitude of *dividend payments. Our employment of alternative dividend measures is motivated by La Porta et al. (2000). T*he authors make use of dividends scaled by firms' revenue/sales earned as a commonly used measure of dividend payouts. Our measures for corporate dividend payouts are consistent with Chay and Suh (2009) by capturing corporate dividend policy as the dividend payout ratio measured as firms' cash dividends declared on their common/ordinary shares (DVC), see also Attig et al. (2021); Brockman and Unlu (2009).

We use three alternative measures of dividends: dividend/common share outstanding (dividend per share), dividend/sales, and log(1+dividend). Results reported in columns (1) to (3) in Panel A of Table 3 show that the coefficient estimates of temperature anomaly are statistically significantly negative, at least at the 5% level for all measures.

[Table 3 Inserted Here]

### Additional controls

Prior studies on corporate payout and agency problems suggest that firms conduct payouts to mitigate prospective overinvestment practices by a firm's management (Farre-Mensa et al., 2014). Payouts are increased when firms become mature, and higher amounts of repurchases and dividends paid by firms are appreciated with more free cash flow [FCF]. Agency problem models motivate our study to include FCF to investigate how agency-based models apply to firms' payout policy when they are exposed to SLCC.  Finance literature has paid attention to the paths that a firm's payout policy could be affected by potential conflicts of interest between a firm's management board and its shareholders, which is known as a free cash flow problem; see prior established studies by Easterbrook (1984); Jensen (1986); Jensen and Meckling (1976). Furthermore, such potential conflicts could drive corporate payout choices with potential conflicts between minority and majority shareholders, and between shareholders and debt holders (Myers, 1977). We hereby include FCF as our additional control variable to investigate whether the impacts of SLCC on corporate dividend policy remain robust in the presence of the FCF problem.

Further studies on corporate payouts document that variant firm characteristics and a lower propensity of dividend payouts retain firm characteristics less variant (DeAngelo et al., 2006). Firm characteristics with corporate maturity present their importance in explaining a decreasing fraction of dividend-paying firms. Regarding a maturity hypothesis by Grullon et al. (2002), older firms are likely to make more payouts. Additionally, DeAngelo et al. (2006) suggest that corporate maturity can be captured by the earned/distributed mix, with evidence that such that such earned/distributed mix quantitatively imposes a greater effect on corporate payout decisions rather than firm financial performance and growth opportunities. In the context of SLTA, climate change could pose a greater challenge because of their size and asset tangibility, which are sensitive to physical risks. Motivated by related literature, we control corporate maturity [Age] as our additional control variable to examine whether our expectation remains robust. By including firm age, we further explain how SLCCE affects corporate payout policy when larger firms are assumed to be greatly sensitive to climate drivers.

Payout policy remains the core of corporate finance is how much cash firms decide to pay out to their shareholders. Distributing cash reserves could drive a firm's investment decisions and valuation, with potential effects on tax amounts to be paid by its investors (Farre-Mensa et al., 2014). Such cash distribution for a firm's payout may convey informative insights into the market about how well the firm is performing compared to its peer firm. With the presence of market frictions, corporate payouts do not just imply operating cash flow residuals and a firm's net of investments. In real-life practice, a firm's managers might inform that they could refrain from projects with a positive net present value (NPV) before omitting dividend payouts (Brav et al., 2005). Given the context, a firm's payout policy drives its investment decisions, along with sound implications for the firm's value as well as the whole economy. Therefore, we might acknowledge that a firm's payout policy is closely related to its other firm policies, such as cash holdings, financing choices, and capital structure dynamics. For our investigation of the impacts of SLCCE on corporate payout policy, we hereby liaise our study with related literature by controlling additional corporate policies, including cash holdings, interest expense, income taxes, and changes in debt and cash ratios.

Column (4) in Table B shows that after controlling additional variables in the baseline regression, the coefficient estimate of temperature anomaly remains -0.0001 with statistical significance at the 1% level, implying that our finding is robust to additional controls.

### Controlling for year dummies

Since the 21st century started, financial economists have paid attention to 'disappearing dividends' (Fama & French, 2001; Fatemi & Bildik, 2012; Kuo et al., 2013). Prior literature documents a decrease of 66.5% in 1978 and a decrease of 20.8% in 1999 for disappearing dividends of publicly traded firms. The study explains that such reductions in corporate dividends are due to changes in firm characteristics.  Given the growing number of newly listed firms, disappearing dividends are explained by an increasing proportion of young firms with huge growth opportunities and low profitability. The study documents that firms exhibit their low propensity to pay dividends, regardless of their characteristics. Firms have become less likely to pay dividends. Fama and French (2001) document that such a lower propensity of dividend payouts is also important as firm characteristics are changing, which leads to a decrease in decreasing proportion of dividend-paying firms. Roughly a decade later, since the study of Fama and French (2001), Fatemi and Bildik (2012) document the disappearance of dividends worldwide. In a similar spirit to Fama and French (2001), Fatemi and Bildik (2012) document that a decrease in the propensity of dividend payouts is derived from a large proportion of smaller and less profitable firms with substantial growth opportunities. The study finds that the number of dividend-paying firms varies significantly across industries. Even when changes in firm characteristics are well controlled, the number of dividend-paying firms has proportionally decreased over the years, as globally documented by Fatemi and Bildik (2012). The proportional decrease in dividend payouts is documented to be more pronounced for firms located in civil law countries (Fatemi & Bildik, 2012). Just a year later, Kuo et al. (2013) investigated the potential factors that drive the disappearance of dividend payouts. The study sheds light on the role of liquidity, risk, and catering in the changing propensity to pay dividends. Kuo et al. (2013) argue that risk is a principal determinant of corporate dividend policy. For firms located in economies like the US, UK, France, and some other European markets, liquidity plays an important additional determinant of firms' dividends. The study shows that catering incentives among firms are persistent in common-law countries only. Even when risk is adjusted, the study finds weak support for the catering theory for firms that are incorporated in common law economies. Kuo et al. (2013) document that catering incentives represent the risk-reward relation in the changes of dividend-paying propensity by firms.

More recently, Kahle and Stulz (2021) document a substantial increase in corporate payouts paid by public firms over the recent decades. Compared to the period of 1971-1999, the study documents that corporate payouts in the form of dividends and share repurchases are three times larger for the period of 2000-2019. The authors present that the accumulated income accounts for an increase of roughly 37% in annual payouts of sample firms. Firms exhibit an increase of 63% in their payout rates. The study highlights that such an increase in corporate payouts is not just due to corporate maturity and firm size but is also due to a higher fraction of free cash flow dedicated by firms to be paid to their shareholders. Nevertheless, firms are likely to decrease their capital expenditures since the 2000s; a decrease in capital expenditure is documented to be a common phenomenon regardless of whether firms make payouts or not. A modern study by Michaely and Moin (2022) decomposes the disappearance of dividends for the period of 1970s–2000 and their subsequent disappearance for the period of 2000–2018 for dividend-paying firms. The study shows that changes in firm characteristics and propensity to pay dividends both drive half of the disappearing dividends. A propensity to pay dividends accounts for 82% of reappearing dividends. A proportion of roughly 18% of reappearing dividends is derived from firms' stable earnings. Firms with volatile characteristics are linked to less profitable performance with high volatility of earnings. Firms with a changing propensity to pay dividends are related to their profitable and stable performance. Newly (de)listed firms make the trends with the magnitude and durability of disappearing payouts significantly smaller for corporate dividends, with possible substitution implied between repurchases and dividends.

Given the heterogeneous literature on corporate (dis)appearing dividends, for the context of SLCCE in this study, we control for the time dummy variables for the 2000s, 2010s, and 2018s. While the recent two decades have seen an increasing abnormal climatic conditions for the US and worldwide, the inclusion of the year dummy variables offers two critical aspects. First, we aim to investigate whether the impacts of SLTA on corporate dividends remain robust with the decomposed periods of disappearing dividends as documented by Fama and French (2001); Fatemi and Bildik (2012); Kuo et al. (2013); Michaely and Moin (2022). Second, while Kahle and Stulz (2021) document a roughly triple increase in corporate payouts for the past two decades. Our evidence from SLTA offers added novelties to prior literature by showing that climate risks are inevitable determinants of corporate payouts. In other words, our multiple-decade sample provides insight into the consequences of climate change on corporate payout policy, which prior literature on corporate dividends' (dis)appearance might have missed so far. Reported in Panel C of Table 3, the results of the time dummies without and with additional control variables in Columns 5 and 6, respectively. The coefficient estimates of temperature anomaly remain unchanged when we control for the dummy variables for the 2000s, 2010s, and 2018s.

[Table 3 Inserted Here]

As of 1999, dividend-paying firms fell to 20.8% compared to 66.5% in 1978 (Fama & French, 2001). The study argues that decreased corporate cash dividends are caused by changes in firm characteristics. Also, decreased dividends are caused by new listings with small firms that appeared with strong growth opportunities. Besides firm characteristics, dividend disappearances are later explained by several studies after Fama and French (2001). With over 50% decrease in dividends is further explained by DeAngelo et al. (2004) for the following reasons. The study argues that dividend disappearances occur for those firms with very small dividends paid to shareholders. Furthermore, DeAngelo et al. (2004) argue that top dividend-paying firms overshadow bottom dividend-paying firms. The study shows that industrial firms with high earnings dominate dividend supply, with aggregate impacts of earnings on dividends paid for a majority of firms. Hoberg and Prabhala (2008) examine the puzzle of disappearing dividends through the lens of risk, including explanatory variables market-to-book ratio, corporate asset growth, corporate profitability, and NYSE size percentile. The study shows that risk plays a significant role in dividend-paying prosperity, with dividend disappearances accounting for approximately 40%. Hoberg and Prabhala (2008) find little support for the view that dividend disappearances reflect the catering of firms to their transient fads. A related study by Baker and Wurgler (2004) documents a close association between dividend-paying fluctuations and catering incentives. The authors determine four distinct paths in dividend-paying prosperity for the period between 1963 and 2000. Baker and Wurgler (2004) show that every path is linked to a corresponding volatility in firms' catering incentives and that dividend-paying prosperity increases when the stock market dividend premium is positive and vice versa. Nearly a decade later, Fatemi and Bildik (2012) firmly document dividend disappearances with global evidence. With industry-wide heterogeneity, firm characteristics are a critical determinant of dividend-paying prosperity for firms.  Over the years, dividend-paying proportions and the number of payers has decreased, with which disappearance of dividends by firms being pronounced in civil law countries. A decade later, Michaely and Moin (2022) historical patterns of dividend payouts for the period starting from the 1970s to 2018. The authors document a decreased fraction of dividend-paying firms before 2000 (1970s-2000) and a subsequent recovery in the recent decades (2000-2018). The authors argue that changing firm characteristics as well as dividend-paying proclivity jointly drive the dividend disappearances of firms. Subsequent recovery of corporate dividend payouts is also supported by Kahle and Stulz (2021) with the triple increase in corporate payouts in the recent decades (2000-2019) compared to from 1971 to 1999. While dividend (dis)appearances remain their puzzling findings, we show that climate change is an important and inevitable determinant of corporate payouts, with persistently decreased dividends paid to shareholders. The adverse impacts of climate change (SLTA) on dividends remain robust when we control for the periods documented by Kahle and Stulz (2021). Our findings highlight the fact that global warming has escalated in the US, with complex associated risks[32] imposed on firms, leading to decreased dividends paid to shareholders. Controlling for different periods with dividend (dis)appearances, our study complements prior literature by showing the long-term adverse impacts of climate change on corporate dividend payouts (Baker & Wurgler, 2004; DeAngelo et al., 2004; Fama & French, 2001; Fatemi & Bildik, 2012; Hoberg & Prabhala, 2008; Michaely & Moin, 2022). For the long-term proneness of firms to climate risks, the trends of dividend (dis)appearances could be explained by the increasing threats of global warming across the US states.

[32] Climate change impacts are increasing for Americans | National Oceanic and Atmospheric Administration

Numerous studies show that share repurchases emerge as a substitute for cash dividends (Babenko, 2009; Dittmar, 2000; Grullon et al., 2002; Ikenberry et al., 1995; Vermaelen, 1981; Wang et al., 2021). Michaely and Moin (2022) examine the reappearance of dividends after 2000 in the U.S., followed by "disappearing dividends" in the early 1970s, and show that more stable and profitable firms tend to pay dividends. While Bonaimé et al. (2013) also show that firms favor repurchases over dividends to achieve payout flexibility, which is negatively related to financial hedging, Arena and Julio (2023) find that the high litigation risk leads firms to substitute dividends for share repurchases. Yuyuan Chang et al. (2024), using a large sample of 45 countries, show that firms substitute dividends with repurchases to increase their payout flexibility in response to higher climate risk. To this end, we regress Share repurchases/Total assets on the temperature anomaly with controls. Results reported in Panel D of Table 3 (Column 7) show that the coefficient of temperature anomaly is negative but statistically insignificant, implying that firms do not substitute share repurchases with dividends in the U.S. In Column 8, when we regress Share repurchases/Total Payout to proxy for payout flexibility on the temperature anomaly, the coefficient estimate of the temperature anomaly is statistically insignificant. Thus, our results contrast with the findings of Y. Chang et al. (2024) for a large sample of countries that include U.S. firms.

### Channel Analysis

This section examines the firm-level factors through which temperature anomaly is channeled to firms' decisions to reduce dividends. We explore possible channels including cash holdings, trade credit, and market leverage.

The optimal amount of cash distributed to a firm's shareholders is an important question in its payout policies (Allen & Michaely, 2003). It is because the payout policy is not only important to the amount of liquidity accounted for by a firm and its subsequent repetition, but also because the firm's payout policy is interactively linked to most of the investment and financial decisions the firms execute. Given the current levels of cash holdings, a firm's boards of directors and management need to decide how much cash the firm might optimally distribute to its shareholders in the form of dividends, and what shares the firm would repurchase. The firm might incur costs for its capital investment in real assets, debt issuance, and mergers and acquisitions. In an inefficient capital market, a firm's payout policy interacts with cash policy as well as other financing decisions, see also Baker and Wurgler (2013); Kalay and Lemmon (2008). For the context of climate change, cash holdings modernly show critical roles when corporate profitability is reduced due to climate risk drivers (Dimitrios Gounopoulos & Yu Zhang, 2024; Siamak Javadi et al., 2023). When corporate liquidity is affected by an externality (e.g., climatic anomalies) in the form of unused debt capacity, firms might make substantial debt issuance to finance their operating needs rather than making larger equity payouts (Denis & McKeon, 2012). Given the increasing awareness about climate risks by stakeholders (Andersson et al., 2016; Bolton & Kacperczyk, 2021; PATRICK BOLTON & MARCIN KACPERCZYK, 2023b), a firm's (de)leveraging practices could play a critical role in its payout policy, which could be derived by climate change with greater complexity (DeAngelo et al., 2017; Ginglinger & Moreau, 2023; Huang et al., 2018). A Firm can be financed by its suppliers instead of being financed by financial institutions. This context leads us to trade credit theories. Given the widespread climate change and costly external finance due to climate risks (Chava, 2014; Huynh et al., 2020; S. Javadi & A.-A. Masum, 2021), trade credit could be an alternative financial source for firms that might have limited accessibility to capital markets (Petersen & Rajan, 2015). In the context of stringent mortgage lending due to increasing awareness of loan offers about climate change (Duan & Li, 2024), trade credit could play as an external financing choice under the scenario that monetary transmission mechanisms are changing as extensively elaborated by the literature (Chen et al., 2019; Dafermos et al., 2018; Mateut, 2005; McKibbin et al., 2021; Nilsen, 2002; Petersen & Rajan, 1997, 2015; Schwartz, 1974; Wilner, 2000). When firms are exposed to physical risks, with both supply and demand sides (Ginglinger & Moreau, 2023), our choices of selected variables for channel tests allow our study to elaborate on the ways that firms could have responded to  SLCCE in the form of their dividend policies.

Results reported in Table 4 show that while the coefficient estimate of *Temperature anomaly* is statistically significantly positive in Column (1) with a very low value, the interaction of temperature anomaly and Cash holdings, *Temperature Anomaly* × *Cash Holdings* is significantly negative at the 1% level with a value of -0.0020. While firms pay higher dividends with higher cash holdings, as the coefficient of the variable is 0.0082 with statistical significance at the 1% level, a higher temperature anomaly leads to a lower dividend incrementally. The coefficient estimates of *Trade Credit* and *Market Leverage* are -0.0008 and -0.0274 in Columns (2) and (3), respectively, and are statistically highly significant, suggesting that both variables lead to lower dividend payout. However, the interaction terms, *Temperature Anomaly* × *Trade Credit* and *Temperature Anomaly* × *Market Leverage,* are statistically significantly positive. Given that the *Temperature Anomaly* is also significantly negative in both columns, our findings suggest that a higher abnormal temperature forces firms to dynamically adjust dividend payout policy channeled through trade credit and market leverage to cope with the long-term climate change risk.

[Table 4 Inserted Here]

For the direct associations, the findings show that firms with higher cash holdings maintain higher predicted dividends paid to shareholders (Column 1). On the other hand, firms with higher trade credit and market leverage are predicted to have decreased dividends paid to shareholders. Our findings complement prior literature streams as follows. First, we document the long-term impacts of climate change with US state-level evidence on corporate dividend policy with both supply and demand effects. On the demand side, firms reserving more cash imply that their financial conditions are being constrained by climate change impacts, leading to a decreased dividend paid to shareholders (Temperature Anomaly × Cash Holdings). Corporate liquidity is critical for firms with financial flexibility for a possible dividend payment to shareholders; however, when we control for temperature anomaly, firms' one-year-head dividends are decreased by climate change exposure. The findings also imply that reserving more cash signals firms' exposure to climate change. Our findings from the moderations of cash holdings are supported when firms employing trade credit as an alternative financing source decrease dividends paid to shareholders (Column 2). A similar rationale is evident from firms' market leverage with a subsequent decrease in dividend payouts (Column 3). Firms with access to credit (either trade credit or market leverage) could maintain positive dividends paid to shareholders under climate risk exposure.  Our findings support our second hypothesis (H2), showing moderations of cash holdings, trade credit, and market leverage.

While recent studies highlight the roles of cash reserves for firms to safeguard from climate risks (D. Gounopoulos & Y. Zhang, 2024; S. Javadi et al., 2023; S. H. Lee et al., 2023), our findings suggest that, not just the severe but also the undiversified long-term effects of climate change on the US firms. More importantly, heightened cash holdings imply that firms are severely exposed to systematic climate risks with subsequent decreased dividends. Benchmarking multiple-decade climate change with its geographical divergence for the US, our findings imply the critical roles of credit access to firms when they are exposed to climate risks for operating needs (Dang et al., 2024). It is critical to note that, even with access to credit (trade credit or market leverage) (Benincasa et al., 2024), climate change impacts remain with a predicted decrease in dividends paid to firms' shareholders. Furthermore, prior literature focuses on proving the ways firms deal with contemporary climate risks (e.g., disasters and climate-related events) through payout flexibility and financing choices n(Yuyuan Chang et al., 2024; Yen et al., 2024). Our second hypothesis is empirically supported, proving that the long-term climate change impacts (temperature anomaly) on firms are undiversifiable, channeling into corporate cash reserves and financing policies.

### Moderating Effects

This section explores the moderating effects of three factors, mainly external to firms. We focus on three factors: COP21, disaster-prone states, and vulnerability. First, following P. Bolton and M. Kacperczyk (2023) and Y. Chang et al. (2024), we employ the Paris Agreement at the United Nations Climate Change Conference, COP21, enforced from 2016 as an event. The agreement aims to keep the global average temperature below 2°C above pre-industrial levels and limit the temperature increase to 1.5°C above pre-industrial levels. Although the Trump administration decided to withdraw from the Paris Agreement in 2017, President Joe Biden signed an executive order on 20th January 2021 to rejoin the agreement. The agreement is supposed to increase awareness of climate change and the associated transition risk among the firms. We define *COP21* as a dummy variable that equals 1 for post-agreement from 2016 and 0 otherwise. We include the interaction term, *Temperature anomaly×COP21,* to decipher the moderating effect of the Paris Agreement. Regardless of the changing commitments of the US to our global climate action[33], recent studies document the climate transition risks of the Paris Agreement [COP21] on corporate decisions for firms located in the US (Yuyuan Chang et al., 2024; Ginglinger & Moreau, 2023). Regarding Bolton and Kacperczyk (2021); PATRICK BOLTON and MARCIN KACPERCZYK (2023b), COP21 imposes transitional effects on equity markets with an increasing awareness of stakeholders about climate risks. Under the exposure of firms to climate change, in the context of SLTA, for the internationalization of US equity markets (Frankel, 1994), a landmark global agreement like COP21 could spill over its transitional risks to shareholders with their stock portfolios of firms headquartered in states with abnormal positive temperature anomalies that indicate the increasingly severe phenomenon of global warming in those states. Given the context, COP21 could additionally impose transitional effects on firms to be more conservative in equity payouts. The regression results are reported in Table 5. Column (1) shows that the coefficient estimate of *Temperature anomaly×COP21* is negative and statistically significant at the 10% level, implying that after the Paris Agreement, firms decrease their dividend payout even further when facing an increase in abnormal temperature.

Natural disasters impose potential insolvency on banking systems for which banks could experience financial fragility (Klomp, 2014). Dal Maso et al. (2024) show that banks located in U.S. counties that are prone to disaster risks are likely to have larger loan loss provisions [LLP]. The study implies an increasing concern about natural disasters with potential economic consequences affecting the ways that banking systems could proactively hedge such credit risk through LLP due to natural disasters. From the supply side, the financial fragility of banks could affect the accessibility of firms to external financing choices due to abnormal climactic outcomes

[33] On the U.S. Withdrawal from the Paris Agreement - United States Department of State; The United States Officially Rejoins the Paris Agreement - United States Department of State

(Huang et al., 2018). Financial sentiment is affected by its subsequent rises following the emergence of natural disasters (Jha et al., 2021), generating adverse consequences to the financial development of economies (Keerthiratne & Tol, 2017). Natural disasters lead to a rational reallocation by institutional investors for information-processing resources (Blanco et al., 2024). The study shows that, with firm-level evidence, institutional investors yield the consequences of disasters to non-affected stocks by decreasing the incorporation of firm-related information, specifically to stocks of the firms that represent a lower portfolio weight. Such behaviors by institutional investors are assumed to be rational in reallocating their information processing sources. Natural disasters could also affect earnings forecasts by firms' analysts in economies like the United States (Zhang & Kanagaretnam, 2024). The study shows that natural disasters are related to the deteriorated properties of analyst forecasts in terms of forecast dispersion and forecast errors. The reason is that natural disasters induce volatile return on assets and corporate cash flows, as well as a lower comparability of firms' financial statements. With those three potential channels, Zhang and Kanagaretnam (2024) elaborate on the ways that climate disasters affect the properties of analyst forecasts of firms. Such effects of natural disasters are pronounced for firms from industries with high vulnerability to natural disasters. The financial impacts of natural disasters on local firms are also documented by Collier et al. (2024) with evidence from Hurricane Harvey, as well as their spillover effects among firms with significant externalities for management forecast (Park, 2024). To validate the robustness of our predicted impacts of SLCCE proxied by SLTA, we control the proneness of firms located in US states that are exposed to natural disasters. Regarding the U.S.News (2024), natural disasters emerge in several and diverse forms, such as menacing earthquakes, tornadoes, flooding, fires, and many more climate disasters that could pose risks to firms in specific US states. Given the chronic proneness to natural disasters of specific US states, we test for the moderating effects of the proneness of firms to natural disasters by using a dummy variable to depict our sample firms located in the leading disaster-prone states [DPS] for the US. Regarding U.S.News (2024), the top ten disaster-prone states of the United States include 1) California, 2) Texas, 3) Oklahoma, 4) Washington, 5) Florida, 6) New York, 7) Alabama, 8) Colorado, 9) New Mexico, 10) Louisiana, and Oregon (tie)[34]. Given the short-term climatic conditions that have been used recently in the literature (Yuyuan Chang et al., 2024; Huang et al., 2018), controlling for DPS allows us to not just validate the robustness of our empirical findings, but also support validating our arguments on the differences between climate change measures used for this current study compared to prior literature.

Our regression of dividends on SLTA moderated by Disaster-Prone States provides the following insightful implications. First, our predicted impacts of temperature anomaly on dividends remain negative and statistically significant at the 1% level. The robust standalone effects of SLCCE proxied by SLTA remain consistent for our prediction of the long-term and chronic consequences of climate change to corporate dividend policy, for which firms become conservative in making large equity payouts to shareholders. The rationale is that decreasing equity payouts allows firms to reserve their ample corporate liquidity to cope with costly financial distress and to finance operating needs under climate change exposure (Ginglinger & Moreau, 2023; Dimitrios Gounopoulos & Yu Zhang, 2024; Siamak Javadi et al., 2023; Nguyen et al., 2022). Regarding signaling theories, our findings show that firms located in Disaster-Prone States, under SLCCE across the US, have maintained positive dividend payouts to their

[34] The 10 Most Disaster-Prone States in the U.S. (usnews.com); Natural Disasters by State: The 25 Most Disaster-Prone Areas in the US | Moneywise

shareholders. The findings bring critical implications as follows. First, to some extent, the payout policy being adversely affected by climate risks is conditional on corporate liquidity, risk management, and financing choices by firms. In our case, a predicted positive payout shows that firms located in DPS are capable of better risk management under state-level climate change. Even though firms are in Disaster-Prone States, firms have prepared for periodic disaster events. Firms with positive payouts convey a positive signal to investors about their growth prospects, regardless of whether their locations are more prone to natural disasters compared to firms located in other states that are less prone to natural disasters. While mitigating climate change is our long-term effort with subsequent physical risks, corporate payouts play their roles in mitigating agency problems between directors, the management board, and shareholders of firms. Therefore, such proneness to natural disasters could have increased firms' awareness about long-term climate risks for suitable risk management toward a positive payout to their shareholders. Our findings add to a recent study by Yuyuan Chang et al. (2024) by showing that the proneness to climate physical risks could induce firms to have more suitable risk management strategies in advance, for which those firms might still maintain positive equity payouts to their shareholders. Our explanations are aligned with signaling models and agency-based theories of corporate payouts with literature surveys (Allen & Michaely, 2003; Farre-Mensa et al., 2014; Kalay & Lemmon, 2008).

Third, firms in vulnerable industries are more likely to be highly affected by climate-related risk, inducing them to cut dividends in the future. Following Human et al. (2018) and Chang et al. (2024), we identify the industries as vulnerable based on Fama–French industry codes. These industries are agriculture, business services, communication, energy, coal, oil, food products, health care, and transportation. We define *Vulnerability* as a dummy variable that equals 1 for the vulnerable industries and 0 otherwise. We include the interaction term, *Temperature anomaly× Vulnerability,* to find the moderating effect of the vulnerable industries. An increase in abnormal temperatures is more likely to affect vulnerable industries, forcing firms to pay less dividends. Results reported in Column (3) show that the coefficient estimate of *Temperature anomaly ×Vulnerability* is significantly negative at the 5% level, which is consistent with our expectations.

[Table 5 Inserted Here]

For the standalone associations, the adverse effects of SLTA on corporate dividends paid are persistent for all the fitted models (Columns 1-3), showing the long-term effects of state-level climate change on corporate payouts. We observe that, since COP21, firms have been likely to maintain positive dividend payouts to their shareholders (Column 1). On the other hand, firms located in disaster-prone states decrease dividends paid to shareholders (Column 2), while we observe a positive but not significant increase in dividends for corporate vulnerability (Column 3). The joint effects between climate change and proneness to natural disasters (Temperature Anomaly × Disaster-Prone States) result in predicted positive dividends paid to shareholders, while the joint effects between climate change and COP21 (Temperature Anomaly × COP21) and corporate vulnerability (Temperature Anomaly × Vulnerability) show a strong predicted decrease in dividends paid by firms to shareholders. Our findings imply the following rationales, which could be critical to related streams of literature. Transition risks (e.g., stringent environmental policies, etc.) could be (un)beneficial to firms for the following reasons. First, stringent climate policies could be beneficial to firms with progressive innovations that are friendly to the environment (e.g., progressive R&D, eco-innovation, overall ESG, etc.), while transition risks could be unfavorable to polluting firms (e.g., carbon risk), which are unfriendly to the environment. Our findings prove the moderation of COP21 (a binding, legally international treaty for climate action) by showing the negative joint effects of SLTA and COP21 (Temperature Anomaly × COP21) on corporate dividends. Not just domestic climate transition risks (Cao et al., 2024; Dang et al., 2024), firms are likely to decrease dividends paid to shareholders due to associated risks caused by our global climate action to firms located in the US states. The rationale is that polluting firms would likely have co-founding effects of transition risks for our climate action to mitigate climate change impacts (e.g., drought risks, etc.) (Do et al., 2021; Huynh et al., 2020; S. Javadi & A. A. Masum, 2021).

Another critical insight from our moderation analyses is that, under long-term climate change, firms might learn from historical climate events for risk management (e.g., natural disasters, etc.). Since natural disasters impose potential fragility on financial institutions (e.g., banks, etc.) (Celil et al., 2022; Hansen, 2022; Ivanov et al., 2022). Hence, firms might be more conservative with their financial policies to safeguard themselves from frequent occurrences of natural disaster risks. Under long-term global warming with SLTA, we find that firms located in disaster-prone states maintain positive dividends paid to shareholders (Temperature Anomaly × Disaster-Prone States). Our findings are crucial to prior literature focusing on physical risks by showing that adjustments of financial policies could be conditional on firms' awareness of climate risks. For instance, climate risks, depending on their nature (long-term vs short-term risks; physical vs transition risks), would possibly not always induce firms to ignore dividends (Y. Chang et al., 2024). Our findings also prove why prior literature on the impacts of climate risks is heterogeneously exhibited in corporate financing choices (Ginglinger & Moreau, 2023; Huang et al., 2018). Overall, our findings support the third hypothesis (H3), showing the long-term moderation of climate transition risk (COP21), physical risks (Disaster-prone states), and corporate vulnerability (Vulnerability) to the impacts of SLTA on corporate dividend payouts. Our third hypothesis is empirically proven, showing the persistent and adverse impacts of state-level climate change on corporate dividends, moderated by related climate risk drivers.

Our moderation tests highlight the important contributions to prior studies with heterogeneity of corporate behaviors in dividend policies in responding to long-term systematic climate risk. The dividend payout policy is driven by various factors such as external climate transitional policy (COP21), geographic exposure of a firm's location (disaster-prone states), and systemic risk (corporate vulnerability to carbon transition risk).

### Subsample Analysis

In this section, we conduct subsample analysis at three levels related to the life-cycle theory of firms. For the sub-sample analyses, we classify firms into two sub-groups with median values above and below our median values for the full sample.  The current study is consistent with prior studies of Fama and French (2001); Fatemi and Bildik (2012); Kahle and Stulz (2021); Kuo et al. (2013); Michaely and Moin (2022) by focusing on firm size, corporate maturity measured by firm age, and tangibility for our sub-sample analyses.

[Table 6 Inserted Here]

The sub-sample analyses show that small and younger firms are highly sensitive to climate change, with significantly higher levels of temperature anomaly on corporate dividends. Firms with higher tangibility (fixed assets) are also highly sensitive to temperature anomalies. Our findings support the life-cycle theorem, showing that the impacts of climate change on dividend policies could follow a firm's life cycle (DeAngelo et al., 2006). Regarding the life-cycle theory for corporate dividends, the proportions of publicly traded dividend-paying firms could be higher when their retained earnings to assets (to total equity) are sufficiently large, while they could decrease when a firm's retained earnings are near zero and the firm's equity is distributed instead of being earned. Corporate earnings could be more volatile under climate risk exposure (Huang et al., 2018), specifically for younger firms with lower financial flexibility (e.g., cash flows) for payouts when they are still in their earlier life cycle, see Faff et al. (2016). Corporate payouts signal firms' growth prospects to shareholders, for which a firm's dividends could be (dis)appearing through life-cycle stages under climate change exposure. We also observe that firms with higher tangibility are significantly sensitive to temperature anomalies (global warming), leading to frequent and increasingly severe impacts of physical risks where firms are located (e.g., hurricanes, droughts, flooding, etc.) (Collier et al., 2024; Huang et al., 2018). Overall, our sub-sample analyses support our baseline findings for the long-term impacts of climate change benchmarked by SLTA, for which climate change impacts are propounded for earlier-cycle firms and those with large tangible assets. under the long-term climate change impacts, our findings are aligned with prior literature showing that the impacts of SLTA on dividends are conditional on changing firm characteristics (e.g., growth opportunities, profitability, earnings, etc.) and dividend-paying proclivity (Kahle & Stulz, 2021; Michaely & Moin, 2022). Furthermore, our findings from sub-sample analyses show that climate change impacts on firms could be pronounced for firms that are in the later stages of their life cycle (e.g., larger firms with substantial fixed assets, etc.). For our study, global warming, with its related climate risks, benchmarks long-term climate change impact specifically for those with large tangible assets.

**Table 1:** Descriptive statistics

| Variable | N | Mean | Min | p50 | Max | SD |
|---|---|---|---|---|---|---|
| **Corporate Payout Measures** | | | | | | |
| Dividend/Assets | 147836 | 0.0077 | 0.0000 | 0.0000 | 0.0851 | 0.0151 |
| Dividend/Common shares Outstanding | 147807 | 0.2287 | 0.0000 | 0.0000 | 2.4637 | 0.4687 |
| Dividend/Sales | 147836 | 0.0069 | 0.0000 | 0.0000 | 0.0941 | 0.0153 |
| Log (1+ Dividend) | 147836 | 0.7592 | 0.0000 | 0.0000 | 6.3648 | 1.4543 |
| Shares repurchase | 141035 | 0.0100 | 0.0000 | 0.0000 | 0.1886 | 0.0293 |
| Payout flexibility | 79806 | 0.4085 | 0.0000 | 0.1642 | 1.0000 | 0.4404 |
| **State-Level Climate Change** | | | | | | |
| State-Level Temperature Anomaly | 147836 | 0.9029 | -1.9167 | 0.7500 | 4.2500 | 1.3094 |
| State-Level Abnormal Warmer | 147836 | 0.7272 | 0.0000 | 1.0000 | 1.0000 | 0.4454 |
| State-Level Abnormal Cooler | 147836 | 0.2728 | 0.0000 | 0.0000 | 1.0000 | 0.4454 |
| **Firm-Level Control Variables** | | | | | | |
| Firm size | 147836 | 4.6744 | 0.0677 | 4.4952 | 10.2088 | 2.2013 |
| Book to market | 147807 | 0.6302 | -6.9974 | 0.5479 | 4.4826 | 1.2352 |
| Log (1+Tobin's Q) | 147836 | 4.7740 | -0.1791 | 4.5545 | 10.4843 | 2.2989 |
| Capex | 147836 | 0.0647 | 0.0000 | 0.0427 | 0.4327 | 0.0709 |
| R&D to Assets | 147836 | 0.0415 | 0.0000 | 0.0000 | 0.9185 | 0.1022 |
| Leverage | 147836 | 0.2983 | 0.0000 | 0.2277 | 3.9645 | 0.4157 |
| Operating cash flow | 147836 | -0.0557 | -6.7868 | 0.0550 | 0.4286 | 0.6207 |
| Sga to Sales | 147836 | 0.5414 | 0.0247 | 0.2373 | 12.8216 | 1.4830 |
| Xad to Sales | 147836 | 0.0129 | 0.0000 | 0.0000 | 0.2116 | 0.0311 |
| **Additional Variables** | | | | | | |
| FCF/Assets | 147836 | 31.1508 | 0.0000 | 0.0000 | 903.0000 | 124.7421 |
| Log (1 + Age) | 147836 | 1.0606 | 0.0000 | 0.0000 | 3.8712 | 1.5255 |
| Cash/Assets | 147833 | 0.1423 | 0.0000 | 0.0716 | 0.9598 | 0.1750 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Interest/Assets | 147836 | 0.0312 | 0.0000 | 0.0177 | 0.4644 | 0.0574 |
| Income Taxes/Asset | 147836 | 0.0233 | -0.0878 | 0.0146 | 0.1512 | 0.0387 |
| Change in Debt | 147752 | 0.0162 | -0.7728 | 0.0000 | 0.6639 | 0.1672 |
| Change in Cash | 147831 | -0.0039 | -0.6709 | 0.0009 | 0.4268 | 0.1330 |
| 2000s dummy | 147836 | 0.3941 | 0.0000 | 0.0000 | 1.0000 | 0.4887 |
| 2010s dummy | 147836 | 0.1716 | 0.0000 | 0.0000 | 1.0000 | 0.3770 |
| 2018 dummy | 147836 | 0.0146 | 0.0000 | 0.0000 | 1.0000 | 0.1201 |
| Trade credit | 147474 | 0.2379 | 0.0119 | 0.1094 | 4.6250 | 0.5658 |
| Market leverage | 147836 | 0.2012 | 0.0000 | 0.1575 | 0.7597 | 0.1852 |
| Tangibility | 147280 | 0.5561 | 0.0192 | 0.4673 | 2.2502 | 0.4095 |
| COP21 | 147836 | 0.0749 | 0.0000 | 0.0000 | 1.0000 | 0.2632 |
| Disaster-Prone States | 147836 | 0.4793 | 0.0000 | 0.0000 | 1.0000 | 0.4996 |
| Vulnerability | 147836 | 0.3377 | 0.0000 | 0.0000 | 1.0000 | 0.4729 |

**Table 2**: Baseline regressions

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| VARIABLES | Dividend/Assets | Dividend/Assets | Dividend/Assets | Dividend/Assets |
| Temperature Anomaly | -0.0001** | -0.0001*** | | |
| | (0.0000) | (0.0000) | | |
| Abnormal warmer | | | -0.0002*** | |
| | | | (0.0001) | |
| Abnormal cooler | | | | 0.0002*** |
| | | | | (0.0001) |
| Firm Size | | -0.0023*** | -0.0023*** | -0.0023*** |
| | | (0.0002) | (0.0002) | (0.0002) |
| Book to Market | | -0.0009*** | -0.0009*** | -0.0009*** |
| | | (0.0001) | (0.0001) | (0.0001) |
| Log of Tobin's Q | | 0.0041*** | 0.0041*** | 0.0041*** |
| | | (0.0002) | (0.0002) | (0.0002) |
| Capex | | -0.0119*** | -0.0119*** | -0.0119*** |
| | | (0.0011) | (0.0011) | (0.0011) |
| R&D to Assets | | -0.0029*** | -0.0029*** | -0.0029*** |
| | | (0.0009) | (0.0009) | (0.0009) |
| Leverage | | -0.0063*** | -0.0063*** | -0.0063*** |
| | | (0.0004) | (0.0004) | (0.0004) |

| | | | | |
|---|---|---|---|---|
| Operating cash flow | | -0.0004** | -0.0004** | -0.0004** |
| | | (0.0002) | (0.0002) | (0.0002) |
| Sga to Sales | | -0.0002*** | -0.0002*** | -0.0002*** |
| | | (0.0001) | (0.0001) | (0.0001) |
| Xad to Sales | | 0.0131** | 0.0131** | 0.0131** |
| | | (0.0055) | (0.0055) | (0.0055) |
| Constant | 0.0178*** | 0.0163*** | 0.0164*** | 0.0162*** |
| | (0.0054) | (0.0053) | (0.0053) | (0.0053) |
| | | | | |
| Observations | 128,313 | 128,307 | 128,307 | 128,307 |
| R-squared | 0.1846 | 0.2788 | 0.2788 | 0.2788 |
| Year-FE | Yes | Yes | Yes | Yes |
| Industry-FE | Yes | Yes | Yes | Yes |
| State-FE | Yes | Yes | Yes | Yes |
| Cluster SE | Yes | Yes | Yes | Yes |

The table reports ordinary least-squares linear regressions. The regressions perform cluster-robust standard errors at the firm level. The regressions include the fixed effects for time/year, industry (SIC), and state (location) levels. Standard errors in parentheses. The characters report statistical significance at the 1%, 5%, and 10% levels, respectively *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

**Table 3:** Robustness Checks

| | Panel A: Alternative measures of dividends | | Panel B: Additional controls | | Panel C: Year dummies | | Panel D: Share repurchases | |
|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| VARIABLES | Dividend /Shares | Dividend /Sales | Log(1+Dividend) | Dividend /Assets | Dividend/ Assets | Dividend /Assets | Repurchase /Assets | Repurchase /Total payout |
| Temperature Anomaly | -0.0042*** | -0.0001*** | -0.0060** | -0.0001*** | -0.0001*** | -0.0001*** | -0.0000 | 0.0002 |
| | (0.0009) | (0.0000) | (0.0026) | (0.0000) | (0.0000) | (0.0000) | (0.0001) | (0.0014) |
| Firm Size | 0.0708*** | -0.0017*** | 0.2455*** | -0.0009*** | -0.0023*** | -0.0009*** | -0.0048*** | -0.0309*** |
| | (0.0052) | (0.0002) | (0.0155) | (0.0002) | (0.0002) | (0.0002) | (0.0003) | (0.0073) |
| Book to Market | -0.0214*** | -0.0005*** | -0.0648*** | -0.0004*** | -0.0009*** | -0.0004*** | 0.0003*** | 0.0364*** |
| | (0.0022) | (0.0001) | (0.0067) | (0.0001) | (0.0001) | (0.0001) | (0.0001) | (0.0051) |
| Log of Tobin's Q | 0.0295*** | 0.0037*** | 0.2083*** | 0.0022*** | 0.0041*** | 0.0022*** | 0.0071*** | 0.0068 |
| | (0.0044) | (0.0002) | (0.0131) | (0.0002) | (0.0002) | (0.0002) | (0.0003) | (0.0069) |
| Capex | -0.2604*** | -0.0134*** | -0.8121*** | -0.0119*** | -0.0119*** | -0.0119*** | -0.0186*** | 0.0274 |
| | (0.0328) | (0.0014) | (0.1002) | (0.0010) | (0.0011) | (0.0010) | (0.0017) | (0.0494) |
| R&D to Assets | 0.1118*** | -0.0035*** | 0.3029*** | -0.0018** | -0.0029*** | -0.0018** | -0.0083*** | 0.2134** |
| | (0.0221) | (0.0009) | (0.0741) | (0.0008) | (0.0009) | (0.0008) | (0.0015) | (0.0859) |
| Leverage | -0.1215*** | -0.0048*** | -0.3034*** | -0.0034*** | -0.0063*** | -0.0034*** | -0.0053*** | 0.0298* |
| | (0.0093) | (0.0003) | (0.0254) | (0.0003) | (0.0004) | (0.0003) | (0.0006) | (0.0161) |
| Operating cash flow | -0.0654*** | -0.0005*** | -0.2204*** | 0.0001 | -0.0004** | 0.0001 | 0.0018*** | 0.0500*** |
| | (0.0046) | (0.0002) | (0.0132) | (0.0001) | (0.0002) | (0.0001) | (0.0004) | (0.0140) |
| Sga to Sales | 0.0048*** | -0.0003*** | 0.0116*** | -0.0001*** | -0.0002*** | -0.0001*** | -0.0002** | 0.0227*** |
| | (0.0012) | (0.0001) | (0.0040) | (0.0000) | (0.0001) | (0.0000) | (0.0001) | (0.0042) |
| Xad to Sales | 0.1631 | 0.0111** | 0.9652*** | 0.0129*** | 0.0131** | 0.0129*** | 0.0114** | 0.2832** |
| | (0.1186) | (0.0044) | (0.3632) | (0.0049) | (0.0055) | (0.0049) | (0.0057) | (0.1230) |
| FCF/Assets | | | | 0.0000*** | | 0.0000*** | | |
| | | | | (0.0000) | | (0.0000) | | |
| Log (1+Age) | | | | -0.0009*** | | -0.0009*** | | |
| | | | | (0.0001) | | (0.0001) | | |
| Cash/Assets | | | | 0.0060*** | | 0.0060*** | | |
| | | | | (0.0007) | | (0.0007) | | |
| Interest/Assets | | | | 0.0016 | | 0.0016 | | |
| | | | | (0.0013) | | (0.0013) | | |
| Income Taxes/Asset | | | | 0.1081*** | | 0.1081*** | | |
| | | | | (0.0034) | | (0.0034) | | |
| Change in Debt | | | | 0.0014*** | | 0.0014*** | | |
| | | | | (0.0002) | | (0.0002) | | |
| Change in Cash | | | | -0.0069*** | | -0.0069*** | | |
| | | | | (0.0004) | | (0.0004) | | |
| 2000s dummy | | | | | -0.0066*** | -0.0022*** | | |
| | | | | | (0.0005) | (0.0005) | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 2010s dummy | | | | | -0.0014*** | -0.0011*** | | |
| | | | | | (0.0004) | (0.0004) | | |
| 2018 dummy | | | | | 0.0015*** | 0.0014*** | | |
| | | | | | (0.0003) | (0.0003) | | |
| Constant | -0.0380 | 0.0214*** | -0.8841*** | 0.0127** | 0.0163*** | 0.0127** | 0.0015 | 0.0664 |
| | (0.0808) | (0.0067) | (0.2363) | (0.0051) | (0.0053) | (0.0051) | (0.0128) | (0.1085) |
| Observations | 128,286 | 128,307 | 128,307 | 128,240 | 128,307 | 128,240 | 122,624 | 72,268 |
| R-squared | 0.3913 | 0.2407 | 0.5180 | 0.3485 | 0.2788 | 0.3485 | 0.1076 | 0.2870 |
| Year-FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Industry-FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| State-FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Cluster SE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |

The table reports ordinary least-squares linear regressions. The regressions perform cluster-robust standard errors at the firm level. The regressions include the fixed effects for time/year, industry (SIC), and state (location) levels. Standard errors in parentheses. The characters report statistical significance at the 1%, 5%, and 10% levels, respectively *** p<0.01, ** p<0.05, * p<0.1.

**Table 4: Channel Test**

| VARIABLES | (1)<br>Dividend/Assets | (2)<br>Dividend/Assets | (3)<br>Dividend/Assets |
|---|---|---|---|
| Temperature Anomaly × Cash Holdings | -0.0020*** | | |
| | (0.0003) | | |
| Temperature Anomaly × Trade Credit | | 0.0004*** | |
| | | (0.0001) | |
| Temperature Anomaly × Market Leverage | | | 0.0029*** |
| | | | (0.0003) |
| Temperature Anomaly | 0.0002*** | -0.0002*** | -0.0006*** |
| | (0.0001) | (0.0000) | (0.0001) |
| Cash holdings | 0.0082*** | | |
| | (0.0008) | | |
| Trade credit | | -0.0008*** | |
| | | (0.0001) | |
| Market leverage | | | -0.0274*** |
| | | | (0.0007) |
| Firm Size | -0.0020*** | -0.0023*** | -0.0005*** |
| | (0.0002) | (0.0002) | (0.0002) |
| Book to Market | -0.0008*** | -0.0009*** | -0.0001** |
| | (0.0001) | (0.0001) | (0.0001) |
| Log of Tobin's Q | 0.0038*** | 0.0041*** | 0.0024*** |
| | (0.0002) | (0.0002) | (0.0002) |
| Capex | -0.0100*** | -0.0116*** | -0.0127*** |
| | (0.0011) | (0.0011) | (0.0011) |
| R&D to Assets | -0.0036*** | -0.0028*** | -0.0041*** |
| | (0.0009) | (0.0009) | (0.0008) |
| Leverage | -0.0055*** | -0.0063*** | 0.0027*** |
| | (0.0004) | (0.0004) | (0.0003) |
| Operating cash flow | -0.0004*** | -0.0004** | 0.0015*** |
| | (0.0002) | (0.0002) | (0.0002) |
| Sga to Sales | -0.0003*** | -0.0002*** | -0.0002*** |
| | (0.0001) | (0.0001) | (0.0000) |
| Xad to Sales | 0.0122** | 0.0132** | 0.0115** |

| | | | |
|---|---|---|---|
| | (0.0055) | (0.0055) | (0.0053) |
| Constant | 0.0153*** | 0.0163*** | 0.0232*** |
| | (0.0051) | (0.0053) | (0.0055) |
| | | | |
| Observations | 128,304 | 128,129 | 128,307 |
| R-squared | 0.2823 | 0.2787 | 0.3149 |
| Year-FE | Yes | Yes | Yes |
| Industry-FE | Yes | Yes | Yes |
| State-FE | Yes | Yes | Yes |
| Cluster SE | Yes | Yes | Yes |

The table reports ordinary least-squares linear regressions. The regressions perform cluster-robust standard errors at the firm level. The regressions include the fixed effects for time/year, industry (SIC), and state (location) levels. Standard errors in parentheses. The characters report statistical significance at the 1%, 5%, and 10% levels, respectively *** p<0.01, ** p<0.05, * p<0.1.

**Table 5: Moderation effects**

| VARIABLES | (1)<br>Dividend/Assets | (2)<br>Dividend/Assets | (4)<br>Dividend/Assets |
|---|---|---|---|
| Temperature Anomaly × COP21 | -0.0004* | | |
| | (0.0002) | | |
| Temperature Anomaly × Disaster-Prone States | | 0.0003*** | |
| | | (0.0001) | |
| Temperature Anomaly × Vulnerability | | | -0.0002** |
| | | | (0.0001) |
| Temperature Anomaly | -0.0001** | -0.0002*** | -0.0000 |
| | (0.0000) | (0.0001) | (0.0001) |
| COP21 | 0.0050*** | | |
| | (0.0016) | | |
| Disaster-Prone States | | -0.0088* | |
| | | (0.0049) | |
| Vulnerability | | | 0.0007 |
| | | | (0.0005) |
| Firm Size | -0.0023*** | -0.0023*** | -0.0023*** |
| | (0.0002) | (0.0002) | (0.0002) |
| Book to Market | -0.0009*** | -0.0009*** | -0.0009*** |
| | (0.0001) | (0.0001) | (0.0001) |
| Log of Tobin's Q | 0.0041*** | 0.0041*** | 0.0041*** |
| | (0.0002) | (0.0002) | (0.0002) |
| Capex | -0.0119*** | -0.0119*** | -0.0118*** |
| | (0.0011) | (0.0011) | (0.0011) |
| R&D to Assets | -0.0029*** | -0.0029*** | -0.0029*** |
| | (0.0009) | (0.0009) | (0.0009) |
| Leverage | -0.0063*** | -0.0063*** | -0.0063*** |
| | (0.0004) | (0.0004) | (0.0004) |
| Operating cash flow | -0.0004** | -0.0004** | -0.0004** |
| | (0.0002) | (0.0002) | (0.0002) |
| Sga to Sales | -0.0002*** | -0.0002*** | -0.0002*** |
| | (0.0001) | (0.0001) | (0.0001) |
| Xad to Sales | 0.0130** | 0.0130** | 0.0134** |
| | (0.0055) | (0.0055) | (0.0055) |

| | | | |
|---|---|---|---|
| Constant | 0.0163*** | 0.0164*** | 0.0164*** |
| | (0.0053) | (0.0053) | (0.0052) |
| Observations | 128,307 | 128,307 | 128,307 |
| R-squared | 0.2789 | 0.2789 | 0.2790 |
| Year-FE | Yes | Yes | Yes |
| Industry-FE | Yes | Yes | Yes |
| State-FE | Yes | Yes | Yes |
| Cluster SE | Yes | Yes | Yes |

The table reports ordinary least-squares linear regressions. The regressions perform cluster-robust standard errors at the firm level. The regressions include the fixed effects for time/year, industry (SIC), and state (location) levels. Standard errors in parentheses. The characters report statistical significance at the 1%, 5%, and 10% levels, respectively *** p<0.01, ** p<0.05, * p<0.1.

**Table 6: Subsample Analysis**

| | Panel A: Firm size | | Panel B: Firm age | | Panel C: Tangibility | |
|---|---|---|---|---|---|---|
| | (1) Small Firms | (2) Large Firms | (3) Young Firms | (4) Old Firms | (5) Lower Tangibility | (6) Higher Tangibility |
| VARIABLES | Dividend/Assets | Dividend/Assets | Dividend/Assets | Dividend/Assets | Dividend/Assets | Dividend/Assets |
| Temperature Anomaly | -0.0001** | -0.0001* | -0.0001*** | -0.0000 | -0.0001 | -0.0001*** |
| | (0.0000) | (0.0001) | (0.0000) | (0.0000) | (0.0001) | (0.0000) |
| Firm Size | -0.0006*** | -0.0043*** | -0.0015*** | -0.0040*** | -0.0020*** | -0.0027*** |
| | (0.0002) | (0.0004) | (0.0002) | (0.0003) | (0.0004) | (0.0003) |
| Book to Market | -0.0007*** | -0.0010*** | -0.0008*** | -0.0008*** | 0.0001 | -0.0010*** |
| | (0.0001) | (0.0001) | (0.0001) | (0.0001) | (0.0001) | (0.0001) |
| Log of Tobin's Q | 0.0019*** | 0.0064*** | 0.0029*** | 0.0061*** | 0.0026*** | 0.0046*** |
| | (0.0002) | (0.0003) | (0.0002) | (0.0003) | (0.0003) | (0.0002) |
| Capex | -0.0082*** | -0.0177*** | -0.0153*** | -0.0195*** | -0.0093*** | -0.0120*** |
| | (0.0011) | (0.0021) | (0.0020) | (0.0012) | (0.0023) | (0.0012) |
| R&D to Assets | -0.0031*** | -0.0103*** | -0.0045*** | -0.0035*** | -0.0018* | -0.0029** |
| | (0.0007) | (0.0034) | (0.0011) | (0.0013) | (0.0011) | (0.0012) |
| Leverage | -0.0039*** | -0.0140*** | -0.0055*** | -0.0075*** | -0.0006 | -0.0077*** |
| | (0.0002) | (0.0013) | (0.0004) | (0.0005) | (0.0008) | (0.0004) |
| Operating cash flow | -0.0003** | 0.0140*** | -0.0005** | -0.0004 | 0.0006* | -0.0004* |
| | (0.0001) | (0.0018) | (0.0002) | (0.0003) | (0.0003) | (0.0002) |
| Sga to Sales | -0.0002*** | 0.0001 | -0.0002*** | -0.0002** | -0.0001** | -0.0002*** |
| | (0.0000) | (0.0002) | (0.0001) | (0.0001) | (0.0001) | (0.0001) |
| Xad to Sales | 0.0004 | 0.0234** | 0.0151** | 0.0181** | -0.0029 | 0.0220*** |
| | (0.0041) | (0.0091) | (0.0061) | (0.0084) | (0.0058) | (0.0069) |
| Constant | 0.0106 | 0.0285*** | 0.0252 | 0.0140*** | 0.0320*** | 0.0129* |
| | (0.0083) | (0.0038) | (0.0163) | (0.0049) | (0.0092) | (0.0072) |
| Observations | 61,034 | 67,273 | 62,020 | 66,287 | 19,775 | 106,227 |
| R-squared | 0.2137 | 0.3647 | 0.2448 | 0.3555 | 0.2178 | 0.3099 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Year-FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Industry-FE | Yes | Yes | Yes | Yes | Yes | Yes |
| State-FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Cluster SE | Yes | Yes | Yes | Yes | Yes | Yes |

The table reports ordinary least-squares linear regressions. The regressions perform cluster-robust standard errors at the firm level. The regressions include the fixed effects for time/year, industry (SIC), and state (location) levels. Standard errors in parentheses. The characters report statistical significance at the 1%, 5%, and 10% levels, respectively *** p<0.01, ** p<0.05, * p<0.1.

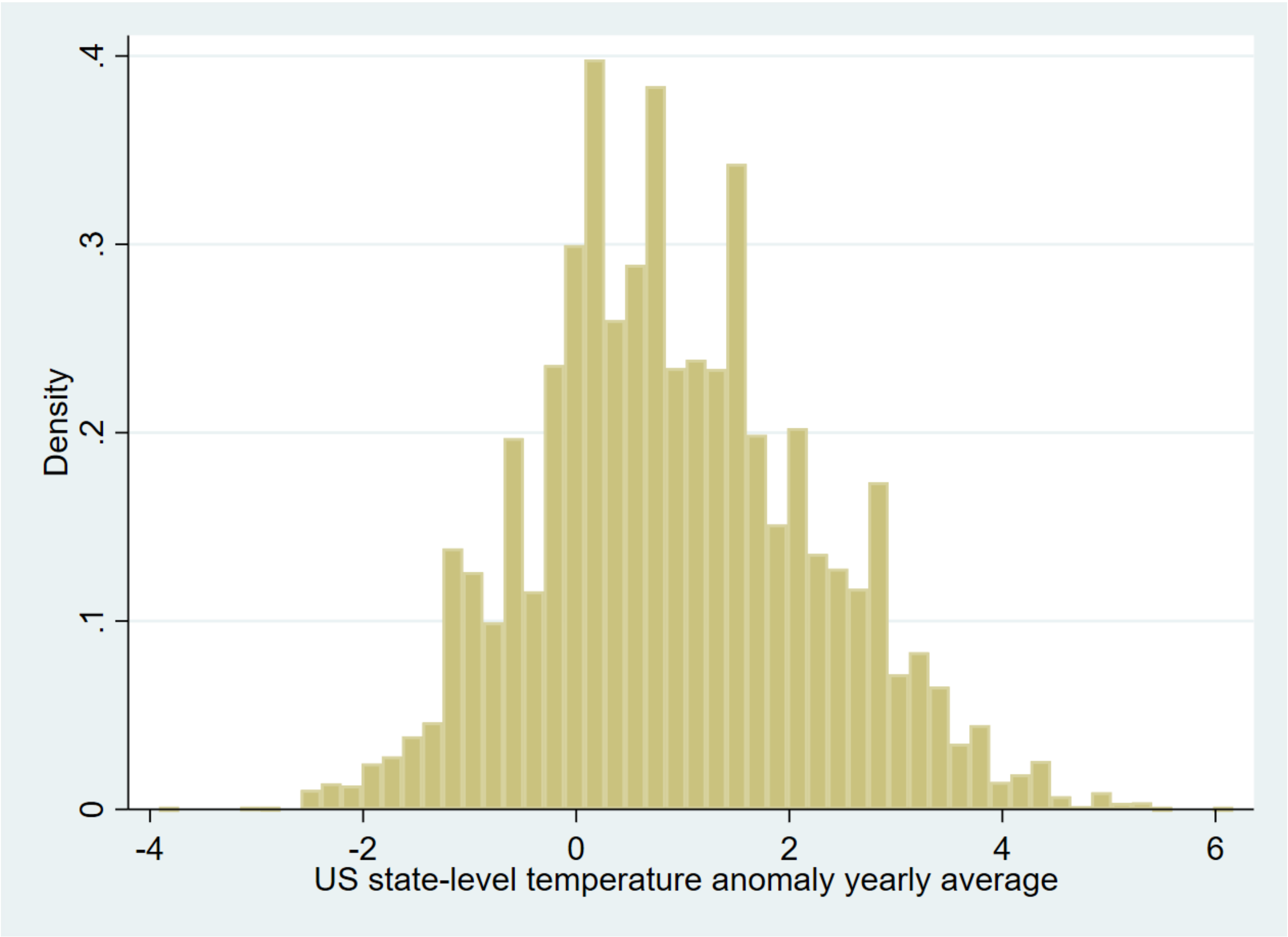


*Figure 2: US state-level temperature anomaly yearly average 1971-2020*[35].

[35] [Anomalies vs. Temperature | Did You Know? | National Centers for Environmental Information (NCEI) (noaa.gov)]

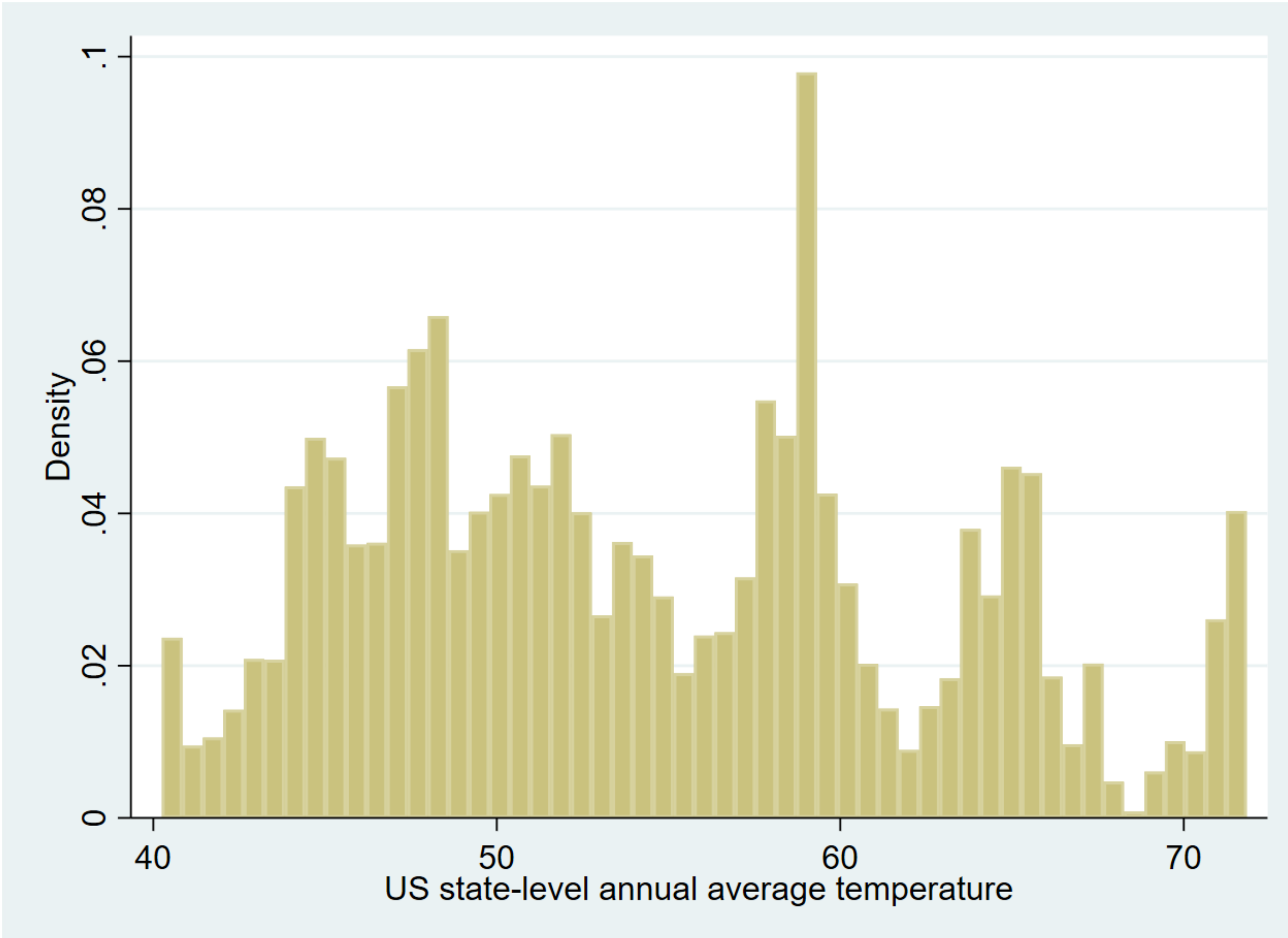


**Figure 3**: US state-level annual average temperature 1971-2020.[36]

[36] New maps of annual average temperature and precipitation from the U.S. Climate Normals | NOAA Climate.gov

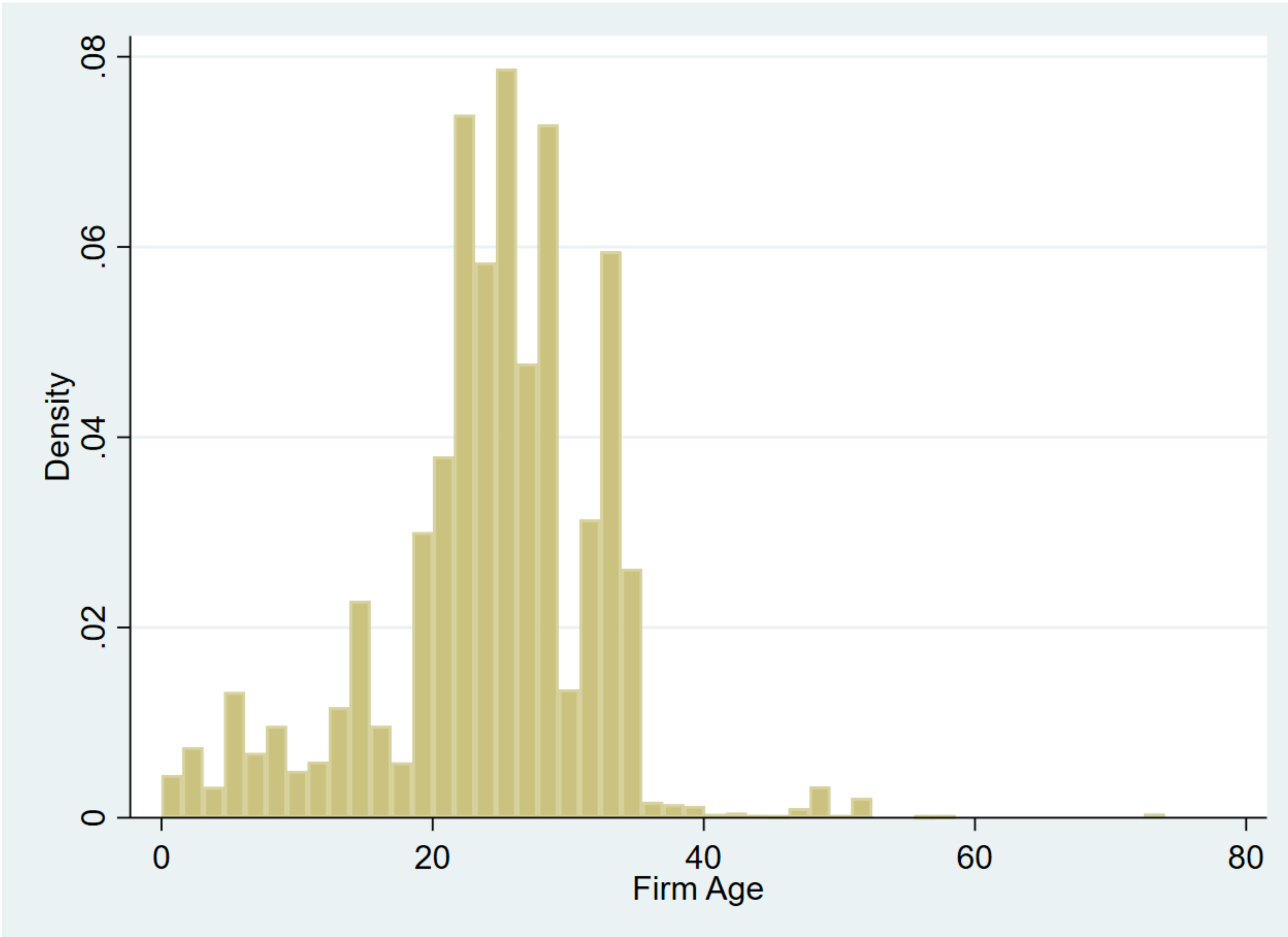


***Figure 4:*** Firm Age, 1971-2020. Source: Author’s work.


**Figure 5:** US Statewide Temperature Anomaly. Source: Raw datasets are extracted from NCEI-NOAA (2024b) and handled by the PhD candidate.

# **Chapter Two:** State-Level Climate Change and Corporate Financial Flexibility

## Introduction

Financial flexibility plays a critical role in risk management and corporate policies (Bonaimé et al., 2013); GAMBA and TRIANTIS (2008), affecting firm value. Regarding the capital structure theory, financial flexibility with unused debt capacity is crucial to firms' capital structure choices (Denis & McKeon, 2012). A firm's financial flexibility presents its value depending on the cost of capital, tax rates, growth prospects (maturity and life cycles), and capital reversibility (GAMBA & TRIANTIS, 2008). To make a simpler sense of the context of corporate financial flexibility, enormous literature documents the importance of cash balances, financing choices, and payout policies to firms' financial flexibility. Denis (2011) synthesizes a collection of articles on corporate liquidity to highlight the importance of cash policies toward corporate financial flexibility. The collection shows the burgeoning literature encompassing the consequences and determinants of corporate cash holdings, and how firms' cash reserves are closely linked to firms' flexibility considerations on their capital structure dynamics and payout choices. The context of financial flexibility implies whether, how, and to what extent firms' capacity to respond to unexpected changes in the firm's cash flow or investment opportunity mixes in a value-maximizing and timely manner. Since the collection of articles by Denis (2011), related streams of literature have continued investigating the ways firms could prepare themselves for liquidity shortfalls in the forms of their leverage targets, investment decisions, and payout policies (Bonaimé et al., 2013; Byoun, 2021; DeAngelo et al., 2017; Denis & McKeon, 2012; Fahlenbrach et al., 2020; Garmaise & Natividad, 2021; Kumar & Vergara-Alert, 2020; Rapp et al., 2014), with earlier established literature (DeAngelo & DeAngelo, 2007; GAMBA & TRIANTIS, 2008; Jagannathan et al., 2000; Erik Lie, 2005; Marchica & Mura, 2010).

In the era of climate change with global warming around the world, corporate financial flexibility becomes even more crucial when firms are dealing with escalating financial distress caused by climate-induced risks, with incremental liquidity shortfalls and ever-volatile earnings (Yuyuan Chang et al., 2024; Chava, 2014; Ginglinger & Moreau, 2023; Huang et al., 2018; S. Javadi & A.-A. Masum, 2021; Siamak Javadi et al., 2023; Nguyen et al., 2022; Pankratz et al., 2023). The roles of corporate financial flexibility in coping with such complex climate-induced risk drivers could be even more critical when firms are facing both demand and supply side effects of climate change risks (BROWN et al., 2021; Chava, 2014; Ginglinger & Moreau, 2023; S. Javadi & A.-A. Masum, 2021). For the US markets, climate change is geographically divergent with substantial complexity, imposing adverse, unpredictable impacts on firms. In this study, we aim to answer the following important questions. The first question is, how do we capture long-term climate change? The second question is how climate change affects the value of the financial flexibility of firms headquartered in the US.

Emerging literature has documented the impacts of climate change on corporate financial decisions, for which firms have been preparing themselves to deal with financial distress caused by climate change risks. For instance, firms adjust leverage for operating needs under climate, physical, and transition risks. In the context of physical risks, firms might prefer share repurchases over dividends to cope with financial distress. Recent studies show that firms are likely to hoard cash to reserve shrinking corporate liquidity caused by climate risks (Dimitrios

Gounopoulos & Yu Zhang, 2024; Siamak Javadi et al., 2023). Emerging studies have just focused on the ways that firms temporarily deal with climate risks in terms of their responsive financing choices. Such efforts provide foundational evidence on the climate change impacts; however, critical research gaps remain. In the era of global warming, the failure to adapt to climate change is placed at the top of the global risks due to its long-term severity[37]. This study contributes to related literature streams on climate change and corporate finance by investigating the impacts of long-term climate change on the value of financial flexibility. Some recent studies employ drought severity as a proxy for climate change (Huynh et al., 2020; S. Javadi & A.-A. Masum, 2021; Siamak Javadi et al., 2023); however, regarding NOAA, temperature anomalies are exhibited to be a benchmarked proxy to capture long-term climate change. For firms located in the US[38], the world's largest equity market, climatic conditions are divergent across the US states, with the temperature hitting extreme levels monthly[39]. State-level temperature anomalies [hereafter, SLTA] indicate global warming and benchmark local climate change by capturing the 30-year average difference from historical temperature values across the US states. Raising SLTA leads to diverse climatic conditions such as drought risks, heat waves, environmental degradation, degraded biodiversity, and many other abnormal climatic phenomena in the US and global economies[40]. Therefore, this study employs SLTA data to quantify geographically

[37] Global Risks Report 2023 | World Economic Forum | World Economic Forum (weforum.org)
[38] Climate Change: Global Temperature | NOAA Climate.gov
[39] Climate in the United States | USAFacts
[40] Consequences and Effects of Global Warming -- What is the Impact? (nrdc.org); What are the effects of global warming? (nationalgeographic.com); Effects - NASA Science; Climate change widespread, rapid, and intensifying – IPCC — IPCC; Causes and Effects of Climate Change | United Nations; 6 ways climate change is already affecting our lives | World Economic Forum (weforum.org).

divergent and long-term impacts of climate change [hereafter, SLCC] on the value of financial flexibility [hereafter, VOFF][41].

Using SLTA data, we benchmark long-term climate change risks with US state-level evidence. Also, instead of using single proxies of financial flexibility measures that are likely to correlate with prior corporate financial decisions, we employ forward-looking and market-based measures to capture the impact of climate change on the value of financial flexibility. Therefore, our current study offers insightful insights into the long-term implications of climate change on the value of financial flexibility over the past decades. With US state-level evidence, the study documents a long-term and adverse association between climate change risks and the value of financial flexibility. The long-term impacts of SLCC on the value of financial flexibility are adverse and persistent. Our findings are robust when we control for endogenous (e.g., corporate financial policies) and exogenous other climate risk drivers (e.g., physical and transitional risks) used in emerging literature. For the channel tests, the study documents significant mediating effects of financial leverage and PAYOUT FLEXIBILITY on the association between SLCC and VOFF. The impact of SLCC on VOFF has become statistically insignificant for dividend-paying firms with higher levels of cash holdings. For the moderation tests, we do not observe any significant and direct effects of other climate risk drivers on the VOFF under long-term climate change exposure across the US states. Overall, our findings show persistent and adverse impacts of SLCC on VOFF, implying chronic and negative consequences of climate change to firms with their robust decrease in VOFF.

[41] We use SLTA and SLCC interchangeably with the similar meaning and implications of climate change to firms located in the US states.

We theoretically explain the adverse association between SLCC and VOFF with the prospects of firms' growth opportunities. The predicted decrease in VOFF offers insightful evidence of the systematic risks of climate change to a firm's growth opportunity in the long term. Regarding Lang et al (1996), corporate future growth is negatively associated with leverage. The association between leverage and growth is sensitive to firms with a lower Tobin's Q ratio. Because leverage does not decrease growth for firms with profitable INV opportunities. Leverage is negatively associated with a firm's growth when the financial markets do not recognize its growth opportunities, or the firm might be unable to reconcile its debt levels. Our findings support this rationale by showing the long-term adverse impacts of climate change on VOFF. Our state-level evidence might imply that climate change risks decrease growth opportunities for firms. Our mediation tests show that dividend-paying firms present positive predicted VOFF. Regarding payout literature, dividend payouts convey the future growth prospects of firms to their shareholders. In the context of SLCC, with promising growth opportunities, dividend-paying firms present a positive predicted value of financial flexibility in the future. We observe that the negative impacts of climate change on VOFF become insignificant for firms with PAYOUT FLEXIBILITY and higher cash holdings for the interaction terms. For the single and direct relations, we find that firms with higher leverage and cash holdings present their predicted increase in VOFF. The predicted associations between SLCC and VOFF are robust when we control for local areas prone to natural disasters (e.g., disaster-prone states - DPS), and local transitional climate risks using a dummy variable that captures US states with state-led adaptation plans finalized (SAPF). Our broad findings imply that long-term climate change decreases growth opportunities for firms, leading to a persistent decrease in VOFF.

Our evidence on the exposure of SLCC to corporate financial flexibility offers related findings with the following contributions to the related finance streams of literature, with a specific focus on climate change. We complement the prior study by Huang et al. (2018) by implying the escalating severe exposure of climate change to firms with SLTA that leads to abnormal and more frequent physical climatic outcomes. Not just using SLTA for benchmarking climate change, we differentiate from Huang et al. (2018) by showing that firms decrease their long-term leverage targets with dynamic demands, but with weak statistical significance for short-term debts. To explain our findings, we argue that SLCC imposes related and more severe risks not just to firms on the demand side, but also to the supply side, such as banks, financial institutions, and stakeholders (Ginglinger & Moreau, 2023). Given that external financial choices become more costly (BROWN et al., 2021; Chava, 2014; Duan & Li, 2024; Huynh et al., 2020; S. Javadi & A.-A. Masum, 2021), firms are hindered from the ease of financial flexibility options by accessing capital markets. With both demand and supply effects, our SLCC evidence makes the points even more robust, with a constant predicted decrease in financial leverage ratios in the context of SLTA exposure to firms. Given the stringent accessibility to capital markets for financing operating needs, hoarding cash balances exhibits its critical role in maintaining financial flexibility when corporate liquidity is being shrinker due to climate change across the US markets. Aligned with Denis (2011) on corporate liquidity for the context of financial flexibility, we offer additional evidence on the roles of cash holdings when firms are exposed to climate risks (Dimitrios Gounopoulos & Yu Zhang, 2024; Siamak Javadi et al., 2023). Our findings retain their robustness when we test for capital structure theory in the form of unused debt capacity of firms (Denis & McKeon, 2012). Adding further to Denis and McKeon (2012), in the context of SLTA more specifically, proactive leverage increases might present even severe and clear conditions of firms' subsequent financial deficits due to climate-induced risks incurred by those firms through different stages of financial flexibility preparation (Byoun, 2021). Regarding Denis (2011), maintaining optimal cash balances with minimal leverage targets seems a reliable way that firms have relied on for their safeguarded financial flexibility in climate-related risk management.

Both risk management and payout decisions matter to corporate financial flexibility to mitigate financial distress costs as well as under-investment decisions (Bonaimé et al., 2013). Under the exposure of firms to severe climatic conditions, Yuyuan Chang et al. (2024) offer evidence of payout flexible distribution by arguing that firms favor share repurchase over dividends for their financial flexibility in the form of their payout decisions. Under the channels of operating volatility and financial constraints for which climate risks could affect firms' payout flexibility, Yuyuan Chang et al. (2024) argue that firms might substitute dividends with repurchases to have more flexible payout choices in the scenario of escalated and severe climatic conditions. Our evidence from SLTA differentiates our current study from Yuyuan Chang et al. (2024) by showing that, under long-term and more benchmarking climate change, firms give up their payout choices in the form of both share repurchases and dividends paid to their shareholders. Our first explanation for such findings is that, in the context of financial flexibility, favoring share repurchases over dividends for payout flexibility (PAYOUT_FLEX) could depend on how flexible a firm's financial conditions were in prior financial years. Even with the standalone effects of SLCC, we find a negative association between SLTA and payout choices as well as PAYOUT FLEXIBILITYmeasures. Another explanation is that different measures could reflect a variant nature of climate change that might impose subsequent effects on corporate decisions. Accounting for the geographical divergence of climate change, our SLTA overcomes such challenges and is aligned with the literature on climate economics, which is modernly surveyed by Tol (2024)[42]. With SLTA evidence, we add novelties to corporate financial flexibility in the forms of payout choices (Bonaimé et al., 2013; Brav et al., 2005; Chay & Suh, 2009; DeAngelo & DeAngelo, 2007; Iyer & Rao, 2017; Jagannathan et al., 2000; Kahle & Stulz, 2021; Kumar & Vergara-Alert, 2020; Erik Lie, 2005; Rapp et al., 2014), given the context of escalating challenges of climate change for economics (Nordhaus, 2019b) and established streams of literature on economics of climate change (Guest, 2010; McKibbin & Wilcoxen, 2002; Stern, 2008; Weitzman, 2007).

With evidence from SLCC in the context of corporate financial flexibility, this current study also contributes to broader streams of finance literature as follows. Since global warming, proxied by SLTA, emerged in the US some decades ago, SLCC could be a long-lasting determinant of corporate policies. Costly financial distress and constraints could be escalated further given the financial inflexibility becoming severe to firms that are highly vulnerable to climate risks, leading to their subsequent corporate deleveraging (Ginglinger & Moreau, 2023; Nguyen & Phan, 2020; Nguyen et al., 2022). Given the escalating climatic abnormal phenomenon, here is SLTA in our context, firms would mostly deleverage from their historical peak leverage targets to secure their ample financial flexibility, which could be challengingly reconciled by most firms, given the widespread climate change. Our findings are theoretically framed in the prior study by DeAngelo et al. (2017) by suggesting the inevitable determinant, namely, climate change. Since the Paris Agreement, stakeholders have exhibited their increasing awareness with a premium demanded by investors exposed to climate risk drivers (Andersson et al., 2016;

[42] Such challenges have been increasingly documented in modern literature with working papers on firm-level climate change exposure as well as the puzzling perspectives of corporate ESG/CSR angles.

Bolton & Kacperczyk, 2021; PATRICK BOLTON & MARCIN KACPERCZYK, 2023b; Shaojun  Zhang, 2024). With shrinking retained earnings, corporate liquidity could be a priority given the increasing cash-flow sensitivity of firms to both climate transition and physical risks. With the SLCC exposure, firms exhibit conservative to speedy leverage adjustments (Nguyen et al., 2022), given costly external financing choices (BROWN et al., 2021; Chava, 2014; Duan & Li, 2024; Huynh et al., 2020; S. Javadi & A.-A. Masum, 2021). To mitigate costly financial distress and liquidity shortfalls, our evidence from SLCC could complement prior studies on excessive cash holdings by firms (Almeida et al., 2004; Asem & Alam, 2014; BATES et al., 2009), for which a firm's cash balances and corporate liquidity are closely linked to its payout policy (Brav et al., 2005; Chay & Suh, 2009; Denis, 2011).

To sum up, more briefly, our study contributes to at least three streams of corporate finance literature for climate risk management by looking at temperature anomalies as a benchmarking proxy for climate change. At first glance, not just corporate cash holdings to hedge cash flow volatility due to climate change risks (Dimitrios Gounopoulos & Yu Zhang, 2024; Siamak Javadi et al., 2023), climate change adversely affects corporate long-term debt by making firms more financially flexible, with a predicted poor financial performance. Under the pressure of global warming, consistent with the literature (Rapp et al., 2014), the value of financial flexibility and corporate financial policy is empirically exhibited when firms' accounting performance is adversely affected by climate risk, and shareholders prefer share repurchases to dividends with lower book leverage ratios. Given the long-term severe impacts of climate risk across the contiguous US states, firms are likely to increase their cash reserves and decrease corporate long-term debt. With the US state-level evidence on the long-term severe impacts of climate risk, our study complements the nascent climate finance literature by showing the values of corporate financial flexibility, payout policies, and capital structure choices (Bonaimé et al., 2013; Byoun, 2021; DeAngelo et al., 2017; Denis & McKeon, 2012; Fahlenbrach et al., 2020; GAMBA & TRIANTIS, 2008; Garmaise & Natividad, 2021; Kumar & Vergara-Alert, 2020; Marchica & Mura, 2010; Rapp et al., 2014) with fast-growing attention to climate-related risks in finance literature (Bolton & Kacperczyk, 2021; PATRICK BOLTON & MARCIN KACPERCZYK, 2023b; Ceccarelli et al., 2023; Duan et al., 2023; Ginglinger & Moreau, 2023).

## Literature and Hypotheses

### The value of financial flexibility

Emerging literature has documented the impacts of climate risk drivers on corporate financial policies. For instance, polluting firms exposed to climate transition risks might need to give up their dividends paid to shareholders due to earnings uncertainty (Balachandran & Nguyen, 2018). Transition risks induce polluting firms to have limited access to credit, affecting corporate financial policies (Dang et al., 2023; Dang et al., 2025). While Huang et al (2015) argue that firms might opt to increase long-term debt leverage for their financing needs when exposed to physical risks, going beyond the demand side by firms, climate-induced leveraging by firms is also caused by increasing concern about climate change from stakeholders. Recent studies by Dimitrios Gounopoulos and Yu Zhang (2024); Siamak Javadi et al. (2023) show that firms might hoard cash to safeguard themselves from climate change risks. Prior literature on financial flexibility highlights the roles of corporate liquidity and credit access when firms need to finance operating needs. While firms might flexibly adjust their financing choices for operating needs, climate risk drivers impose inevitable adverse impacts on a firm's growth opportunities. With escalated uncertainty in corporate earnings, leveraging could even bring greater challenges to firms because debt leverage could be hard to reconcile. Also, liquidity could be an effective hedging tool for corporate financial flexibility temporarily in the short term; however, chronic climate risks could systematically degrade the value of financial flexibility in the longer term. Using an aggregated market-based and forward-looking measure to capture the value of financial flexibility for firms, with state-level evidence from US long-term climate change, we posit the following main hypothesis. Regarding the theoretical model of Gamba and Triantis (2008), along with growth opportunities and profitability, the effective costs of cash holdings, external financing, and capital reversibility are the critical determinants of the value of financial flexibility. As all these factors reflect the firm's business model and its external environment. On the other hand, these factors could be independent of the current financing policies. Regarding the trade-off theory of capital structure, firms may define financial leverage levels by balancing the tax versus debt financing benefits against the costs of financial distress (Ai et al., 2021; Miller, 1977). Climate exposure risks have caused increasing bankruptcy risk (Feng et al., 2024), leading to more pronounced effects on exposed firms with higher asset tangibility, cash flow volatility, or profit volatility. Also, climate risks induce firms to have higher-cost external financing choices (Huynh et al., 2020; Nguyen et al., 2022). Given both the demand and supply-side effects (Ginglinger & Moreau, 2023), the climate-induced decrease in corporate leverage implies a predicted lower value of financial flexibility to firms.

**H1:** Based on the theoretical predictions, including the trade-off theory, with potential increases in bankruptcy risks and constrained unused debt capacity, SLCC induces a predicted decrease in VOFF for firms.

### Corporate payout policies

Payout policy is critical to risk management, with more flexible financing conditions created for firms. Under physical climate risks, firms might decrease dividends paid to shareholders and use share repurchases for their payout flexibility. While access to credit could be a challenge for polluting firms in some countries, like the US and Australia, under climate transition risks (Dang et al., 2023; Dang et al., 2025), increasing long-term debt and hoarding cash reserves could be a solution for firms in dealing with climate change impacts (Dimitrios Gounopoulos & Yu Zhang, 2024; Huang et al., 2018; Siamak Javadi et al., 2023). Acknowledging the severe long-term climate change impacts imposed on firms, flexible financing choices could be helpful to firms in the short term. Motivated by emerging literature, we develop our second hypothesis as follows.

**H2:** As SLCC may systematically affect a growth prospect of firms, payout flexibility, leverage, and cash holdings present mediating roles to the impacts of long-term climate change on a firm's value of financial flexibility.

Regarding the signaling theory, firms may make use of flexible payout decisions (e.g., dividends vs. repurchases) to cope with the systematic effect of SLCC on VOFF, due to severe and possibly undiversified growth prospects.

### Climate risks and emerging finance literature

While prior studies focus on firms' polluting levels to define how climate transition risks could affect a firm's financial policies, transitional efforts could present a long lag from the real and timely phenomena of climate change impacts on institutions and the economy. For instance, while temperature anomalies appeared many decades ago, international treaties for climate action have been formed in recent decades for our carbon neutrality targets. Like other temporary physical risks employed in the recent literature (Adrian et al., 2023; Ginglinger & Moreau, 2023; Hong et al., 2019; Huynh et al., 2020; S. Javadi & A.-A. Masum, 2021; Nguyen et al., 2022), the consequences of multiple-decade climate change are caused by greenhouse gas emissions. Using state-level temperature anomaly as the benchmark measure for long-term climate change risks, we develop our third hypothesis below.

**H3:** The association between long-term climate change and the value of financial flexibility is moderated by transitional and physical climate risk drivers.

Our third hypothesis validates two important points. First, the study mitigates endogeneity issues by benchmarking the long-term climate change across the US states. With state-level evidence, the study also accounts for the geographical aspects of climate change impacts on firms. Endogeneity issues could be mitigated further with a predicted persistent association between SLCC and a firm's value of financial flexibility, controlled for other types of climate risk drivers. Overall, the study shows severe consequences of long-term climate change to firms' growth prospects, with a decreased value of financial flexibility. Our third hypothesis strengthens our 1st and 2nd developed hypotheses when we control for endogenous and exogenous factors. Since firms have been chronically exposed to long-term climate change risks, the global economy is transitioning to its net-zero target by 2050[43]. Consequently, firms are not just exposed to local risks, but also international climate transition risk, with the treatment effects of the Paris Agreement (COP21). The circumstance could be significant for listed firms in a highly internationalized financial market like the US[44]. By the fact, the study examines the potential moderating effects of both local transition risks with State-led Adaptation Plans Finalized (SAPF) and international transition risk (COP21) on the relationship between SLCC and VOFF.

[43] Net Zero by 2050 | OECD; The What, When, and How of Net-Zero Emissions | World Resources Institute; 2050 long-term strategy - Climate Action - European Commission

[44] See, Jeffrey A. Frankel. 2019. The Internationalization of Equity Markets. University of Chicago Press. https://www.nber.org/books-and-chapters/internationalization-equity-markets.

## Methodology, Models, and Data

### Estimating the Value of Financial Flexibility (VOFF)

Based on the theoretical framework of GAMBA and TRIANTIS (2008), financial flexibility is defined as a firm's ability to access financing sources at a low cost with possible restructuring. The study argues that financial flexibility brings value to firms with mitigated under-investment due to insufficient financing sources, avoiding financial distress. We hereby follow the literature to construct a market-based and forward-looking measure to capture the value of financial flexibility (VOFF) with its five determinants. The five empirical determinants of VOFF are described as follows:

i) The first determinant is a firm's growth opportunities. Consistent with the literature (Rapp et al., 2014), a firm's growth opportunities are captured by its logarithm form's sales growth rate ($SGR_{i,t}$). Regarding GAMBA and TRIANTIS (2008), growth opportunities are positively associated with a firm's VOFF, with a correlation to cash flow uncertainty. Therefore, VOFF is critical to firms with high-growth opportunities

ii) The second determinant is a firm's profitability. We employ the change ratio of a firm's earnings $\Delta E_{i,t}$ scaled by its market capitalization $M_{i,t-1}$. We capture $E_{i,t}$ using a firm's earnings before extraordinary items, plus deferred taxes and interest. Consistent with the literature (Rapp et al., 2014), the study employs changes in $E_{i,t}$ to capture the intertemporal differences in the firm's operating health. Firms with higher profitability could use internal cash flow, leading to lower VOFF (GAMBA & TRIANTIS, 2008).

iii) The third determinant is the effective cost of cash holdings $T$, which is captured by the level of corporate and personal tax rates (Chen et al., 2010). $T$ is determined by the difference between individual tax rate $T_{It}$ and corporate tax rate $T_{Ci,t}$. Hence, we define $T_{i,t}= T_{Ci,t}/T_{It}$. $T_{Ci,t}$ is the corporate effective tax rate, indicating the ratio of cash taxes paid to its pretax income in the year $t$ for a firm $i$. $T_{It}$ is the annual individual federal income tax rate for the median-income households in the US[45]. When the effective cost of cash holdings, $T_{i,t}$ is higher than one, the corporate taxation is more heavily on firms, leading to higher effective costs a firm might incur to hold cash. Therefore, shareholders could have a greater incentive to hold more cash, leading to a lower VOFF for the firm.

iv) The fourth determinant is the cost of external financing, captured by the bid-ask spread of a firm's stock (Anderson et al., 2009). The cost of external financing could affect a firm's VOFF via two possible channels. First, a higher cost of external financing choices could increase the firm's VOFF because external financing sources are time-consuming and costly to firms. Second, higher external financing costs could convey escalating agency problems of a firm due to a concern about managerial expropriation (Jensen, 1986; Rozeff, 1982). Hence, shareholders could attribute a lower VOFF to mitigating agency costs.

v) The fifth determinant is capital reversibility, captured by a firm's tangibility. Corporate tangibility is measured as the ratio of the firm's property, plant, and equipment values to its total assets. Given that a firm's shareholders could

[45] Historical U.S. Federal Individual Income Tax Rates and Brackets In Nominal Dollars, Income Years 1862-2021, data extracted as of 2024-09-22 from https://taxfoundation.org/data/all/federal/historical-income-tax-rates-brackets/; Who Pays Federal Income Taxes? | IRS Federal Income Tax Data, 2023; Who Pays Federal Income Taxes? Latest Federal Income Tax Data

liquidate fixed assets with a low discount, this could lower the firm's VOFF. Therefore, a firm's tangibility (capital reversibility) could be negatively associated with its VOFF. A large percentage of tangible assets can help businesses because they ease financial limitations and permit additional investment (Campello & Hackbarth, 2012).

Based on the five theoretically motivated determinants, which are consistent with prior studies (GAMBA & TRIANTIS, 2008; Rapp et al., 2014), the study empirically aggregates them into a single VOFF proxy. The study constructs a capital market-based and forward-looking method that relies on the relevant value of changes in corporate cash holdings, the most important measure for corporate liquidity, toward a firm's financial flexibility. Hence, the aggregated VOFF measure used for this study captures the shareholders of a firm assigned to its financial flexibility. Unlike other single financial flexibility measures used in the literature (Rapp et al., 2014), a firm's historical financial decisions do not affect our market-based and forward-looking VOFF measure, mitigating endogeneity issues. In a firm's capital structure choices, for example, the current leverage levels determine the capacity that the firm could borrow in the upcoming years, moderating its financial flexibility. Also, to explain why some firms might have higher leverage ratios than others, a possible explanation is that their shareholders might assign a higher level of VOFF to the firm.

The aggregation method includes three steps for our VOFF measure. The first step is calculating the five proxies of the VOFF described above based on the theoretical frame of GAMBA and TRIANTIS (2008). Those five determinants reflect the important aspects of a firm, including the business model of the firm and externality, which are both independent of the firm's financial position. The next step is defining appropriate weights assigned to the five determinants of

VOFF. For assigning weights, we follow Faulkender and Wang (2006) to quantify the marginal value of a firm's cash with the reactions of capital markets to changes in a firm's cash holdings. Regarding the literature, cash ratios are the most liquid measure of a firm's financial flexibility. By regressing changes in a firm's market capitalization on the five determinants of VOFF interacted with a firm's cash changes, the predicted coefficients can then be used for our weighing assignments when aggregating all five factors for our aggregated VOFF measure at a later stage for each of our sample firms.

We define a firm's unexpected changes in its cash holdings using the following equation:

$$\frac{\Delta C_{i,t}}{M_{i,t-1}} = \alpha_0 + \alpha_1 Tobin's\, Q_{i,t-1} + \alpha_2 \frac{CFAL_{i,t-1}}{M_{i,t-1}} + \alpha_3 SIZE_{i,t-1} + \epsilon_{i,t} \quad (1)$$

$\Delta C_{i,t}$ is the change in a firm's cash holdings, which is the difference between the current cash level, $C_{i,t}$ and its cash holdings in the previous year $C_{i,t-1}$. $M_{i,t-1}$ is the firm's market equity (capitalization) market value in the previous year. $Tobin's\, Q_{i,t-1}$ is the lagged value of Tobin's Q ratio, which is calculated as the product of total assets and market capitalization minus book value of equity, scaled by total assets. $CFAL_{i,t-1}$, it is the lagged value of a firm's earnings before extraordinary income, depreciation, and after dividends. $SIZE_{i,t-1}$ is the lagged value of a firm's size that is calculated as its logarithm value of one plus its total assets, adjusted for inflation.

Once the unexpected changes in cash holdings are predicted using Equation (1), we then examine the reactions of capital markets by using the following regression model:

$$r_{i,t} - R_{i,t}^{B} = \beta_0 + \beta_1 \frac{\Delta C_{i,t}}{M_{i,t-1}} + \beta_2 \Delta SGR_{i,t} + \beta_3 \frac{\Delta E_{i,t}}{M_{i,t-1}} + \beta_4 T_{i,t} + \beta_5 SPREAD_{i,t} + \beta_6 TANG_{i,t}$$

$$+ \beta_7 SGR_{i,t} \times \frac{\Delta C_{i,t}}{M_{i,t-1}} + \beta_8 \frac{\Delta E_{i,t}}{M_{i,t-1}} \times \frac{\Delta C_{i,t}}{M_{i,t-1}} + \beta_9 T_{i,t} \times \frac{\Delta C_{i,t}}{M_{i,t-1}}$$

$$+ \beta_{10} SPREAD_{i,t} \times \frac{\Delta C_{i,t}}{M_{i,t-1}} + \beta_{11} TANG_{i,t} \times \frac{\Delta C_{i,t}}{M_{i,t-1}} + \beta_{12} \frac{C_{i,t-1}}{M_{i,t-1}} + \beta_{13} \frac{\Delta NA_{i,t}}{M_{i,t-1}}$$

$$+ \beta_{14} \frac{\Delta RD_{i,t}}{M_{i,t-1}} + \beta_{15} \frac{\Delta I_{i,t}}{M_{i,t-1}} + \beta_{16} \frac{\Delta D_{i,t}}{M_{i,t-1}} + \beta_{17} L_{i,t} + \beta_{18} \frac{NF_{i,t}}{M_{i,t-1}} + \beta_{19} Z_{i,t}$$

$$+ \epsilon_{i,t} \quad (2)$$

$r_{i,t} - R_{i,t}^{B}$ is a firm's abnormal stock return, calculated as the difference between a firm's stock return $r_{i,t}$ and benchmark portfolio return $R_{i,t}^{B}$. To quantify the reaction of capital markets to unexpected cash changes, we regress a firm's abnormal stock returns on the firm's unexpected cash changes $\frac{\Delta C_{i,t}}{M_{i,t-1}}$, five determinants of VOFF, and the interactions between the five determinants of VOFF and unexpected changes in the firm's cash holdings. We also include a diverse set of firm-level control variables including changes in a firm's net assets $\Delta NA_{i,t}$, research and development expenditure $\Delta RD_{i,t}$, interest expense $\Delta I_{i,t}$, common DIVs paid $\Delta D_{i,t}$, MKT_LEV $L_{i,t}$, net financing $NF_{i,t}$, industry and year dummy variables $Z_{i,t}$.

Using the weights of the interaction terms extracted from Equation 2, we estimate the VOFF measure based on the five determinants. Our VOFF measure is estimated using the following equation.

$$VOFF_{i,t} = \beta_1 + \beta_7 SGR_{i,t} + \beta_8 \frac{\Delta E_{i,t}}{M_{i,t-1}} + \beta_9 T_{i,t} + \beta_{10} SPREAD_{i,t} + \beta_{11} TANG_{i,t} \quad (3)$$

## Empirical models

Using the aggregated VOFF measure, we set up the following empirical models to examine the impacts of SLCC on VOFF with potential moderators.

$$VOFF_{i,t} = \beta_0 + \beta_1 SLCC_{s,t-1} + \beta_k \sum_{i=0}^{n} X_{i,t-1} + \varepsilon_{i,t} \qquad (4)$$

$$VOFF_{i,t} = \beta_0 + \beta_1 SLCC \times M_{s,t-1} + \beta_2 SLCC_{i,s,t-1} + \beta_3 M_{i,s,t-1} + \beta_k \sum_{i=0}^{n} X_{i,t-1} + \varepsilon_{i,t} \qquad (5)$$

The characters $i$, $s$, and $t$ indicate firm $i$ located in the State $s$ in year $t$. We benchmark long-term SLCC using the yearly-mean state-level temperature anomaly (SLTA). $X$ indicates a vector of control variables including firm size (SIZE), corporate investment (INV), working capital (WC), dividend payout (DIV), operating expense (OX), research and development expenditure (R&D), and Tobin's Q ratio (Q). While Equation 4 establishes the association between SLCC and VOFF, Equation 5 tests for the potential endogenous and exogenous factors for the mediation and moderation (M) tests, respectively.

For the literature-based endogenous mediating factors, we test for corporate dividend payout, financial leverage, and corporate cash holdings. We test physical and transitional climate risk drivers as our exogenous moderators of interest. For the physical risk, we employ a disaster-prone state (DPS) dummy that is set to one for US states with long-term proneness to natural disasters; otherwise, it is set equal to zero. For transitional climate risk, we employ the SAPF (SAPF) that is set equal to one for firms located in a US state with SAPF; otherwise, it is set equal to zero. SAPF captures local state-level climate action for which firms are exposed to transitional risks. The study employs the Paris Agreement (COP21) as a global climate transition risk to US firms under the SLCC exposure. Since the Paris Agreement was adopted in 2015, COP21 is a time dummy variable set equal to one for the post-2015 period; otherwise, it is set equal to zero. The study implements dynamic panel data regressions with our independent variables lagged for one year. Consistent with prior literature (Adrian et al., 2023; Huynh et al., 2020; Nguyen et al., 2022), the study implements panel data regressions including fixed effects (FE) for time/year, industry, and state levels. Standard errors are clustered by firm.

## Data sources

### *Statewide climate change data*

The study benchmarks climate change data by collecting monthly statewide time series for temperature anomalies from NCEI-NOAA[46]. Temperature anomalies benchmark climate change by capturing the long-term historical difference between current temperature values of US states and their historical 30-year average or more benchmarked temperature records. A positive value of state-level temperature anomalies [SLTA] indicates that a specific state is warmer than its normal historical 30-year average temperature, while a negative value of SLTA indicates that a specific state is cooler than its normal historical average value. Given the monthly time series for SLCC, we then take the yearly average value for SLTA to merge with the COMPUSTAT data. For climate science, temperature anomalies play a more crucial role in capturing climate change. Tol (2024) provides a modern meta-analysis of the economic impacts of climate change, highlighting those earlier studies that miss temperature change in modeling climate change. Temperature change leads to other kinds of climatic outcomes, such as drought risk, natural

[46] Climate at a Glance | Statewide Time Series | National Centers for Environmental Information (NCEI) (noaa.gov)

disasters, and diverse physical risks that have been examined in the related literature (Adrian et al., 2023; Yuyuan Chang et al., 2024; Ginglinger & Moreau, 2023; Huang et al., 2018; Huynh et al., 2020; S. Javadi & A.-A. Masum, 2021; Nguyen et al., 2022). More recently, Dimitrios Gounopoulos and Yu Zhang (2024) made use of monthly temperature values to forecast corporate cash holdings. Recalling the meta-analysis by Tol (2024), our study benchmarks the importance of real climate change in the longer term by using temperature anomalies. With the state-level data, the study captures the geographical divergence of climate change across the US states where our sample firms are headquartered.

### *Firm-level financial accounting data*

The study extracts financial accounting data from the COMPUSTAT Annual File. While NCEI-NOAA offers SLCC data dating back to 1895, we follow (Kahle & Stulz, 2021) to collect corporate data from COMPUSTAT starting from 1971 onward. The reason is that data on corporate payouts available comprehensively for listed firms located across the US states starts from the 1970s. Regarding Bonaimé et al. (2013); Denis (2011); Denis and McKeon (2012), payout choices are critical to a firm's financial flexibility. We stop our sample in the year 2019, which is before the COVID-19 pandemic, for modeling the long-term impacts of SLCC on corporate financial flexibility measures as our main dependent variables of interest. We merge SLCC data with firms' headquarters in their US states [STATE] every year. Comparable to the literature (Denis, 2011; Denis & McKeon, 2012), we remove financial firms [SIC 6000-6999] and utility firms [SIC 4000-4999] for our empirical research. After matching SLCC with firms' headquarters, our sample covers roughly 127,337 state-firm-year observations from 1970 to 2019. In the spirit of finance literature (Brogaard et al., 2017; Fang et al., 2009; FANG et al., 2014), to mitigate the potential effects of outliers, we winsorize all the continuous firm-level variables at the 1st and 99th percentiles. This is a common approach in finance literature to mitigate the potential effects of outliners in the used sample.

## Findings

[Table 1 Inserted Here]

Table 1 reports the sample used for empirical findings. The non-financial sample includes 112,840 state-firm-year observations for the period 1980-2019. SLCC presents a mean value of 1.136, ranging from -1.917 (minimum) to 4.250 (maximum), with a standard deviation of 1.252. The values indicate that US states experience a mean value of 1.136 Degrees Fahrenheit warmer than their normal temperature for the base period of 1901-2000. With a maximum value of 4.250 and a standard deviation of 1.252, the findings show that US states have experienced abnormally warmer temperatures, showing long-term climate change compared to their normal values. The sample firms present a mean of 0.068 for the value of financial flexibility (VOFF), ranging from 0.051 (minimum) to 0.083 (maximum), with a standard deviation of 0.665. For the period 1980-2019, the VOFF of the current study presents a relatively lower mean value with a higher standard deviation compared to Rapp et al. (2014) for the period 1988 and 2010[47].

[Table 2 Inserted Here]

Table 2 reports the baseline regressions. The findings show a negative association between SLCC and VOFF. Statistically, a unit increase in SLCC induces a 0.004-unit decrease in VOFF. The findings are consistent with our control variables, reported in Column 2. For the additional

[47] In Table 3 Panel A, the study of Rapp et al (2014) does not provide the minimum and maximum values. Also, the study does not provide COMPUSTAT variable codes for replication. Through reading the article, the current study replicates prior literature approximately.

control variables, we observe a negative association between firm size (SIZE), capital expenditure (INV), operating expense (OX), Tobin's Q, and VOFF. We observe a positive association between WC, R&D, and VOFF.

Regarding Huang et al. (2018), climate risks impose volatility on firms' earnings, leading to decreased short-term leverage. Firms might need to increase their long-term leverage ratios for financing needs. When firms are exposed to climate physical risks, they might have less access to credit, leading to decreased leverage ratios. Limited accessibility to credit sources is documented when firms are exposed to climate transition risks. For instance, the Kyoto Protocol serves exogenous shock to the credit accessibility of polluting firms, leading to lower leverage ratios. Recent studies document the value of cash holdings for firms when they are exposed to physical climate risks. Under uncertainties, financial flexibility is valuable to firms for operating needs. Changes in growth opportunities could moderate a firm's corporate debt structure and maturity. For instance, Goyal et al. (2002) provide evidence from the US defense industry, showing that, when growth opportunities decline, firms use more debt financing. The study also documents that corporate debt maturity could be lengthened as their growth opportunities decline. In the context of diverse climate change risks, firms could become more conservative about growth opportunities with increasingly uncertain earnings. While financial flexibility could be valuable to firms for financing operating needs, the impacts of climate change are widespread with increasing severity worldwide. Given the context, VOFF might not be able to safeguard firms' operating needs in the longer term when their growth opportunities are shrinking than ever due to various sources of climate risk drivers. With state-level evidence, our findings empirically show that long-term climate change is adversely associated with VOFF. Our findings could be supported by the rationale that, while VOFF is critical to firms to finance their financing needs, climate change could downgrade VOFF given its demand and supply effects. For the demand side, as debt levels could be challenging for firms to reconcile (DeAngelo et al., 2017). Hence, with uncertain growth prospects, firms might reserve their ample financial flexibility by deleveraging debt levels. On the supply side, stakeholders present their increasing concerns about climate change impacts. For instance, loan officers might decrease loan approval rates with higher interest rates imposed on loan financing amounts (Duan & Li, 2024), leading to higher costs of bank loans (S. Javadi & A.-A. Masum, 2021). Investors might demand for climate premium to hold securities exposed to climate change risk drivers for stock and bond markets (Bolton & Kacperczyk, 2021; PATRICK BOLTON & MARCIN KACPERCZYK, 2023b; Huynh & Xia, 2021; Huynh & Xia, 2023; Shaojun Zhang, 2024).

[Table 3 Inserted Here]

Degraded growth opportunities might explain the predicted decrease in VOFF under SLCC exposure. Table 3 reports the regressions of the market-to-book value (MB) on SLCC testing for firm size. The findings document a robust adverse association between MB and SLCC. The findings retain their statistical significance for large firms. For the VOFF, there are advantages and disadvantages to cash holdings. Managers and shareholders may have agency issues due to (large) cash holdings (Jensen, 1986). According to Myers and Majluf (1984), cash holdings, on the other hand, enable businesses to swiftly finance investment possibilities when external financing, such as debt or equity, is expensive and/or time-consuming. Funding investments with cash holdings is faster and less susceptible to possible market disruptions than debt financing. Equity financing is the most time-consuming method of funding an investment and, more significantly, is also impacted by market mood. According to Denis and Sibilkov (2009), changes in cash flow have a positive correlation with firm value in this context. For firms that have trouble obtaining external funding sources, such as because banks won't give them money, this relationship is stronger. Therefore, firms with a high VOFF are expected to have higher cash holdings. Regarding  Chen and Zhao (2006), firms with greater market-to-book ratios have higher profitability and lower borrowing costs, implying that taking on more debt is advantageous. The "classical" trade-off hypothesis states that when firms choose their capital structure, they weigh the tax advantages of debt against the risks of bankruptcy. However, empirical data indicate that observed leverage ratios fall short of theoretical expectations. Firms seem to stray from the ideal level of leverage, leaving large sums of money unaccounted for (Graham, 2000; Miller, 1977). According to DeAngelo et al. (2011); Denis and McKeon (2012); Graham and Harvey (2001), debt conservatism may be explained by financial flexibility. According to this viewpoint, firms keep a portion of their loan capacity to swiftly finance unforeseen cash flow shocks and/or future investment initiatives. Firms can raise debt faster than they can with equity funding. In the context of long-term SLCC, the findings show that long-term climate change induces a decrease in MB, and the predicted climate-induced decrease in VOFF is persistent for firms with high MB ratios. While prior literature focuses on firms' responsive financial policies to climate risk exposures (Ginglinger & Moreau, 2023; Dimitrios Gounopoulos & Yu Zhang, 2024; Huang et al., 2018; Siamak Javadi et al., 2023), the findings complement prior studies by showing the long-term severity of SLCC on corporate financial flexibility. Notably, a decrease in VOFF caused by SLCC is significant for high-MB firms.

[Table 4 Inserted Here]

Table 4 reports the findings of channel tests for endogenous moderators. The findings show a negative and statistically significant association between the DIV dummy and VOFF for the single effects. Firms with higher PAYOUT FLEXIBILITY, MKT_LEV, and CASH present a predicted increase in VOFF. We find a statistically significant positive association between leverage, cash holdings, and VOFF. For the interaction terms with SLCC, the findings present a positive and statistically significant association between DIV DUMMY x SLCC and VOFF. The findings document a negative and statistically significant association between SLCC x MK_LEV and VOFF. The findings imply the mediation effects of financial decisions on VOFF when firms are exposed to long-term climate change. Regarding Rahaman (2011), firms rely more on internal finance when constrained by external financing choices. For our predicted findings, the VOFF decreases when firms have access to leverage under climate change exposure (LEVERAGE x SLCC). DIV-paying firms present their predicted positive VOFF under climate change exposure (DIV DUMMY). The VOFF is decreased when firms have flexible payout choices (PAYOUT FLEXIBILITY x SLCC) and liquidity (CASH x SLCC). Our mediation tests suggest the moderating effects of firms' financial decisions on the association between SLCC and VOFF. The findings imply that the impacts of SLCC on VOFF are mediated by endogenous corporate financing decisions in which a firm's access to credit is a critical and sensitive factor.

The findings imply the role of leverage in financing operating needs when firms are exposed to long-term climate change risks. While (de)leveraging is justifiably documented as an effective tool for firms to maintain their financial flexibility, the findings show that the impacts of climate change persistently remain. Under long-term climate change exposure, dividend-paying firms convey their promising growth prospects. In the same vein, the impacts of SLCC on financial flexibility become statistically insignificant when firms have flexible payout choices. Firms with higher liquidity experience no significant impacts of climate change on their financial flexibility. Our findings convey critical implications, showing firms with increasing leverage are highly sensitive to SLCC risks, for which they could have experienced shortfalls in financing operating needs. On the other hand, flexible payout choices and cash reserves are presented as a hedging mechanism in dealing with climate risks, conveying continuous growth prospects for firms. Given the context that climate change risks have become systematically a greater threat to firms' growth opportunities, financial policies could be just temporary tools for firms to deal with climate change risks in the short term.

[Table 5 Inserted Here]

Table 5 reports moderation tests for exogenous climate risk drivers. For the direct effects, we observe positive but statistically insignificant associations between physical risk (disaster-prone state – DPS), local and international transitional climate risks (state-led adaptation plans finalized – SAPF and the Paris Agreement – POST2015), and VOFF. The associations between VOFF and climate risk drivers become negative and statistically significant when interacting with SLCC. Empirically interacting with SLCC, we find a predicted decrease in VOFF under the impacts of SLCC x DPS and SLCC x SAPF interactions. Interacted with POST2015, the association between SLCC x POST2015 and VOFF becomes negative but statistically insignificant. Controlling diverse exogenous climate risk drivers, the findings show that SLCC persistently decreases VOFF. With state-level evidence on long-term climate change exposure, the findings show no significant relations between DPS, SAPF, COP21, and VOFF.  On the other hand, the findings present persistent statistically significant and negative effects of SLCC on VOFF.

Controlling diverse climate risk drivers, the study shows that state-level temperature anomaly benchmarks the systematic impacts of long-term climate change VOFF for firms headquartered across the US states. The findings present no significant direct impacts of transitional and physical risks on VOFF. Compared with other climate risk drivers, global warming is a critical determinant of a firm's financial flexibility, showing that firms have been systematically and chronically exposed to local climate change risks.  Corporate financial policies could be adjusted by firms to cope with climate change impacts. VOFF is persistently affected due to firms' growth uncertainty, for which global warming in multi-decade periods leads to diverse climate risks imposed on firms.  The findings support our developed hypotheses on the hypothesized predictions of the impact of long-term climate change on the value of financial flexibility.

**Table 1**: Descriptive statistics

| Variable | N | Mean | Min | p50 | Max | SD |
|---|---|---|---|---|---|---|
| VOFF | 64,069 | 0.068 | 0.051 | 0.068 | 0.083 | 0.007 |
| VOFF [multiplied by 100] | 64,069 | 6.822 | 5.096 | 6.843 | 8.311 | 0.665 |
| SLCC | 112,840 | 1.136 | -1.917 | 1.083 | 4.250 | 1.252 |
| SIZE | 112,840 | 5.360 | 0.069 | 5.177 | 10.196 | 1.981 |
| INV | 111,969 | 0.061 | 0.000 | 0.040 | 0.434 | 0.068 |
| WC | 110656 | 0.289 | -8.735 | 0.278 | 0.894 | 0.291 |
| DIV | 112,840 | 0.008 | 0.000 | 0.000 | 0.109 | 0.017 |
| OX | 112,840 | 1.147 | 0.059 | 0.968 | 9.143 | 0.861 |
| R&D | 112,840 | 0.059 | 0.000 | 0.004 | 0.983 | 0.125 |
| Q | 112,825 | 2.069 | 0.615 | 1.497 | 10.834 | 1.688 |
| MB | 108,376 | 2.126 | 0.521 | 1.474 | 72.770 | 2.419 |
| DIV DUMMY | 112840 | 0.333 | 0.000 | 0.000 | 1.000 | 0.471 |
| PAYOUT_FLEX | 60,543 | 0.293 | 0.000 | 0.000 | 1.000 | 0.372 |
| MKT_LEV | 112,472 | 0.214 | 0.000 | 0.140 | 0.945 | 0.230 |
| CASH | 112840 | 0.196 | 0.000 | 0.099 | 0.958 | 0.229 |

| **Table 2**: Baseline regressions | | |
|---|---|---|
| | (1) | (2) |
| VARIABLES | VOFF $_t$ | VOFF $_t$ |
| SLCC $_{t-1}$ | -0.004** | -0.004** |
| | (0.002) | (0.002) |
| SIZE $_{t-1}$ | | -0.182*** |
| | | (0.003) |
| INV $_{t-1}$ | | -1.357*** |
| | | (0.056) |
| WC $_{t-1}$ | | 0.266*** |
| | | (0.018) |
| DIV $_{t-1}$ | | -2.120*** |
| | | (0.200) |
| OX $_{t-1}$ | | -0.114*** |
| | | (0.007) |
| R&D $_{t-1}$ | | 0.064* |
| | | (0.034) |
| Q $_{t-1}$ | | -0.006*** |
| | | (0.002) |
| Constant | 6.827*** | 7.960*** |
| | (0.006) | (0.022) |
| Observations | 64,068 | 62,512 |
| R-squared | 0.341 | 0.564 |
| Year FE | Yes | Yes |
| Industry FE | Yes | Yes |
| State FE | Yes | Yes |
| Clustered SE | Yes | Yes |

The table reports linear regression with multiple fixed effects for time (financial years), industry (SIC codes), and location (US states) levels. Robust standard errors are clustered by firm and reported in parentheses. The characters *** p<0.01, ** p<0.05, * p<0.1 indicate the significant levels at the 1%, 5%, and 10%, respectively.

**Table 3:** Robustness checks for growth opportunities and firm size

| VARIABLES | (1)<br>MB $_t$<br>Full sample | (2)<br>MB $_t$<br>Full sample | (3)<br>MB $_t$<br>Small Firms | (4)<br>MB $_t$<br>Large Firms | (5)<br>VOFF $_t$<br>Small Firms | (6)<br>VOFF $_t$<br>Large Firms |
|---|---|---|---|---|---|---|
| SLCC $_{t-1}$ | -0.019** | -0.018*** | -0.013 | -0.020** | 0.002 | -0.008*** |
| | (0.008) | (0.007) | (0.011) | (0.008) | (0.003) | (0.002) |
| SIZE $_{t-1}$ | | -0.038*** | -0.179*** | 0.009* | -0.177*** | -0.178*** |
| | | (0.005) | (0.022) | (0.005) | (0.006) | (0.004) |
| INV $_{t-1}$ | | -0.863*** | -1.122*** | -0.249** | -1.187*** | -1.362*** |
| | | (0.144) | (0.222) | (0.106) | (0.072) | (0.082) |
| WC $_{t-1}$ | | -0.283*** | -0.264** | -0.066 | 0.294*** | 0.295*** |
| | | (0.093) | (0.122) | (0.044) | (0.022) | (0.024) |
| DIV $_{t-1}$ | | 3.414*** | 2.560*** | 4.057*** | -3.182*** | -0.813*** |
| | | (0.380) | (0.619) | (0.455) | (0.316) | (0.201) |
| OX $_{t-1}$ | | 0.034** | 0.023 | 0.034*** | -0.105*** | -0.112*** |
| | | (0.013) | (0.021) | (0.008) | (0.009) | (0.009) |
| R&D $_{t-1}$ | | 2.189*** | 2.127*** | 1.359*** | -0.004 | 0.224*** |
| | | (0.200) | (0.228) | (0.232) | (0.038) | (0.065) |
| Q $_{t-1}$ | | 0.743*** | 0.738*** | 0.712*** | 0.009*** | -0.034*** |
| | | (0.018) | (0.025) | (0.015) | (0.002) | (0.002) |
| Constant | 2.048*** | 0.661*** | 1.203*** | 0.347*** | 7.827*** | 8.016*** |
| | (0.018) | (0.044) | (0.091) | (0.040) | (0.031) | (0.033) |
| Observations | 96,101 | 93,629 | 45,747 | 47,878 | 29,282 | 33,219 |
| R-squared | 0.143 | 0.457 | 0.424 | 0.571 | 0.429 | 0.589 |
| Year FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Industry FE | Yes | Yes | Yes | Yes | Yes | Yes |
| State FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Clustered SE | Yes | Yes | Yes | Yes | Yes | Yes |

The table reports linear regression with multiple fixed effects for time (financial years), industry (SIC codes), and location (US states) levels. Robust standard errors are clustered by firm and reported in parentheses. The characters *** p<0.01, ** p<0.05, * p<0.1 indicate the significant levels at the 1%, 5%, and 10%, respectively. The study sorts firms into quartiles to divide the sample dataset into equal parts. In the Stata package, we can calculate quartiles using the (Quartile – xtile command) function and the egen command for quartile sorts.

**Table 4:** Channel tests.

| VARIABLES | (1)<br>VOFF $_t$ | (2)<br>VOFF $_t$ | (3)<br>VOFF $_t$ | (4)<br>VOFF $_t$ |
|---|---|---|---|---|
| SLCC $_{t-1}$ | -0.008*** | -0.004 | 0.001 | -0.004 |
| | (0.002) | (0.003) | (0.002) | (0.002) |
| DIV DUMMY $_{t-1}$ | -0.126*** | | | |
| | (0.012) | | | |
| SLCC x DIV DUMMY $_{t-1}$ | 0.013*** | | | |
| | (0.003) | | | |
| SIZE $_{t-1}$ | -0.174*** | -0.172*** | -0.182*** | -0.180*** |
| | (0.003) | (0.003) | (0.003) | (0.003) |
| INV $_{t-1}$ | -1.363*** | -1.525*** | -1.351*** | -1.332*** |
| | (0.056) | (0.091) | (0.057) | (0.055) |
| WC $_{t-1}$ | 0.268*** | 0.267*** | 0.270*** | 0.160*** |
| | (0.018) | (0.024) | (0.019) | (0.019) |
| DIV $_{t-1}$ | -0.577** | -1.438*** | -2.103*** | -2.130*** |
| | (0.224) | (0.200) | (0.199) | (0.199) |
| OX $_{t-1}$ | -0.110*** | -0.105*** | -0.113*** | -0.105*** |
| | (0.007) | (0.009) | (0.007) | (0.007) |
| R&D $_{t-1}$ | 0.076** | 0.261*** | 0.063* | -0.013 |
| | (0.034) | (0.070) | (0.034) | (0.034) |
| Q $_{t-1}$ | -0.007*** | -0.019*** | -0.005*** | -0.010*** |
| | (0.002) | (0.003) | (0.002) | (0.002) |
| PAYOUT FLEXIBILITY$_{t-1}$ | | 0.019 | | |
| | | (0.012) | | |
| SLCC x PAYOUT FLEXIBILITY$_{t-1}$ | | -0.001 | | |
| | | (0.005) | | |
| MKT_LEV $_{t-1}$ | | | 0.048** | |
| | | | (0.024) | |
| SLCC x MKT_LEV $_{t-1}$ | | | -0.029*** | |
| | | | (0.010) | |
| CASH $_{t-1}$ | | | | 0.206*** |
| | | | | (0.025) |
| SLCC x CASH $_{t-1}$ | | | | -0.000 |
| | | | | (0.007) |

| | | | | |
|---|---|---|---|---|
| Constant | 7.943*** | 7.886*** | 7.947*** | 7.940*** |
| | (0.022) | (0.030) | (0.023) | (0.021) |
| | | | | |
| Observations | 62,512 | 32,256 | 62,328 | 62,512 |
| R-squared | 0.567 | 0.583 | 0.564 | 0.566 |
| Year FE | Yes | Yes | Yes | Yes |
| Industry FE | Yes | Yes | Yes | Yes |
| State FE | Yes | Yes | Yes | Yes |
| Clustered SE | Yes | Yes | Yes | Yes |

The table reports linear regression with multiple fixed effects for time (financial years), industry (SIC codes), and location (US states) levels. Robust standard errors are clustered by firm and reported in parentheses. The characters *** p<0.01, ** p<0.05, * p<0.1 indicate the significant levels at the 1%, 5%, and 10%, respectively.

**Table 5**: Moderation tests

| VARIABLES | (1)<br>VOFF $_t$ | (2)<br>VOFF $_t$ | (3)<br>VOFF $_t$ |
|---|---|---|---|
| SLCC $_{t-1}$ | 0.005** | -0.003 | -0.004** |
| | (0.002) | (0.002) | (0.002) |
| DPS $_{t-1}$ | 0.000 | | |
| | (0.000) | | |
| SLCC x DPS $_{t-1}$ | -0.022*** | | |
| | (0.004) | | |
| SIZE $_{t-1}$ | -0.182*** | -0.182*** | -0.182*** |
| | (0.003) | (0.003) | (0.003) |
| INV $_{t-1}$ | -1.355*** | -1.357*** | -1.357*** |
| | (0.056) | (0.056) | (0.056) |
| WC $_{t-1}$ | 0.267*** | 0.266*** | 0.266*** |
| | (0.018) | (0.018) | (0.018) |
| DIV $_{t-1}$ | -2.124*** | -2.119*** | -2.122*** |
| | (0.199) | (0.200) | (0.200) |
| OX $_{t-1}$ | -0.113*** | -0.114*** | -0.114*** |
| | (0.007) | (0.007) | (0.007) |
| R&D $_{t-1}$ | 0.065* | 0.064* | 0.064* |
| | (0.034) | (0.034) | (0.034) |
| Q $_{t-1}$ | -0.006*** | -0.006*** | -0.006*** |
| | (0.002) | (0.002) | (0.002) |
| SAPF $_{t-1}$ | | 0.018 | |
| | | (0.014) | |
| SLCC x SAPF $_{t-1}$ | | -0.009* | |
| | | (0.004) | |
| POST2015 $_{t-1}$ | | | 0.063 |
| | | | (0.047) |
| SLCC x POST2015 $_{t-1}$ | | | -0.013 |
| | | | (0.011) |
| Constant | 7.961*** | 7.958*** | 7.957*** |
| | (0.022) | (0.022) | (0.022) |
| Observations | 62,512 | 62,512 | 62,512 |
| R-squared | 0.565 | 0.564 | 0.564 |
| Year FE | Yes | Yes | Yes |
| Industry FE | Yes | Yes | Yes |
| State FE | Yes | Yes | Yes |
| Clustered SE | Yes | Yes | Yes |

The table reports linear regression with multiple fixed effects for time (financial years), industry (SIC codes), and location (US states) levels. Robust standard errors are clustered by firm and reported in parentheses. The characters *** p<0.01, ** p<0.05, * p<0.1 indicate the significant levels at the 1%, 5%, and 10%, respectively.

# **Chapter Three:** State-Level Climate Change and Stock Returns

## Introduction

Climate change, a public bad that is an ultimate challenge for economics (Nordhaus, 2019a). According to NASA/GISS[48], the Earth's average surface temperature in 2023 was the warmest on record since records first started in 1880. The National Oceanic and Atmospheric Administration (NOAA) and other research organizations have produced independent studies that are aligned with NASA's analysis. Overall, the Earth's temperature in 2023 was 2.45 degrees Fahrenheit (or 1.36 degrees Celsius) higher than the preindustrial average of the late 19th century (1850–19000)[49]. The ten hottest years on record have been the last ten years. For the United States (US), the contiguous 48 US states' average surface temperature has increased by 0.17°F on average every ten years since 1901[50]. Since the late 1970s, average temperatures have increased more quickly, 0.32 to 0.51°F every decade since 1979. The two warmest years on record for the contiguous United States were 2012 and 2016, with nine of the ten warmest years on record having occurred since 1998. Global warming leads to diverse climate risks with profound effects and escalating consequences worldwide[51]. The main objective of the Paris Agreement is to fortify international efforts to combat climate change by limiting global temperature rise this century to well below 2 degrees Celsius above pre-industrial levels and by pursuing efforts to restrict temperature increases to 1.5 degrees Celsius.[52].

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[48] data.giss.nasa.gov/gistemp/graphs/graph_data/Global_Mean_Estimates_based_on_Land_and_Ocean_Data/graph.txt
[49] Global Temperature | Vital Signs – Climate Change: Vital Signs of the Planet (nasa.gov)
[50] Climate Change Indicators: U.S. and Global Temperature | US EPA
[51] Effects - NASA Science; What are the effects of global warming? (nationalgeographic.com); Global warming - Climate Change, Melting Ice, Rising Sea Levels | Britannica; Global Warming of 1.5 ºC — (ipcc.ch)
[52] Key aspects of the Paris Agreement | UNFCCC

For the US, more warming has occurred in some regions than in others. For instance, temperatures have increased most in the North, West, and Alaska, whereas they have not changed much in several Southeast regions. Temperature is a basic unit of measurement used to characterize climate, and local temperatures can have diverse impacts on ecosystems and human existence. Increases in air temperature, for instance, can result in stronger heat waves.[53], which can be fatal or cause disease, especially in susceptible groups. Seasonal and annual temperature variations also influence plants and animals in a particular area. Many different ecological processes can be affected by temperature changes, especially if they happen faster than plant and animal species can adjust. While prior literature focuses on different climate risk drivers (e.g., drought, hurricane, flooding, etc.), capturing temporary climate events (Adrian et al., 2023; Billings et al., 2022; Collier et al., 2024; S. Javadi & A.-A. Masum, 2021; S. Javadi et al., 2023; Tyndall, 2023), temperature anomaly benchmarks long-term climate change given many years of greenhouse gas emissions. This study employs state-level temperature anomaly data to benchmark long-term climate change in the US, which is divergently complex across the country. In other words, we are not just benchmarking climate change in the long term but are also capturing the geographical divergence of climate change exposure across the US states.

Prior studies examine the pricing of financial markets to climate risks, which are contemporary climate events such as natural disasters (Hong et al., 2023; Huynh & Xia, 2023), physical risk using drought index (Hong et al., 2019), and transition risk using climate change news index (Huynh & Xia, 2021). In other words, prior literature fails to benchmark long-term climate change. It is critical to capture long-term climate change because all kinds of climate events

[53] Climate Change Indicators: Heat Waves | US EPA

result from multidecade greenhouse gas emissions. Temperature anomalies are the difference between the current temperature values for a specific location (i.e., US states) and its 30-year average or more temperature values, capturing the real and long-term climate change risk. Using US state-level data temperature anomaly, this study aims to prove whether corporate climate sensitivity (a beta) related to state-level climate factors (temperature anomaly) is priced in the financial markets, becoming a new systematic risk factor. The study builds on Cuculiza et al. (2024) by developing a time-varying firm-level temperature sensitivity (FLTS) measure. Our measure is advantageously different from Cuculiza et al. (2024) as follows. While Cuculiza et al. (2024) use US nationwide temperature data to develop their FLTS measure with their self-calculated temperature anomaly, we use state-level temperature anomaly (SLTA) data provided by NCEI-NOAA to develop our state-level time-varying FLTS measure for each of our sample firms' stocks headquartered in US states. Our approaches minimize self-calculation errors of statewide temperature anomaly in predicting FLTS. Furthermore, our FLTS measure is time-varying and captures the statewide geographical divergence of corporate sensitivity to climate change for each firm's stock.

For our empirical purposes, we start with predicting state-level corporate climate sensitivity (hereafter, SL-CCS) for each firm's stock headquartered across US states. A (negative) positive value of SL-CCS indicates that a firm's stock is (negatively) positively sensitive to state-level climate change factors (hereafter, SLCC). As mentioned earlier, we benchmark SLCC by state-level temperature anomalies (SLTA), which is the difference between the current temperature value and baseline 30-year or more average values for US states where firms are located. In climate science, temperature anomaly is fundamentally critical in displaying the trend of temperature changes over time. Anomalies, as opposed to absolute temperatures, more effectively depict how the climate is changing across broader areas by indicating whether temperatures are above or below average[54]. In one part of the world, an absolute temperature may be considered typical, while in another, it may be over average. This ambiguity over what constitutes "normal" is eliminated by anomaly, which provides data illustrating local temperature variations. Regarding the established literature on the economics of climate change (Heal, 2009, 2017; Nordhaus, 2019a; Nordhaus, 1993, 2007; Stern, 2008; Tol, 2018, 2024; Weitzman, 2007), given the geographical divergence of US climatic changing conditions[55], we employ temperature anomalies to investigate whether SL-CCS beta is priced in the US equity markets with state-level evidence, being possibly a new systematic risk factor.

Our findings show robust associations between SL-CCS and firms' stock returns (RET). The association between SL-CCS and RET is negative and significant for the full sample and negative temperature anomalies (abnormal cooler weather). The association between SL-CCS and RET becomes positive and statistically significant with positive temperature anomalies (abnormal warmth). The positive association between SL-CCS and RET is robust when we control carbon-intensive stocks (e.g., polluting firms), long-term proneness to natural disasters for firms' stocks located in disaster-prone states (DPS benchmarking long-term climate physical risks), and state-led adaptation plan finalized (SAPF for climate transition risks). Our standalone predicted associations between SL-CCS and RET are constantly robust. We do not observe positive standalone associations between DPS and RET. We only observe a positive association between DPS and RET when DPS interacts with our predicted SL-CCS (DPS x SL-CCS), indicating the moderation of global warming. Similar findings are observed for SAPF; we

[54] Global surface temperature anomaly - Energy Education; World of Change: Global Temperatures (nasa.gov)
[55] United States - Climatology | Climate Change Knowledge Portal (worldbank.org)

observe a weak and marginally positive association between SAPF and RET. An increase in RET becomes more significant with a higher predicted magnitude when SAPF interacts with SL-CCS, specifically with positive temperature anomalies. Our findings remain unchanged when we exclude the COVID-19 pandemic and penny stocks.

Overall, our findings broadly imply that SL-CCS is priced by the stock markets, and state-level climate factors, namely positive temperature anomalies (global warming), could be acknowledged as the new systematic risk factor. Our state-level evidence suggests that the pricing of stock markets to climate risks is conditional on positive temperature anomalies (e.g., also known as global warming). Investors demand a premium to hold stocks exposed to climate risks under global warming. Also, the premium investors demand for holding stocks exposed to climate risks (climate transition versus physical drivers) is driven by temperature anomalies, for which firms are positively sensitive to global warming.

Our findings complement the emerging literature on asset pricing and climate risks. First, for the climate transition risks, we observe that the increasing sensitivity to state-level climate change (e.g., global warming) induces a premium (positive predicted stock returns) demanded by investors to hold polluting stocks (SL-CCS x RET). For panel data on monthly firms' stocks tested, we observe a negative association between SL-CCS and RET when we test for negative temperature anomalies (cooler weather). Our findings make sense in recent studies on the pricing of stock markets to corporate carbon risks (Bolton & Kacperczyk, 2021; P. Bolton & M. Kacperczyk, 2023; Shaojun  Zhang, 2024). While Bolton and Kacperczyk (2021); P. Bolton and M. Kacperczyk (2023) document the presence of a carbon premium in the US and global equity markets since the Paris Agreement (COP21), Shaojun  Zhang (2024) argues that the carbon premium has become negative and insignificant when test for global equity markets, which are conditional on how stringent climate policies are. Our evidence from SL-CCS supports prior studies with the following implications. Our foremost goal is to limit global warming to 1.5°C. Greenhouse gas emissions should reach their peak before 2025 at the latest. For the US, over the recent decades, we have observed global warming across the country more clearly since the 2000s. For the contiguous US states, there are nine of the ten warmest years recorded since 1998, and the years 2012 and 2016 were the two warmest years recorded[56]. Our findings imply that investors demand premiums when firms are positively sensitive to abnormally positive temperatures. Even though the US has presented its changing commitments to our global climate action[57], with the carbon premium presented by Bolton and Kacperczyk (2021); P. Bolton and M. Kacperczyk (2023), the Paris Agreement has somehow urged investors to care about the pollution of stocks they are holding, with a subsequent premium demanded. Our evidence shows that the stock markets price carbon risks when investors feel abnormally heated. Incentives for investors to demand a premium under corporate sensitivity to state-level climate factors appear for firms' stocks located in US states that have progressive local climate action with state-led adaptation plans finalized (local climate transition risks). Our evidence aligns with Shaojun Zhang (2024), showing that the pricing of equity markets to corporate carbon risks is conditional on the stringency of environmental policies (exogenous transition risks) instead of on firms' investors. Our evidence from SLTA (state-level global warming) shows that transition risks (e.g., climate policies) present a lag from real abnormal climatic changing conditions imposed on our economy.  Pooling all arguments and theoretical predictions together, the study shows that the

[56] Climate Change Indicators: U.S. and Global Temperature | US EPA
[57] On the U.S. Withdrawal from the Paris Agreement - United States Department of State; The United States Officially Rejoins the Paris Agreement - United States Department of State

associations between climate transition risks and stock returns are conditional on the levels of temperature anomalies, indicating global warming, with the subsequent climate policies to hedge systematic climate-induced risks. Our findings imply that global warming is being priced by the equity markets, possibly becoming a new systematic risk factor.

For the climate physical risks, at first glance, we do not observe any positive association between the long-term proneness to natural disasters where firms' stocks are headquartered in disaster-prone states (DPS). We even observe a negative association between DPS and RET for the full sample, which is only statistically significant when we test for negative temperature anomalies in the sub-sample. The association between DPS and RET becomes positive and significant when DPS interacts with SL-CCS (SL-CCS x DPS), implying that global warming is showing its dominant driver.  Our predicted associations between SL-CCS and RET remain robust, implying that the pricing of equity markets to climate physical risks is also conditional on abnormally positive temperature change. Investors demand a premium to hold stocks where their firms are in the DPS only when they feel abnormally hot. Our findings again strengthen our argument that temperature anomalies benchmark climate change risks as our foremost climate action.[58]. Our findings complement prior studies on asset pricing and physical risks, including natural disasters. (Huynh & Xia, 2023), And sea level rises (Bernstein et al., 2019; Goldsmith-Pinkham et al., 2021),  showing that, combined with the proneness to natural disasters, the financial markets price climate risks when our economy experiences abnormal heat. The rationale is that global warming induces diverse kinds of severe physical risks that are documented in recent literature

[58] The Paris Agreement | UNFCCC

(Hong et al., 2019; Hong et al., 2023; Huynh & Xia, 2023), benchmarking real long-term climate change.

Our study offers an important contribution to the related literature. First, firms with higher temperature sensitivity earn lower returns. The negative state-level evidence of the negative association remains for the full sample and negative temperature anomalies in the sub-sample. Regarding Cuculiza et al. (2024), the findings might suggest that the performance anomaly of firms with higher temperature sensitivity does not reflect different riskiness between firms with divergent temperature sensitivity. Furthermore, such negative associations theoretically convey that market participants might not fully recognize the sensitivity of firms to temperature anomalies. This leads to the overpricing of market participants to stocks with higher temperature sensitivity, with a subsequent lower return. In other words, market participants underreact to the impacts of temperature anomalies on firms. In our state-level evidence, we find that the association between SL-CCS and RET becomes positive and statistically significant under positive temperature anomaly. The positive association is persistent even when we test for diverse climate, physical, and transition risk drivers. Our findings show that the US equity markets do price global warming with a firm's sensitivity to positive temperature anomaly. Regarding climate science, global warming leads to diverse climate risks with consequential effects on firms. Our findings support such theoretical predictions by showing that investors demand compensation for holding stocks exposed to global warming, which is a long-term consequence of climate change. More importantly, firms could be unable to effectively manage their exposure to global warming. Therefore, a firm's sensitivity to temperature anomaly, global warming with abnormally positive temperature, more specifically, has been priced by financial markets (US equity markets for our study) to become a new systematic risk-priced factor. Our study expands related streams of literature on asset pricing studies about climate risk premium by introducing a state-level temperature sensitivity of firms' stocks and demonstrating that such firm-level temperature sensitivity to state-level long-term climate factors is empirically becoming a new systematic risk factor priced by financial markets. More importantly, the (mis)pricing of financial markets is subject to the levels of global warming, highlighting that long-term time-varying climate change, with its geographical heterogeneity, is a dominant driver of a firm's stock return. Our findings add critical complementary to theoretical predictions on the demand for climate change premiums from investors that are exposed to diverse risk drivers.

## Literature and Hypotheses

The literature's first major result is that, while price predictions of climate risks have begun to appear in markets for durable assets like stocks, real estate, and long-term bonds, the degree of pricing varies significantly between markets and over time; for instance, a review paper by Campiglio et al. (2023).

According to today's latest report from the Intergovernmental Panel on Climate Change (IPCC), scientists are seeing changes in Earth's climate throughout the planet's climate system and in every region.[59]. A significant number of the climate change risks that have been noticed are unexpected in several thousand, if not hundreds of thousands of years, and some of the changes that have already occurred, such as the ongoing rise in sea level, cannot be reversed over hundreds or thousands of years. Bernstein et al. (2019), for instance, predicted that residential properties vulnerable to potential flooding risk would sell for roughly 7% less than unexposed

[59] Climate change widespread, rapid, and intensifying – IPCC — IPCC

but otherwise equivalent properties if the average worldwide sea level rose by six feet, as is predicted to happen by 2100.

Water cycle intensity is increasing due to climate change. This causes increased drought in many areas, as well as more rainfall and the ensuing flooding. Hong et al. (2019) investigate whether food stock prices effectively discount these risks. The authors use the Palmer Drought Severity Index to rank thirty-one countries with publicly traded food companies annually based on their long-term trends toward droughts. A nation's low trend score portends comparatively slow profit growth for its food industry. Additionally, it predicts comparatively low profits on food stocks in that nation. This predictability of returns is consistent with food stock prices undervaluing the risks associated with climate change.

According to multiple studies, the coastal real estate markets in the United States have begun to price the risk associated with the predicted surge in future flooding brought on by sea level rise (SLR)[60]. Baldauf et al. (2020) Investigate whether disparities in climate change beliefs are reflected in housing prices. The authors demonstrate that prices exhibit various elasticities to climate risk in an equilibrium model of housing choice, and agents derive benefit from ownership in a neighborhood of comparable agents. Utilizing extensive transaction data, the study establishes a connection between pricing, individual property inundation forecasts, and climate change belief assessments. The study discovers that, compared to homes in non-flooded neighborhoods, houses predicted to be flooded in flood-prone areas sell for less money. The findings imply that differences in opinions regarding the long-term risks of climate change are

[60] Sea Level Rise and Housing Markets | News | National Centers for Environmental Information (NCEI) (noaa.gov)

reflected in housing prices. Because of rising ocean temperatures and melting land ice, the rate of future global sea level rise is likely to increase.

According to Giglio, Maggiori, et al. (2021), housing markets can offer insight into the proper discount rates to use when pricing investments in mitigating climate change. Real estate has a term structure of discount rates that slopes downward and reaches 2.6% for payoffs longer than 100 years. It is susceptible to both consumption and climate risk. Using a tractable asset pricing model that accounts for the distinctive features of climate change, the study shows that the term structure of discount rates for investments that hedge against climate change is consequently upward sloping but is bounded above by the risk-free rate. The anticipated housing discount rates offer an upper bound at horizons where risk-free rates are not accessible.

Municipal bond markets started pricing higher risk of sea level rise (SLR) exposure in 2013, coinciding with upward revisions to SLR estimates (Goldsmith-Pinkham et al., 2021). Bonds with longer maturity are more adversely affected, and short-term flood risk is not a primary cause of the damage. The study uses a structural model of credit risk to quantify the predicted economic impact and distinguish between the effects of uncertainty with underlying asset prices. The SLR exposure premium is unaffected by controlling home prices, suggesting that uncertainty over the future effects of SLR has a greater impact on bond prices than lowering present asset values.

Huynh and Xia (2021) investigate whether corporate bonds are valued for the risk of climate change news. In line with the consequences of demand for bonds with a high potential to buffer against climate risk for asset pricing, the authors estimate bond covariance using a climate change news index and find that bonds with a greater climate change news beta earn lower future returns. Furthermore, investors who worry about climate risk are prepared to pay more for bonds issued by companies that have demonstrated improved environmental performance. According to their research, corporate initiatives to enhance environmental performance are beneficial when investors are worried about the possibility of climate change.  A recent study by Huynh and Xia (2023) looks at investors' responses to natural disasters in the U.S. corporate bond and stock markets. The study also examines how exposed a corporation is to physical climate risk using disaggregated establishment-level data. It has been shown that investors tend to overreact when a corporation is exposed to natural disasters, which lowers the current bond and stock prices and increases future profits. Though their fundamentals deteriorated after the disasters, companies with a high environmental reputation face less selling pressure on their bonds and equities.

For the equity markets, Bolton and Kacperczyk (2021) investigate the potential impact of carbon emissions on the US stock return cross-section. After adjusting for size, book-to-market, and other return predictors, the study finds that stocks of companies with higher overall carbon dioxide emissions (and changes in emissions) generate higher returns. This carbon premium cannot be explained by variations in unforeseen profitability or by other established risk factors. Additionally, the study discovers that in a few notable businesses, institutional investors use exclusionary screening based on direct emission intensity or the ratio of total emissions to sales. All things considered, the findings support the theory that investors are already requesting payment for the risk associated with carbon emissions. For global equity markets, firms are exposed to carbon transition risk as a result of the energy transition away from fossil fuels (P. Bolton & M. Kacperczyk, 2023). The study finds that greater stock returns are associated with higher levels and growth rates of carbon emissions in all sectors and most countries, based on our estimation of the market-based premium associated with carbon transition risk in a cross-section of 14,400 enterprises across 77 nations. Firms based in nations with less developed economies, more expansive energy sectors, and less inclusive political systems are subject to higher carbon premia associated with emissions growth. Emissions-related priorities are greater in nations with more stringent national climate regulations. The latter has grown in tandem with investor knowledge of the risks associated with climate change.

The discussion of investments considering climate change revolves around the cost of carbon transition risk. The data in this article, which is only accessible to investors with substantial lag, shows that emissions increase linearly with firm sales (Shaojun  Zhang, 2024). Rather than the risk premium, the positive carbon return, or brown-minus-green return differential, reported in earlier studies comes from the emissions' forward-looking company performance information. Carbon returns become negligible internationally and negative in the United States once the data release latency is taken into consideration. Because of strong shocks related to climate change, developed markets have lower carbon returns, whereas nations with stricter climate laws have higher carbon returns.

Prior literature focuses on climate risk drivers but misses their benchmarked climate change measure, namely, temperature anomaly. Temperature anomaly is a multi-year consequence of greenhouse gas emissions (e.g., corporate carbon emissions, etc.) for which climate risk drivers present their long-lag phenomena under global warming. For instance, economies worldwide have increasingly experienced frequent abnormal climate events, escalating in recent years. The Paris Agreement was adopted recently since 2015 for our global climate action, mitigating global warming, for which net-zero targets are our foremost climate goal by 2050. Global warming emerged in the US and worldwide some decades ago, and its phenomenon with associated climate risks is becoming more serious than ever in recent years. Pooling altogether, our main hypothesis (H) is as follows.

**H1:** Benchmarking long-term climate change, temperature anomaly is the principal driver of stock return.

Because global warming leads to diverse climate risk drivers with both endogenous and exogenous factors for physical versus transition risks, our additional hypotheses are as follows:

**H1A:** Stock returns are positively associated with global warming, for which firms are positively sensitive to temperature anomaly (warmer than normal).

**H2:** Climate risk drivers matter to stock returns, and investors demand premiums when their firms' stocks are positively sensitive to global warming.

Our tested hypotheses are critical to emerging literature on climate change and financial markets by benchmarking long-term climate change risks. Based on our hypotheses tested, we complement heterogeneous findings on the pricing of financial markets to climate risk drivers discussed throughout the literature review section.

## Data sources.

### State-level climate change data

Regarding the established literature on the economics of climate change (Heal, 2009, 2017; McKibbin & Wilcoxen, 2002; Nordhaus, 1993, 2007; Stern, 2008; Tol, 2018, 2024; Weitzman, 2007), the study benchmarks climate change using temperature anomalies. For state-level evidence, we collect monthly statewide temperature data archives from the National Centers for Environmental Information [NCEI], and the National Oceanic and Atmospheric Administration [NOAA]. The study handles time series data archives in long format for each state's temperature values and anomalies and transforms statewide data archives into panel data. Our monthly statewide temperature panel data includes 75,002 state-year-month observations from 1895-01 to 2023-02[61] for a total of 49 US states.

### Firms' stocks and market data

The study collects data on US common stocks [Share codes 10-11] from the Center for Research in Security Prices [CRSP]. We collect monthly stock files [CRSP-MSF][62], including a total of 3,875,228 monthly stock observations[63]. We keep exchanging code [EXCHCD 1-3] the US primary stock exchanges [PRIMEXCH], including: 1) New York Stock Exchange, 2) American Stock Exchange, 3) The Nasdaq Stock Market (SM)[64]. We remove financial firms' stocks [SICCD 6000-6999]. We generate CRSP useful variables following CRSP's guidance for handling the "Negative" Prices, Adjusting Prices and Shares for Splits, Returns with Dividends, Delisting Returns, and Market Capitalization[65]. We generate a quarter variable based on the date variable that CRSP provided us. Our processed CRSP-MSF data includes 3,203,886 monthly stock observations. We drop stock prices [PRC] less than one and remove stock returns [RET] with missing values. For setting panel data with CRSP-MSF files, we drop the repeated values

[61] State-level climate data archives were extracted, handled, and processed as of 2023-04-01.
[62] CRSP-MSF was extracted as of 2024-02
[63] For the raw CRSP-MSF file: Variables: 64. Observations: 3,875,228. Size 1,788.72M. Memory: 2,144M. Created: Wednesday, 21 February 2024, 8:51:23 pm [New Zealand time]. Size: 1.74 GB (1,875,651,850 bytes). DTA File (.dta) labeled 'crsp_msf.dta'.
[64] Code Exchange: N for NYSE; A for AMEX; Q for NASDAQ; X for Other Exchange; R for ARCA
[65] See, Wharton Research Data Services (upenn.edu)

for the date variable for each of our sample firms' stocks. With additional processing steps, our CRSP-MSF processed file includes 2,484,482 monthly stock observations.

### Fama-French Five Factors data

The study collects historical data for the five factors of Fama and French (2015) [FF5] from the authors' website[66]. We merge FF5 data with CRSP-MSF files that generate a merged file with 2,794,196 observations matched. We keep only matched observations for the CRSP-MSF-FF5 merged data.[67]. We then merge the CRSP-MSF-FF5 merged data with the US national monthly time series that generates a merged file with 2,772,319 month-stock observations. We again keep only matched observations.[68]

### Firm-level fundamentals data

The study extracts corporate fundamentals from the COMPUSTAT Quarterly file. We merged the COMPUSTAT Quarterly file with the CRSP-MSF-FF5 and merged monthly data using CUSIP, quarter, and year variables. The merging step generates a total of 559,321 matched observations. We also collect monthly firm-level financial ratios from the WRDS (Beta) database.[69] and merge it with CRSP_MSF stock files, Fama-French 5 Factors, and US statewide

[66] Historical Data - Fama/French 5 Factors (2x3) extracted at https://mba.tuck.dartmouth.edu/pages/faculty/ken.french/Data_Library/f-f_5_factors_2x3_archive.html. Downloaded the file "July 2023 Data CSV" at https://mba.tuck.dartmouth.edu/pages/faculty/ken.french/Data_Library/Historical_Archives/08%202023%20Update/ftp/F-F_Research_Data_5_Factors_2x3_CSV.zip

[67] It is saved as 'crsp_msf_processed_ff5.dta'

[68] 22,699 observations deleted and the merged file is saved as 'crsp_msf_processed_ff5_climate.dta'

[69] Financial Ratios Suite by WRDS is the latest addition to the WRDS analytics platform. It's a web-based engine that delivers over 70 pre-calculated financial ratios for all U.S. companies across eight different categories (Valuation, Liquidity, Profitability, and etc).

and nationwide climate monthly merged file. This merging procedure generates a total of 411,894 month-stock observations.

### Other data archives

We collect data on the 3-Month Treasury Bill Secondary Market Rate, Monthly Discount Basis (TB3MS), from FRED[70].

## Methods and Models

### Predicting state-level corporate climate sensitivity

The study starts predicting state-level corporate climate sensitivity for each sample firm's stocks in each US state using state-wide climate-stock monthly data. The study measures the state-level corporate climate sensitivity by regressing stock excess return on the market factor and state-level temperature anomaly. The study estimates the regression model for each of the sample stocks in our sample as follows:

$$R_{i,s,t} - R_{F,t} = \alpha_{i,s,t} + \beta_{i,s,t}\left(R_{Mkt,t} - R_{F,t}\right) + \beta_{i,s,t} SLCC_{s,t} + \varepsilon_{i,s,t} \quad (1)$$

The characters of $i$, $s$, and $t$ indicate a firm's stock $i$ headquarter location in a US State $s$ at time t (monthly basis). $R_{i,s,t}$ is a monthly stock return. $R_{F,t}$ is the risk-free rate using the 3-Month Treasury Bill Secondary Market Rate, Discount Basis - TB3MS. $R_{Mkt,t}$ is the market return is proxied by the CRSP value-weighted return, including dividends.

[70] https://fred.stlouisfed.org/series/TB3MS

State-level climate change (SLCC) is proxied by the monthly state-level temperature anomaly [SLTA] in state $s$ in month t. Temperature anomalies are more significant than absolute temperature in studies on climate change (NCEI, 2024). The deviation from the average, or baseline, temperature is known as a temperature anomaly. Usually, 30 or more years' worth of temperature data are averaged to determine the baseline temperature for US states. For each US state, a positive anomaly denotes a temperature difference between the observed and baseline values, whereas a negative anomaly denotes a temperature difference between the two values. For each stock, we employ the regressions with a 60-month rolling window. After matching multiple datasets and processing steps, our monthly stock-level data includes 363,022 state-stock-month observations from 1985 to 2023. We frequently come across references to temperature anomalies when investigating global climate change and temperature data[71]. That is the discrepancy between the actual temperature and the long-term average temperature, also referred to as a reference value. The predicted long-term average temperature is represented by the anomaly for each US state, which is the deviation from the expected value. A positive anomaly denotes a temperature warmer than normal for US states, whereas a negative anomaly denotes a temperature cooler than usual for US states[72].

The predicted $\beta_{i,s,t}$ captures the predicted corporate sensitivity to state-level climate change (state-level temperature anomaly) for stock $i$ at time $t$ in state $s$. The positive (negative) $\beta_{i,j,t}$ implies that the excess return of a specific stock $i$ is positively (negatively) associated with the temperature anomaly in the month $t$ in the state $s$ where that firm's stock is headquartered. We

[71] Temperature Anomalies (cet.edu)

[72] See also, NASA SVS | Global Temperature Anomalies from 1880 to 2022; Global Temperature | Vital Signs – Climate Change: Vital Signs of the Planet (nasa.gov)

present a histogram of the State-Level Corporate Climate Sensitivity [SL-CCS] predicted with a kernel density estimate $\beta_{i,s,t}$ in Figure 5. From this stage onward, we use the SL-CCS predicted beta for our regressions of stock returns [RET] on SL-CCS to prove whether our predicted statewide firm-level climate sensitivity (a beta) to state-level climate factor (here is SLTA) is priced in the financial market (the US equity markets for the current study) that could become a new systematic risk priced factor.

It is inevitable to acknowledge that the pricing of climate risks for durable assets (e.g., stocks, bonds, real estate, etc.) has been increasingly attractive to asset pricing literature. For the equity markets more specifically, we find the ongoing debate about whether a carbon premium exists to reflect the pricing of stock markets to transition risks (Aswani et al., 2024; Bolton & Kacperczyk, 2021; P. Bolton & M. Kacperczyk, 2023). Cuculiza et al. (2024) provide evidence from firm-level temperature sensitivity (FLTS or TS) using a time-varying measure to examine the association between temperature changes and firm performance. The study posits that high FLTS is associated with lower future profitability in riskier corporate policies. The study explains that such high-CS firms are overpriced with their lower future returns, and there is potentially a mispricing by market participants. The study shows that high-CS firms exhibit greater portfolio weights from non-local institutional investors, and sell-side equities analysts make fewer accurate projections for these firms. Collectively, the study implies that predictable patterns in returns are produced when financial markets underreact to firm-specific information regarding temperature changes. Between 1968 and 2020, the study finds that an annualized risk-adjusted return of more than 4% is produced by a trading strategy with mispricing.

Since the climatic conditions and their anomalies are divergent across the US, the study by Cuculiza et al. (2024) employs U.S. national temperature data that might miss the geographical heterogeneity of climate change across the US states[73]. Based on US national temperature data, the study also implements self-calculations for temperature anomaly that might generate unexpected calculation errors[74]. It is acknowledged by the study that although temperature variations at the local or regional level may offer a more accurate representation of the changes experienced by the company, the increased level of detail may potentially underestimate the effects of these changes on specific kinds of businesses. For example, temperature variations away from corporate headquarters may have an impact on geographically distributed businesses and those with extensive distribution networks. Furthermore, non-local temperature variations may have an impact on the geographically scattered clients and suppliers of multiple businesses. However, firms' headquarters could be centrally vulnerable to local temperature anomalies, with abnormal climatic phenomena leading to subsequent impacts on their distribution networks. Also, for predicting local firm-headquartered temperature sensitivity (LFHTS), we at least have already controlled local climate factors that a firm is prone to instead of the whole US geography. For instance, some parts of the US experience more extreme weather and abnormal temperatures than other regions[75]. Collectively, we hereby build a step forward contributing to Cuculiza et al. (2024) by directly employing state-level temperature anomaly data to estimate state-level corporate climate change sensitivity (SLCCS, or known as state-level corporate

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[73] See Table A1 Variable Definitions Cuculiza, Carina and Kumar, Alok and Xin, Wei and Zhang, Chendi, Temperature Sensitivity, Mispricing, and Predictable Returns (April 11, 2024). SSRN: http://dx.doi.org/10.2139/ssrn.3331872

[74] See Section 2.1. Temperature Data.

[75] Climate Change Indicators: U.S. and Global Temperature | US EPA; Climate Change Indicators: High and Low Temperatures | US EPA.

temperature anomaly sensitivity – SLCTAS beta)[76]. We then examine its associations with stock returns (RET) to prove whether our corporate climate change sensitivity (an SLCCS beta) linked to state-level climate factor (here is SLTA) is priced in the financial market, US equity markets more specifically, becoming a new systematic risk factor. We support our main hypotheses with the following arguments. First, the associations between SLCCS beta and RET are conditional on SLTA. Furthermore, the associations between SLCCS beta and RET become positive under positive SLTA.

The rationale is that global warming (positive abnormal temperatures induces diverse and complex climate risk drivers. The temperature of our world is rising. Earth has warmed by 1 degree Celsius, or around 2 degrees Fahrenheit, since the Industrial Revolution, which sparked the use of fossil fuels in everything from power plants to transportation. Whilst that might not seem like much, 2023 was the hottest year in history.[77] The last ten warmest years ever recorded have all happened within the past ten years. According to a reconstruction of Earth's average temperature over the previous 485 million years, major extinctions and catastrophic weather occur when the globe warms (Pedersen et al., 2021)[78]. Therefore, we argue that SLTA is the main driver of the associations between SLCCS beta and RET, compared to other climate risk factors, and is a new systematic risk factor. Also, the new systematic risk factor (SLCCS beta) is

[76] We use the terms interchangeably with the same meaning because temperature anomalies benchmark climate change, as discussed in detail earlier.
[77] 2023 was the world’s warmest year on record, by far | National Oceanic and Atmospheric Administration (noaa.gov); Assessing the Global Climate in 2023 | News | National Centers for Environmental Information (NCEI) (noaa.gov)
[78] Although the terms global warming and climate change are frequently used interchangeably, scientists prefer to refer to the complex changes currently influencing our planet's weather and climate systems as "climate change.", see Climate Change Coverage (nationalgeographic.com)

significantly priced in US states that are prone to natural disasters (physical risk), having local climate action (transition risk).

Our additional hypotheses aim to test the rationale that global warming (abnormal warmer temperature or positive temperature anomaly) is a long-term consequence of many years of greenhouse gas emissions. Therefore, the sensitivity of firms, investors, and stakeholders could be long lagged what the earth has experienced over many years. The awareness of investors and financial markets' pricing of climate risks has been just emerging in recent years, for instance (Ilhan et al., 2023; Krueger et al., 2020). Physical risks have become more frequent with higher severity. At the COP21 in Paris on December 12, 2015, nations ratified the Paris Agreement to combat climate change. Less than a year later, the Agreement came into effect. All nations are committed to working toward keeping the rise in global temperatures well below 2 degrees Celsius and, considering the serious hazards, aiming for 1.5 degrees Celsius. For the US, states, and communities around the country have begun to prepare for climate change, and this planning process typically results in a document called an adaptation plan[79]. Environmental policies are becoming more stringent across the world's economies (OECD, 2024). After decades of global warming starting in the US and globally, with escalating severity caused by frequent physical risks[80], our human actions (e.g., climate policies, sustainability initiatives, strategies, investments, etc.) have followed to combat climate change, which is acknowledged as the transition risk[81]. Even though physical risks have become severe with higher frequency and

[79] U.S. Department of State 2024-2027 Climate Adaptation Plan (sustainability.gov); State and Local Adaptation Plans - Georgetown Climate Center; How much progress is the world making to tackle climate crisis? | World Economic Forum (weforum.org)
[80] Billion-Dollar Weather and Climate Disasters | National Centers for Environmental Information (NCEI) (noaa.gov); A record 63 billion-dollar weather disasters hit Earth in 2023 » Yale Climate Connections
[81] Climate policy success depends on transition risk mitigation | World Economic Forum (weforum.org)

significant losses (physical risks), and our awareness of urgent actions needed to combat climate change risks, global warming (positive temperature anomaly) started several decades ago[82]. Therefore, global warming should be acknowledged as the main driver for financial markets' pricing of climate risk drivers that come well after.

### Empirical models

We run regressions of stock returns on SL-CCS betas by proposing the following regression model:

$$RET_{i,s,t} = \alpha + \beta_1 SL - CCS_{i,s,t} + \beta_k \sum_{i=0}^{n} X_{i,s,t} + \varphi_t + \omega_{SICCD} + \delta_i + \varepsilon_{i,t} \quad (2)$$

The main dependent variable is stock return (RET). The main independent variable is the SL-CCS beta predicted by Equation 1, capturing state-level corporate climate sensitivity. Based on the literature on stock returns and determinants, we include a vector of diverse control variables $X$. Our control variables include firm size (SIZE), book-to-market (BM), financial leverage (LEV), Tobin's Q ratio (Q), capital expenditure (CAPEX), corporate tangibility (TANG), return on assets (ROA), revenue (SALE), R&D expenditure (R&D), and cash holdings (CASH). We include fixed effects for time/month $\varphi$ and industry/SICCD $\omega$ with standard errors clustered for firms $\delta$. $\varepsilon$ is the error term. For the baseline regressions (Equation 2), we respectively run regressions of RET on SL-CCS beta and controls for the full sample, with negative and positive temperature anomalies.

[82] What Is Climate Change? - NASA Science; Global Temperature | Vital Signs – Climate Change: Vital Signs of the Planet (nasa.gov)

Next, we discuss the channeling effects of potential climate risk drivers by proposing an additional regression model.

$$RET_{i,s,t} = \alpha + \beta_1 SL - CCS \times M_{i,s,t} + \beta_2 SL - CCS_{i,s,t} + + \beta_1 M_{i,s,t} + \beta_k \sum_{i=0}^{n} X_{i,s,t} + \varphi_t + \omega_{SICCD} + \delta_i + \varepsilon_{i,t} \quad (3)$$

All else equal to Equation 2, we respectively examine the moderation $M$ for climate risk drivers. The first moderator is the pollution of firms' stocks (POLLUTING STOCKS). We classify polluting stocks (labeled 1) based on the Global Industry Classification Standard (GICS) for firms' stocks that belong to Energy, Materials, Industrials, and Utilities (otherwise, labeled 0)[83]. Regarding the literature, corporate carbon emissions are exposed to transitional risk in the era of climate change, for which investors might demand carbon premiums to hold stocks polluting the environment. Our global economy is transitioning to a carbon-neutral economy by 2050; given increasing climate policy stringency, polluting firms are subject to a greater sensitivity to climate transition risk. For the US state-level/local transitional risk, we employ state-led adaptation plans finalized (SAPF), a dummy variable that is set equal to 1 if a specific US state has adopted its SAPF; otherwise, it is set to 0[84]. For climate physical risk drivers, we employ disaster-prone states (DPS). DPS is a dummy variable that is set equal to 1 for states that are chronically prone to natural disasters; otherwise, DPS is set equal to 0. We extensively control diverse climate risk drivers to investigate their potential channeling effects on the pricing of stock markets to the

[83] For details, please direct to GICS® - Global Industry Classification Standard - MSCI
[84] For progress tracker update, please visit State and Local Adaptation Plans - Georgetown Climate Center

sensitivity of firms' stocks to global warming. Our approach offers more insightful and thorough investigations of climate risk factors with minimal biased estimations and interpretations.

## Findings

[Table 1 Inserted Here]

Table 1 reports the descriptive statistics of variables for our full sample. Our sample includes approximately 340,000 observations. For instance, SL-CCS, the main independent variable capturing state-level corporate climate sensitivity beta, has 340,513 state-firm-stock-year-month observations with mean and median values of 0.000, ranging from -0.047 (minimum value – Min) to 0.050 (maximum value - Max). SL-CCS presents its standard deviation (SD) of 0.012. A positive value of SL-CCS indicates that firms' stocks are positively sensitive to temperature anomalies, while a negative value of SL-CCS indicates that firms' stocks are negatively sensitive to temperature anomalies. (Negative) Positive temperature anomalies indicate that the climate is (cooler) warmer than its 30-year or more average temperature in a particular US state. A positive SL-CCS beta shows that a firm's stock is sensitive to warmer-than-normal temperatures, which is global warming across the US states. While the mean and median values of SL-CCS surround zero, for our full sample, we find that its SD is positive, having a value of 0.012. Also, the maximum value of SL-CCS is positive, having a value of 0.050, which is higher than its minimum value of -0.047. The initial statistics show that firms' stocks have been sensitive to positive temperature anomalies, in which our SD shows that SL-CCS deviates positively from its mean value. In other words, the amount of variation of SL-CCS is positively variable in our full sample, showing that firms' stocks are likely sensitive to positive temperature anomalies in the US states.

Our dependent variable, capturing firms' stock returns (RET), has a total of 356,887 observations with a mean value of 0.007 and a median value of 0.000. RET ranges from a minimum value of -0.441 to a maximum value of 0.660 with an SD of 0.170. Our alternative dependent variable, capturing excess stock returns (Ri-Rf), has the same number of 356,887 observations with a mean value of -3.184. the excess returns range from -3.184 (Min) to 0.208 (Max) with an SD of 2.365 and a median value of -3.392. Reflecting on our descriptive statistics, compared to Cuculiza et al. (2024), we observe the following critical distinctions[85]. First, the most important one, the predicted temperature sensitivity is positive for all its statistical values, with no minimum or maximum values reported. Should all firms' stocks be positively sensitive to nationwide temperature anomalies? Also, the statistical values of temperature sensitivity are higher than our state-level current study. As elaborated throughout the study, the US presents its statewide geographical climatic conditions as well as its abnormal values. Therefore, it is critical to predict the state-level sensitivity of stocks for firms' headquarters. Second, the full sample of Cuculiza et al. (2024) presents a total of roughly 2,2 million observations. With no filtering steps reported, the sample of Cuculiza et al. (2024) might include penny stocks as well as non-common stocks listed outside major stock exchanges. Hence, both the number of observations and descriptive statistics might be inadvertently inflated, leading to potentially biased results and interpretations. In Figure 5, we present our predicted US state-level corporate climate sensitivity in its logarithmic value.

[Tables 2 & 3 Inserted Here]

[85] Table 1, Page 46 of Cuculiza, Carina and Kumar, Alok and Xin, Wei and Zhang, Chendi, Temperature Sensitivity, Mispricing, and Predictable Returns (April 11, 2024). Available at SSRN: https://ssrn.com/abstract=3331872 or http://dx.doi.org/10.2139/ssrn.3331872

The baseline regressions show that state-level corporate climate sensitivity [SL-CCS] is strongly associated with stock returns [RET], as reported in Table 2. The association between SL-CCS and RET is negative for the full sample and negative temperature anomaly (Columns 1& 2). The association becomes positive when the temperature anomaly is positive (Column 3). The predicted associations between SL-CCS and RET remain unchanged when we include control variables (Columns 4-6), excluding the COVID-19 pandemic (Table 3). The baseline findings imply that climate sensitivity (beta) to state-level climate factors is priced in the stock markets. The pricing of stock markets to SL-CCS is driven by positive temperature anomalies, indicating that global warming across the US states could be acknowledged as a new systematic risk factor. The findings complement prior studies on the asset pricing of climate risks by showing that climate sensitivity (beta) to state-level climate factors is priced in the stock markets, conditional on global warming (positive temperature anomaly/abnormal warmer temperature). The rationale is that warmer temperatures induce changes in climate patterns that disrupt the common norms of our nature[86]. Furthermore, temperature is the most important climatic element used for our decision-making[87]. Since the beginning of the 20th century, the contiguous United States' yearly average temperature has increased. Overall, the temperature rose until roughly 1940, fell until 1970, and then rose again until 2016 (Vose et al., 2017). Storms, heat waves, floods, and droughts are just a few of the disasters that are getting worse due to rising temperatures. Warmer temperatures provide an atmosphere with an increased capacity to absorb, hold, and release water, altering weather patterns with various climate consequences[88]. Our baseline findings imply that RET is positively associated with climate sensitivity (beta) when the US contiguous

[86] Causes and Effects of Climate Change | United Nations
[87] Temperature Changes in the United States - Climate Science Special Report (globalchange.gov)
[88] Consequences and Effects of Global Warming -- What is the Impact? (nrdc.org)

states experience positive temperature anomalies. Our findings show that state-level corporate climate sensitivity to temperature anomaly is priced by the stock markets, becoming a new systematic risk factor when temperatures are abnormally warmer.

[Table 4 Inserted Here]

Controlling for polluting stocks, we do not observe significant findings for the interaction terms between CL-CCS and a dummy binary variable capturing polluting stocks.  The predicted associations between SL-CCS and RET remain unchanged when we control for polluting stocks (Table 4). Our findings imply that climate sensitivity (beta) to state-level climate factors is priced in the stock markets, conditional on global warming. Investors demand a premium for holding stocks exposed to positive temperature anomalies. Focusing on the pricing of climate transition risk, prior studies theoretically argue that brown firms are exposed to transition risk (e.g., climate policies) toward our net-zero target. Hsu et al. (2023) argue that brown firms are likely to earn higher expected returns. Pástor et al. (2022) show that green assets have presented high returns in recent years, reflecting unexpectedly strong increasing environmental concerns. Bolton and Kacperczyk (2021); P. Bolton and M. Kacperczyk (2023) document existing carbon premiums, indicating that equity markets are pricing carbon transition risks. In et al. (2023); Pástor et al. (2022); Pedersen et al. (2021) show that green stocks present a better performance in U.S. equity, corporate bonds, and global equity markets, suggesting a continuous shift towards the carbon-conscious equilibrium. The association between carbon risk and stock returns could be contemporaneous due to the forward-looking firm performance accounted for in corporate emissions instead of a risk premium. (Shaojun  Zhang, 2024). As Shaojun  Zhang (2024) argues, carbon returns might become negative and insignificant for the US and global equity markets.

Also, the study mentions that developed markets exhibit lower carbon returns due to severe shocks related to climate concerns, while countries with more climate policy stringency experience higher carbon returns. While the pricing of climate transition risk is subject to other transition risk drivers (e.g., policies), forward-looking performance, and scaling issues (Aswani et al., 2024; Shaojun Zhang, 2024). Prior studies show heterogeneous findings on the pricing for financial markets to carbon risk, for which firms are in an additional period to cut their carbon emissions.

Our evidence complements prior studies by showing that the pricing of equity markets to climate risks is subject to global warming, to which firms are equally exposed. While the pricing of equity markets to the sensitivity of firms' stocks to temperature anomaly is robustly unchanged, we do not observe any significant findings when we control for polluting stocks. Similar insignificant findings are observed for the standalone polluting stocks. Our findings provide the following critical complement to related literature. First, global warming and firms' sensitivity to state-level climatic abnormal factors are the dominant drivers of stock returns. Under abnormal positive temperature anomalies, investors demand a premium when their portfolios of firms' stocks are exposed to abnormally warmer temperatures. In the same vein as S. Zhang (2024), the carbon premium demanded for polluting stocks does not appear and becomes negative when we interact with our SL-CCS beta. Our findings imply that the pricing of financial markets to climate risks with carbon returns is our conditional externality (e.g., environmental policy stringency, etc.). For this study, we show that investors demand a premium when their firms' stocks are sensitive to state-level climate long-term factors, namely temperature anomalies. Pooling altogether, our findings present the pricing of equity markets with long-term climate change. More importantly, we also control its geographical and time-varying divergence across the US states.

[Table 5A Inserted Here]

Global warming leads to diverse climate risk drivers documented in the emerging asset pricing literature. Our findings so far have affirmed the pricing of US equity markets to state-level long-term climate change. To support our argument that global warming is the main driver of stock returns, with investors' demand for a premium only when their firms' stocks are exposed to positive temperature anomaly, we test for the potential moderation of physical and transition climate risk drivers. To capture climate physical risks, we employ US disaster-prone states (DPS), a dummy variable capturing the long-term proneness to natural disasters for US states. We employ the US State-Led Adaptation Plans Finalized, local state-level climate action for the US states, capturing climate transition risks.

As reported in Table 5A, the findings show that equity markets price SL-CCS for firms' stocks located in the DPS[89]. The findings from the interactions between SL-CCS and DPS (SL-CCS x DPS) show that investors demand a premium to hold stocks for which their firms are prone to natural disasters. The interaction terms are positive and statistically significant when we test for the full sample (Column 1) and a sub-sample of negative temperature anomalies (Column 2). The interaction term becomes negative and statistically insignificant when we test a sub-sample with positive temperature anomalies (Column 3). The standalone effects of DPS on RET are

[89] Regarding The Most Disaster-Prone States in the U.S. (usnews.com), Disaster-Prone States include: 1. Texas, 2. California, 3. Oklahoma, 4. Washington, 5. Florida, 6. Oregon, 7. New York, 8. New Mexico, 9. Arizona, 10 (tie). Colorado, 10 (tie). Nevada

statistically insignificant for all the fitted models, which is negative, and only statistically significant for the sub-sample of negative temperature anomalies (Column 2). The standalone associations between SL-CCS and RET remain consistent with the predicted signs and statistically significant levels. Our findings imply that equity markets are pricing climate risks, but the pricing is conditional on the levels of global warming. In other words, we observe a strong positive association between SL-CCS and RET when temperatures are abnormally warmer than their long-term baseline values.

Using SL-CCS beta with firm-level environmental performance (e.g., industry-classified pollution levels) and controlled natural disasters (DPS), our findings offer critical complements to the literature. Huynh and Xia (2023) document that, if firms are exposed to disaster risks, their future returns are predicted to be significantly higher for both bond and stock markets[90]. The study argues that investors overreact to disaster risks, depressing stock and bond prices, leading to higher predicted returns. Overall, the study of Huynh and Xia (2023) concludes the relationship between disasters and future returns [$RET_{t+1}$]. Using the SL-CCS beta, our findings show a negative and statistically significant relation between SL-CCS and RET. More importantly, the associations between SL-CCS and RET become positive and significant when global warming emerges across the US states.  Our findings do not show significant findings when we test for one-month-ahead returns (RET and Excess RET). Conditional on global warming (e.g., abnormal warmer temperatures), our predicted associations between RET and SL-CCS are constant when we follow the estimations of Bolton and Kacperczyk (2021) using time [month] and industry [SICCD] fixed effects with standard errors clustered for firms' stocks. Our

[90] Reported in Table 3 Panel A.

findings are unchanged when we use excess return [Ex-RET $_t$], and the estimations show no significant findings when we test for one month ahead [Ex-RET$_{t+1}$] as implemented in Huynh and Xia (2023).

Figure 5 presents a histogram with a kernel density estimate for the SL-CCS. The figure presents the normal distribution of our predicted SL-CCS beta with values ranging from -0.05 (minimum) and 0.05 (maximum). The positive values indicate that stock returns are positively associated with state-level climate change [SLCC], proxied by state-level temperature anomalies [SLTA][91]. Overall, our findings show that the relationship between stock returns and climate risks varies by the level of corporate climate sensitivity to temperature anomalies. We only observe a positive predicted relation between SL-CCS and RET with positive abnormal temperatures, for which global warming is emerging. Our findings imply that state-level climate factors (e.g., temperature anomalies used for this study) are being priced in the financial markets (e.g., US stock markets for this study), and the pricing is conditional on SL-CCS being a systematic risk factor, namely, global warming.

[Table 5B Inserted Here]

Next, we examine the potential moderation of local climate action (transition risk) to the association between SL-CCS and RET, as reported in Table 5B. Using state-level adaptation plans finalized (SAPF), the findings show a positive relation between the interaction term (SL-CCS x SAPF) and RET. The standalone relation between SAPF and RET is positive for all the fitted models and is only statistically significant for the full sample (Column 1) and positive

[91] We use SLCC and SLTA interchangeably for the study with the same meaning.

anomaly (Column 3). The standalone association between SL-CCS and RET remains constant when we control SAPF. More importantly, the relation between the interaction term (SL-CCS x SAPF) and RET is positive with a stronger statistically significant level at the 5% level (Column 3 for positive temperature anomaly) compared to a 1% significant level (Column 3 for the full sample).

Overall, our findings convey critical insights into the pricing of financial markets to global warming (abnormally positive temperature values) at the state level. First, equity markets price climate risks, but the pricing of the markets to climate risks is conditional on the levels of global warming. Our findings are robust when we check climate-related risk drivers tested in prior asset pricing literature, including climate physical (DPS) and transition risk (SAPF) drivers. Second, our findings suggest that investors demand a premium for holding stocks exposed to global warming. The premium demand is more pronounced for firms' stocks sensitive to local state-level climate action (e.g., transition risks). We do not observe any significant findings from polluting stocks (e.g., carbon transition risks). Investors demand a premium for holding firms' stocks sensitive to disaster-prone states for the full sample test and negative temperature anomalies. We argue that the pricing of equity markets to climate risks is inevitable, and the SL-CCS predicted beta could be acknowledged as a systematic long-term risk factor. SL-CCS is also conditional on the levels of proneness of firms' locations to climate risk drivers. Either transition (endogenous versus exogenous factors) and physical risks (long-term vs short-term), our findings predict constant associations between RET and SL-CCS predicted betas to capture the sensitivity of firms' stocks to state-level and long-term climate change benchmarked by temperature anomalies. Our findings complement prior asset pricing literature on climate change, showing that the sensitivity of firms' stocks to long-term climate change is a principal driver of stock returns. Our findings are robust with(out) the COVID-19 pandemic, penny stocks, and using either stock return or excess returns as used in prior literature.

**Table 1:** Descriptive statistics [Full sample]

| Variable | N | Mean | Min | p50 | Max | SD |
|---|---|---|---|---|---|---|
| RET | 356887 | 0.007 | -0.441 | 0.000 | 0.660 | 0.170 |
| Ri-Rf | 356887 | -3.184 | -8.213 | -3.392 | 0.208 | 2.365 |
| SL-CCS | 340513 | 0.000 | -0.047 | 0.000 | 0.050 | 0.012 |
| SLTA | 352325 | 1.303 | -16.000 | 1.000 | 18.000 | 3.326 |
| SIZE | 282516 | 4.931 | 0.054 | 4.909 | 11.005 | 2.521 |
| BM | 230148 | 1.351 | 0.014 | 0.897 | 9.092 | 1.574 |
| LEV | 263073 | 0.311 | 0.000 | 0.185 | 4.104 | 0.528 |
| Q | 244399 | 3.006 | 0.455 | 1.367 | 51.796 | 6.347 |
| CAPEX | 255570 | 0.034 | 0.000 | 0.014 | 0.343 | 0.057 |
| TANG | 272632 | 0.259 | 0.000 | 0.156 | 0.950 | 0.270 |
| ROA | 274833 | -0.041 | -1.575 | 0.008 | 0.131 | 0.210 |
| SALE | 278721 | 0.216 | 0.000 | 0.154 | 1.160 | 0.228 |
| R&D | 362254 | 0.011 | 0.000 | 0.000 | 0.510 | 0.044 |
| CASH | 279224 | 0.181 | 0.000 | 0.070 | 0.974 | 0.241 |

The table reports statistical descriptive values of the variables used for our merged sample.

**Table 2:** State-level corporate climate sensitivity [SL-CCS] and stock returns [RET]

| VARIABLES | (1)<br>RET<br>Full sample | (2)<br>RET<br>Negative Anomaly<br>[Abnormal Cooler] | (3)<br>RET<br>Positive Anomaly<br>[Abnormal Warmer] | (4)<br>RET<br>Full sample | (5)<br>RET<br>Negative Anomaly<br>[Abnormal Cooler] | (6)<br>RET<br>Positive Anomaly<br>[Abnormal Warmer] |
|---|---|---|---|---|---|---|
| SL-CCS | -0.261*** | -2.548*** | 0.840*** | -0.300*** | -2.657*** | 0.784*** |
| | (0.035) | (0.068) | (0.044) | (0.047) | (0.091) | (0.061) |
| SIZE | | | | -0.000** | -0.000 | -0.000 |
| | | | | (0.000) | (0.000) | (0.000) |
| BM | | | | -0.000 | -0.000 | 0.000 |
| | | | | (0.000) | (0.001) | (0.000) |
| LEV | | | | 0.001 | 0.004** | -0.000 |
| | | | | (0.001) | (0.002) | (0.001) |
| Q | | | | -0.000 | -0.000 | -0.000 |
| | | | | (0.000) | (0.000) | (0.000) |
| CAPEX | | | | 0.011 | 0.016 | 0.008 |
| | | | | (0.009) | (0.016) | (0.011) |
| TANG | | | | -0.004** | -0.007* | -0.003 |
| | | | | (0.002) | (0.004) | (0.002) |
| ROA | | | | 0.002 | 0.010 | 0.002 |
| | | | | (0.003) | (0.006) | (0.003) |
| SALE | | | | -0.002 | -0.007* | 0.001 |
| | | | | (0.002) | (0.004) | (0.003) |
| R&D | | | | 0.007 | 0.021 | 0.004 |
| | | | | (0.010) | (0.022) | (0.011) |
| CASH | | | | 0.001 | 0.001 | 0.002 |
| | | | | (0.002) | (0.004) | (0.002) |
| Constant | 0.007*** | 0.006*** | 0.007*** | 0.009*** | 0.010*** | 0.008*** |
| | (0.000) | (0.000) | (0.000) | (0.002) | (0.003) | (0.002) |
| Observations | 337,298 | 96,172 | 201,537 | 189,912 | 53,381 | 114,025 |

| | | | | | | |
|---|---|---|---|---|---|---|
| R-squared | 0.128 | 0.164 | 0.135 | 0.133 | 0.176 | 0.138 |
| Time FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Industry FE | Yes | Yes | Yes | Yes | Yes | Yes |
| SE Clustered | Yes | Yes | Yes | Yes | Yes | Yes |

The table reports linear regressions of stock returns with multiple fixed effects for time (date) and industry (SICCD codes) levels. Robust standard errors are clustered by firm (8-digit CUSIP code) in parentheses. The characters *** p<0.01, ** p<0.05, * p<0.1 indicate the statistical significance at the 1%, 5%, and 10% level, respectively.

**Table 3:** Robustness check excluding Covid-19 period

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| VARIABLES | RET<br>Full sample<br>Excluding<br>Covid-19 | RET<br>Negative Anomaly<br>[Abnormal Cooler]<br>Excluding Covid-19 | RET<br>Positive Anomaly<br>[Abnormal Warmer]<br>Excluding Covid-19 | RET<br>Full sample<br>Excluding<br>Covid-19 | RET<br>Negative Anomaly<br>[Abnormal Cooler]<br>Excluding Covid-19 | RET<br>Positive Anomaly<br>[Abnormal Warmer]<br>Excluding Covid-19 |
| SL-CCS | -0.275*** | -2.488*** | 0.891*** | -0.295*** | -2.579*** | 0.846*** |
| | (0.036) | (0.071) | (0.046) | (0.049) | (0.094) | (0.063) |
| SIZE | | | | -0.000* | -0.000 | -0.000 |
| | | | | (0.000) | (0.000) | (0.000) |
| BM | | | | 0.000 | -0.000 | 0.000 |
| | | | | (0.000) | (0.001) | (0.000) |
| LEV | | | | 0.000 | 0.004* | -0.001 |
| | | | | (0.001) | (0.002) | (0.001) |
| Q | | | | -0.000 | -0.000 | -0.000 |
| | | | | (0.000) | (0.000) | (0.000) |
| CAPEX | | | | 0.012 | 0.017 | 0.010 |
| | | | | (0.009) | (0.016) | (0.011) |
| TANG | | | | -0.004** | -0.007* | -0.003 |
| | | | | (0.002) | (0.004) | (0.002) |
| ROA | | | | 0.001 | 0.009 | 0.000 |
| | | | | (0.003) | (0.006) | (0.004) |
| SALE | | | | -0.002 | -0.008** | 0.001 |
| | | | | (0.002) | (0.004) | (0.003) |
| R&D | | | | 0.003 | 0.021 | -0.002 |
| | | | | (0.010) | (0.022) | (0.011) |
| CASH | | | | 0.001 | 0.001 | 0.003 |
| | | | | (0.002) | (0.004) | (0.003) |
| Constant | 0.007*** | 0.006*** | 0.008*** | 0.009*** | 0.009*** | 0.007*** |
| | (0.000) | (0.000) | (0.000) | (0.002) | (0.003) | (0.002) |

| | | | | | | |
|---|---|---|---|---|---|---|
| Observations | 309,756 | 91,224 | 181,234 | 177,171 | 51,216 | 104,535 |
| R-squared | 0.122 | 0.159 | 0.127 | 0.128 | 0.172 | 0.132 |
| Time FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Industry FE | Yes | Yes | Yes | Yes | Yes | Yes |
| SE Clustered | Yes | Yes | Yes | Yes | Yes | Yes |

The table reports linear regressions of stock returns with multiple fixed effects for time (date) and industry (SICCD codes) levels. Robust standard errors are clustered by firm (8-digit CUSIP code) in parentheses. The characters *** p<0.01, ** p<0.05, * p<0.1 indicate the statistical significance at the 1%, 5%, and 10% level, respectively.

**Table 4:** Mediation tests – Polluting stocks

| VARIABLES | (1)<br>RET<br>Full sample<br>Excluding Covid-19 | (2)<br>RET<br>Negative Anomaly<br>[Abnormal Cooler]<br>Excluding Covid-19 | (3)<br>RET<br>Positive Anomaly<br>[Abnormal Warmer]<br>Excluding Covid-19 |
|---|---|---|---|
| SL-CCS | -0.254*** | -2.508*** | 0.852*** |
| | (0.059) | (0.115) | (0.075) |
| POLLUTING STOCKS | 0.001 | 0.003 | -0.001 |
| | (0.001) | (0.002) | (0.001) |
| SL-CCS x POLLUTING STOCKS | -0.139 | -0.231 | -0.023 |
| | (0.105) | (0.201) | (0.141) |
| SIZE | -0.000* | -0.000 | -0.000 |
| | (0.000) | (0.000) | (0.000) |
| BM | 0.000 | -0.000 | 0.000 |
| | (0.000) | (0.001) | (0.000) |
| LEV | 0.000 | 0.004* | -0.001 |
| | (0.001) | (0.002) | (0.001) |
| Q | -0.000 | -0.000 | -0.000 |
| | (0.000) | (0.000) | (0.000) |
| CAPEX | 0.012 | 0.016 | 0.010 |
| | (0.009) | (0.016) | (0.011) |
| TANG | -0.005** | -0.008** | -0.003 |
| | (0.002) | (0.004) | (0.003) |
| ROA | 0.001 | 0.009 | -0.000 |
| | (0.003) | (0.006) | (0.004) |
| SALE | -0.002 | -0.008** | 0.001 |
| | (0.002) | (0.004) | (0.003) |
| R&D | 0.004 | 0.024 | -0.003 |
| | (0.010) | (0.023) | (0.011) |
| CASH | 0.001 | 0.001 | 0.003 |
| | (0.002) | (0.004) | (0.003) |
| Constant | 0.008*** | 0.009** | 0.008*** |
| | (0.002) | (0.003) | (0.002) |
| Observations | 177,171 | 51,216 | 104,535 |
| R-squared | 0.128 | 0.172 | 0.132 |
| Time FE | Yes | Yes | Yes |
| Industry FE | Yes | Yes | Yes |
| SE Clustered | Yes | Yes | Yes |

The table reports linear regressions of stock returns with multiple fixed effects for time (date) and industry (SICCD codes) levels. Robust standard errors are clustered by firm (8-digit CUSIP code) in parentheses. The characters *** p<0.01, ** p<0.05, * p<0.1 indicate the statistical significance at the 1%, 5%, and 10% level, respectively.

| **Table 5A:** Moderation tests – Disaster-prone states [DPS] | | | |
|---|---|---|---|
| | (1) | (2) | (3) |
| VARIABLES | RET | RET | RET |
| | Full sample<br>Excluding Covid-19 | Negative Anomaly<br>[Abnormal Cooler]<br>Excluding Covid-19 | Positive Anomaly<br>[Abnormal Warmer]<br>Excluding Covid-19 |
| SL-CCS | -0.408*** | -2.814*** | 0.896*** |
| | (0.069) | (0.134) | (0.094) |
| DPS | -0.001 | -0.004** | 0.000 |
| | (0.001) | (0.002) | (0.001) |
| SL-CCS x DPS | 0.216** | 0.471** | -0.094 |
| | (0.097) | (0.188) | (0.126) |
| SIZE | -0.000* | -0.000 | -0.000 |
| | (0.000) | (0.000) | (0.000) |
| BM | -0.000 | -0.000 | 0.000 |
| | (0.000) | (0.001) | (0.000) |
| LEV | 0.000 | 0.004* | -0.001 |
| | (0.001) | (0.002) | (0.001) |
| Q | -0.000 | -0.000 | -0.000 |
| | (0.000) | (0.000) | (0.000) |
| CAPEX | 0.012 | 0.016 | 0.010 |
| | (0.009) | (0.016) | (0.011) |
| TANG | -0.005** | -0.007* | -0.003 |
| | (0.002) | (0.004) | (0.002) |
| ROA | 0.001 | 0.009 | 0.000 |
| | (0.003) | (0.006) | (0.004) |
| SALE | -0.002 | -0.008** | 0.001 |
| | (0.002) | (0.004) | (0.003) |
| R&D | 0.003 | 0.021 | -0.002 |
| | (0.010) | (0.023) | (0.011) |
| CASH | 0.001 | 0.001 | 0.003 |
| | (0.002) | (0.004) | (0.003) |
| Constant | 0.009*** | 0.011*** | 0.007*** |
| | (0.002) | (0.003) | (0.002) |
| Observations | 177,171 | 51,216 | 104,535 |
| R-squared | 0.128 | 0.172 | 0.132 |
| Time FE | Yes | Yes | Yes |
| Industry FE | Yes | Yes | Yes |
| SE Clustered | Yes | Yes | Yes |

The table reports linear regressions of stock returns with multiple fixed effects for time (date) and industry (SICCD codes) levels. Robust standard errors are clustered by firm (8-digit CUSIP code) in parentheses. The characters *** p<0.01, ** p<0.05, * p<0.1 indicate the statistical significance at the 1%, 5%, and 10% level, respectively.

| **Table 5B:** Moderation tests – State-led adaptation plans finalized [SAPF] | | | |
|---|---|---|---|
| | (1) | (2) | (3) |
| VARIABLES | RET | RET | RET |
| | Full sample<br>Excluding Covid-19 | Negative Anomaly<br>[Abnormal Cooler]<br>Excluding Covid-19 | Positive Anomaly<br>[Abnormal Warmer]<br>Excluding Covid-19 |
| SL-CCS | -0.318*** | -2.573*** | 0.821*** |
| | (0.050) | (0.098) | (0.065) |
| SAPF | 0.003* | 0.002 | 0.005** |
| | (0.002) | (0.003) | (0.002) |
| SL-CCS x SAPF | 0.392* | -0.115 | 0.414 |
| | (0.201) | (0.365) | (0.268) |
| SIZE | -0.000* | -0.000 | -0.000 |
| | (0.000) | (0.000) | (0.000) |
| BM | 0.000 | -0.000 | 0.000 |
| | (0.000) | (0.001) | (0.000) |
| LEV | 0.000 | 0.004* | -0.001 |
| | (0.001) | (0.002) | (0.001) |
| Q | -0.000 | -0.000 | -0.000 |
| | (0.000) | (0.000) | (0.000) |
| CAPEX | 0.012 | 0.017 | 0.009 |
| | (0.009) | (0.016) | (0.011) |
| TANG | -0.004* | -0.006* | -0.003 |
| | (0.002) | (0.004) | (0.002) |
| ROA | 0.001 | 0.009 | -0.000 |
| | (0.003) | (0.006) | (0.004) |
| SALE | -0.002 | -0.008** | 0.001 |
| | (0.002) | (0.004) | (0.003) |
| R&D | 0.002 | 0.021 | -0.003 |
| | (0.010) | (0.022) | (0.011) |
| CASH | 0.001 | 0.001 | 0.003 |
| | (0.002) | (0.004) | (0.003) |
| Constant | 0.009*** | 0.009*** | 0.007*** |
| | (0.002) | (0.003) | (0.002) |
| Observations | 177,171 | 51,216 | 104,535 |
| R-squared | 0.128 | 0.172 | 0.132 |
| Time FE | Yes | Yes | Yes |
| Industry FE | Yes | Yes | Yes |
| SE Clustered | Yes | Yes | Yes |

The table reports linear regressions of stock returns with multiple fixed effects for time (date) and industry (SICCD codes) levels. Robust standard errors are clustered by firm (8-digit CUSIP code) in parentheses. The characters *** p<0.01, ** p<0.05, * p<0.1 indicate the statistical significance at the 1%, 5%, and 10% level, respectively.

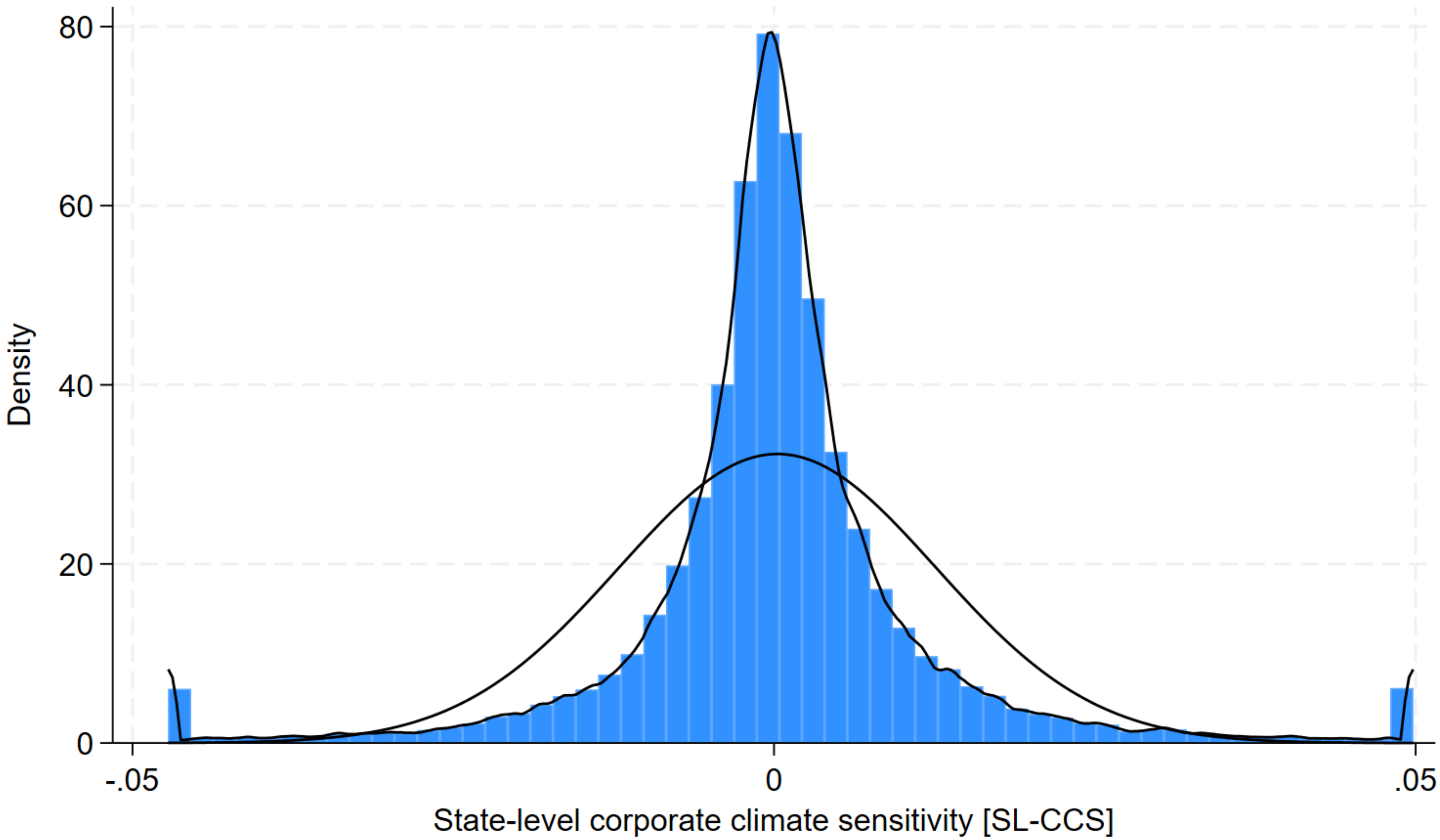


*Figure 5: A histogram of the State-Level Corporate Climate Sensitivity [SL-CCS] predicted with a kernel density estimate.*

# Conclusion

Using US state-level climate change data, this study quantifies the long-term effects of temperature anomalies on corporate dividend policy. The study provides prior literature following contributions. First, state-level temperature anomaly induces firms to become conservative in paying dividends to their shareholders. The predicted impacts of temperature anomalies on corporate dividend policy remain robust with alternative dividend measures. Under the systematic and long-term climate impacts, the study found weak evidence of firms favoring share repurchases over dividends for their payout flexibility. The adverse consequences of state-level climate change on dividend payouts have been pronounced for firms with higher vulnerability to climate risks since the Paris Agreement. Regarding corporate payout literature, our channel tests highlight the roles of corporate cash holdings, trade credit, and market leverage. Firms with higher cash reserves in the prior year continue being conservative in paying dividends to recover their liquidity (Denis, 2011). The consequences of climate change become even more severe for firms with uncertain financial flexibility. Regarding Fahlenbrach et al. (2020), decreased revenues induce firms to reserve more cash. In the context of long-term climate change exposure, the findings highlight the precautionary framework of firms' cash policy which is interactively related to their payout policy (Dimitrios Gounopoulos & Yu Zhang, 2024; Siamak Javadi et al., 2023). Yuyuan Chang et al. (2024) argue that firms might favor share repurchases over dividends for higher payout flexibility in the context of physical risks; benchmarking climate change risks, the findings of the current study are unable to support such argument.

For the proneness to contemporary physical risks as used in Yuyuan Chang et al. (2024), our moderation tests show that firms headquartered in the leading disaster-prone states maintain a positive dividend payout to their shareholders. The findings provide important implications that the proneness to natural disasters induces firms to have a higher awareness about climate change with suitable risk management. Regarding agency-based theories, payout policies are critical to mitigating potential agency problems among management board, directors, and shareholders under the threats imposed by widespread climate change, see Easterbrook (1984); Jensen (1986); Jensen and Meckling (1976). Also, either temporary or long-term climate risks, changes in payout policy by firms are dependent on firm characteristics, life cycle, and corporate earnings (Fama & French, 2001; Fatemi & Bildik, 2012; Kuo et al., 2013; Michaely & Moin, 2022; Moshirian et al., 2017). The study mitigates endogeneity issues by not just testing for the proneness to natural disasters, the findings remain constant with a predicted decrease in dividend payouts when we control for corporate cash holdings, an important determinant of corporate payout policies. In other words, chronic proneness to physical risks could elevate firms' awareness of climate risk drivers for suitable hedging approaches. Also, to some extent, the historical cash reserve might signal incremental conservativeness of firms to climate change exposure with their continuous disappearing dividends.

Our channel tests show that firms with higher trade credit and market leverage maintain positive dividends paid to shareholders under the exposure to state-level climate change. Since the extension of trade credit is associated with a firm's operating performance (Box et al., 2018), aggressive trade credits imply future profitability that is associated with their contemporary trade credit provision with appearing dividends under climate change exposure. Regarding Box et al. (2018), the findings imply potential revenues, market shares, and higher profit margins for firms that are making use of trade credit, compared to peers with comparable characteristics and operational needs exposed to climate change. In the context of climate change, our findings suggest that aggressive trade credit policies could support improved product market performance. While Denis and McKeon (2012) argue that firms predominantly increase leverage for their operating needs rather than large equity payouts, the study finds that, under state-level climate change, firms with proactive leverage maintain a positive dividend payout to their shareholders. The findings imply that, if firms could make use of market leverage for their financing needs, they might still be able to make dividends to their shareholders. With possible leverage increase, paying dividends helps firms mitigating agency problems while conveying positive signals about their growth potential, see Allen and Michaely (2003); Brockman and Unlu (2009); Easterbrook (1984); Farre-Mensa et al. (2014). More importantly, dividends appear to firms that are in disaster-prone states for which they are likely to have adaptive climate management practices to deal with expected climatic changes.

Our findings add a potential novelty to a recent study by Yuyuan Chang et al. (2024); Huang et al. (2018) by showing that, the proneness to physical risks could help firms to manage positive payouts to their shareholders. Payout choices could be predominantly driven by how flexible a firm's financial conditions are, see Bonaimé et al. (2013); Byoun (2021); Yuyuan Chang et al. (2024); DeAngelo and DeAngelo (2007); DeAngelo et al. (2017); Denis (2011); Denis and McKeon (2012); Fahlenbrach et al. (2020); GAMBA and TRIANTIS (2008). How much financial flexibility is valuable to firms that are exposed to long-term climate change? Upon the question, the second chapter examines the impacts of climate change on the value of financial flexibility.

By benchmarking long-term climate change risks, it seems clear that statewide climate change imposes systematic risks on firms' growth prospects with chronic decrease in dividend payouts. Prior literature argues so much on the predicted paths for which firms might adjust their capital structure to be responsive to various climate change risks. It is inevitable that financial leverage plays crucial roles in corporate financial flexibility. Under the multifaceted effects of climate risks, the value of financial flexibility (e.g., leveraging) could be systematically affected. For supporting such argument, the second chapter provides state-level evidence on the impacts of long-term climate change on the value of financial flexibility (VOFF). Distinguished from prior literature, the study captures the state-level geographically divergent nature of LTCC by employing state-level temperature anomalies (SLTA), a benchmark measure in climate science. Using a predicted forward-looking and market-based measure of VOFF, the study provides the following contributions to literature. The study presents a persistent negative association between state-level climate change (SLCC) and VOFF. The impacts of SLCC are pronounced for larger firms with higher market-to-book value (MB), indicating the long-term climate-induced consequences to corporate financial flexibility and growth opportunities for firms. Additional analyses show the importance of access to credit (leverage) to firms dealing with climate change exposure. The findings imply the mediating effects of corporate financial policies on the association between SLCC and VOFF. Under long-term climate change, firms located in disaster-prone states with state-led adaptation plans finalized present persistently decreases in their VOFF. The findings mitigate endogeneity concerns by showing that SLCC benchmarks climate change impacts on the VOFF of firms with the moderation of physical and transitional climate risk drivers.

Prior literature focuses on the responsive corporate policies to climate change risks; the current study shows that long-term climate change, with its geographical complexity and escalating consequences, adversely affects the value of financial flexibility of firms.

The first and second chapters have shown the financial impacts of statewide climate change on corporate payouts and the value of financial flexibility, which are critical to the fast-growing corporate climate finance. Under the geographical complexity of climate change, the first two chapters imply systematic challenges to growth prospects with a predicted decrease in the value of financial flexibility for which firms could maintain positive payouts paid to shareholders. Investors have paid increasing attention to climate risks; therefore, understanding the sensitivity of firms to local climate factors is critical not just to corporate financial decisions but also to the proper pricing of financial markets for firms' stocks.

Taking advantage of such critical research gaps, the third essay predicts state-level corporate climate sensitivity (SL-CCS). Using the uniquely predicted SL-CCS betas, the study examines the pricing of US stock markets to the sensitivity of firms to local climate factors, becoming a potential priced factor in climate-related empirical asset pricing literature. Benchmarking long-term climate change with statewide temperature anomaly, the study shows that the pricing of stock markets to SL-CCS beta is conditional on global warming, the benchmarked long-term climate change risk measure. More specifically, the associations between SL-CCS betas and stock returns are only positive and statistically significant under positive temperature anomalies. The rationale is that global warming leads to diverse climate risk drivers, and investors' awareness of climate risks is clear when their firms' stocks are exposed to abnormally warmer temperatures.  While prior studies claim that RET is positively related to climate risk factors due to the depression of investors to prices, the study shows that long-term climate change is a principal driver of the presence of global warming as a new systematic risk. Without controlling for our SL-CCS betas, the study finds weak evidence on the proper pricing of equity markets to climate risk drivers, which is heterogeneously documented in prior literature (Aswani et al., 2023a, 2023b; Bolton & Kacperczyk, 2021; Patrick Bolton & Marcin Kacperczyk, 2023a, 2023b; Shaojun  Zhang, 2024). The rationale is that prior studies may fail to benchmark climate change risks with their geographical complexity. To test the hypothesized rationale, interacting with our predicted SL-CCS beta with carbon-intensive stocks to capture endogenous transition risk, we find no evidence of the presence of a carbon premium for polluting stocks. For exogenous transition risk, the study finds weak evidence on the association between state-led adaptation plans finalized (SAPF) and stock returns (RET). The SAPF-RET nexuses are marginally positive and statistically significant for the full sample and become stronger in terms of predicted value and significant levels when we interact SAPF with SL-CCS beta and test for positive temperature anomalies in the sub-sample. Controlling for the long-term proneness to natural disasters, we even find a negative and statistically significant association between RET and disaster-prone states (DPS) under negative temperature anomalies, and no significant RET-DPS nexus is detected under positive temperature anomalies. The predicted RET becomes positive and significant when we interact DPS with SL-CCS beta (DPS x SL-CCS) for the full sample and negative temperature anomaly as the sub-sample. The study thoroughly controls for diverse climate risk drivers to consolidate our tested hypotheses.

The study empirically proves that the sensitivity of firms' stocks to state-level and long-term climate change is being priced by the US stock markets which could become a new systematic risk factor. The study finds strong evidence that state-level global warming is a dominant driver of stock returns, with possible premiums demanded by investors for holding stocks exposed to long-term climate change. Capturing the geographical divergence of climate change in the US, the third chapter complements prior literature on asset pricing and climate-related risks with heterogeneous findings (Aswani et al., 2024; Bolton & Kacperczyk, 2021; P. Bolton & M. Kacperczyk, 2023; Huynh & Xia, 2021; Huynh & Xia, 2023; S. Zhang, 2024). The tested hypotheses suggest that the sensitivity of firms' stocks to long-term climate change is the main driver of stock returns. Furthermore, the findings show that investors only demand a premium when their firms' stocks are exposed to global warming (e.g., state-level positive temperature anomaly). There is weak evidence on the other climate risk drivers driving stock returns, with premiums demanded by investors that are documented in the literature. The predicted SL-CCS betas offered by the third essay are crucial to future asset pricing literature on the reliable pricing of financial markets to climate risk factors.

# Appendices

**Chapter One - Appendix A1:** Definitions of variables.

| Variable | Definition | Data Source |
|---|---|---|
| | **State-level climate change** | |
| State-Level Temperature Anomaly | The state-level temperature anomaly that is captured is a divergence from a baseline average temperature. US states' baseline temperature is estimated by averaging 30 years or more of state-level temperature data. A positive temperature anomaly value indicates that a specific state's observed temperature was warmer than its baseline historical average temperature value. The negative value of temperature anomaly indicates the observed temperature of a specific state was cooler than its baseline average temperature value. | NCEI-NOAA |
| State-Level Abnormal warmer | A dummy variable is set equal to one for positive values of state-level temperature anomaly; otherwise, is set equal to zero. | NCEI-NOAA<br>Author's Calculation |
| State-Level Abnormal Cooler | A dummy variable is set equal to one for negative values of state-level temperature anomaly; otherwise, is set equal to zero. | NCEI-NOAA<br>Author's Calculation |
| | **Corporate payout measures** | |
| Dividend/Assets | Dividends common/ordinary [DVC] to assets total. | COMPUSTAT ANNUAL File<br>Author's Calculation |
| Dividend/Common shares Outstanding | Dividends common/ordinary [DVC] to common shares outstanding. | COMPUSTAT ANNUAL File<br>Author's Calculation |
| Dividend/Sales | Dividends common/ordinary [DVC] to sales/turnover (Net). | COMPUSTAT ANNUAL File<br>Author's Calculation |
| Log (1+ Dividend) | The logarithm value of one plus Dividends Common/Ordinary [DVC]. | COMPUSTAT ANNUAL File<br>Author's Calculation |
| Shares repurchase | Shares repurchase to assets total. | COMPUSTAT ANNUAL File<br>Author's Calculation |
| Payout flexibility | Shares repurchase to gross payouts. | COMPUSTAT ANNUAL File<br>Author's Calculation |

| | | |
|---|---|---|
| | Main firm-level control variables | |
| Firm size | The logarithm value of one plus firms' assets total [AT]. | COMPUSTAT ANNUAL File Author's Calculation |
| Book to market | Book to market ratio. | COMPUSTAT ANNUAL File Author's Calculation |
| Log (1+Tobin's Q) | The logarithm value of one plus Tobin's Q. | COMPUSTAT ANNUAL File Author's Calculation |
| Capex | Capital expenditures [CAPX] to assets total [AT]. | COMPUSTAT ANNUAL File Author's Calculation |
| R&D to Assets | Research and development expenditure [XRD] to assets total [AT]. Missing values are replaced by zero. | COMPUSTAT ANNUAL File Author's Calculation |
| Leverage | Book leverage measured as the fraction of firms' debt [DLC + DLTT] to book assets total [AT]. | COMPUSTAT ANNUAL File Author's Calculation |
| Operating cash flow | Firms' operating cash flow [OCF] to assets total [AT] | COMPUSTAT ANNUAL File Author's Calculation |
| Sga to Sales | Selling, general and administrative expense [SGA] to sales/turnover (Net) [SALE] | COMPUSTAT ANNUAL File Author's Calculation |
| Xad to Sales | Advertising expense [XAD] to sales/turnover (Net) [SALE] | COMPUSTAT ANNUAL File Author's Calculation |
| | **Additional firm-level control variables** | |
| FCF/Assets | Free cash flow [FCF] to assets total [AT] | COMPUSTAT ANNUAL File Author's Calculation |
| Log (1 + Age) | The logarithm value of one plus firm age. Missing values are replaced by zero. | COMPUSTAT ANNUAL File Author's Calculation |
| Cash/Assets | Cash and short-term investments [CHE] to assets total. | COMPUSTAT ANNUAL File Author's Calculation |
| Interest/Assets | Interest and Related Expense – Total [XINT] to assets total [AT]. | COMPUSTAT ANNUAL File Author's Calculation |
| Income Taxes/Assets | Income Taxes [TXT] Total to Assets Total [AT] | COMPUSTAT ANNUAL File Author's Calculation |
| Change in Debt | Change in debt total from year t-1 to year t. | COMPUSTAT ANNUAL File Author's Calculation |
| Change in Cash | Change in cash holdings from year t-1 to year t. | COMPUSTAT ANNUAL File Author's Calculation |
| Trade credit | Trade credit measured by accounts payable [AP] to cost of | COMPUSTAT ANNUAL File |

| | | |
|---|---|---|
| | goods sold [COGS] | Author's Calculation |
| Market leverage | Market leverage is measured by debt total [DLC+DLTT] to market value of assets [MVA]. | COMPUSTAT ANNUAL File<br>Author's Calculation |
| 2000s dummy | A time dummy variable that is set equal to one for the years 2000s, otherwise is set equal to zero. | Author's Calculation |
| 2010s dummy | A time dummy variable that is set equal to one for the years 2010s, otherwise is set equal to zero | Author's Calculation |
| 2018 dummy | A time dummy variable that is set equal to one for the year 2018, otherwise is set equal to zero | Author's Calculation |
| | **Variables used for moderating regressions** | |
| COP21 | A time dummy variable that is set equal to one for the years after the Paris Agreement adopted in 2015, otherwise is set equal to zero. | Author's Calculation |
| Disaster-Prone States | A dummy variable that is set equal to one for firms headquartered in disaster-prone states, otherwise is set equal to zero. The 10 Most Disaster-Prone States in the U.S. (usnews.com) | |
| Vulnerability | A dummy variable that is set equal to one form firms that belong to vulnerable industries that are exposed to climate change risk drivers. | Author's Calculation |

Note: To mitigate the potential effects of outliers, we winsorize all the firm-level continuous variables at the 1st and 99th percentiles.

| **Chapter Two - Appendix:** Variables, definitions, and data sources | | |
|---|---|---|
| SLCC | State-level climate change is measured by state-level temperature anomaly [SLTA]. Regarding NCEI-NOAA (2025), temperature anomalies are more significant in climate research than absolute temperature. A temperature anomaly indicates the difference between an average or baseline temperature. The baseline temperature is often calculated by taking the average of more than thirty years of temperature data. A positive anomaly indicates that the observed temperature was higher than the baseline, and a negative anomaly indicates that the observed temperature was lower than the baseline. Factors such as station location and elevation will influence the data when determining a mean of absolute temperatures. However, when it comes to anomalies, these criteria are less important. Using anomalies additionally assists in reducing issues when stations are added, withdrawn, or missing from the network used for monitoring. The graphic above depicts absolute temperatures (lines) for five surrounding sites, with 2008 anomalies shown by symbols. Consider how all anomalies fall into a small range compared to the absolute temperatures. Even if one station were removed from the record, the meaning anomaly would remain constant, but the total average temperature could shift dramatically depending on which station was removed. For example, removing the coolest station (Mt. Mitchell) from the record would result in a much higher average absolute temperature. However, because its anomaly is close to that of the nearby stations, the mean anomaly would change significantly less. Therefore, SLCC benchmarks for long-term climate change for the study. Monthly SLCC indexes are converted into their yearly mean values merged with firm fundamentals located in a specific state State/Province [STATE]. | NCEI-NOAA |
| VOFF | The market-based and forward-looking measure for the Value of Financial Flexibility follows Rapp et al (2014). The study presents step-by-step descriptions in the data and methodology section. As Rapp et al (2014) did not provide COMPUSTAT codes of variables used for replication, the study hereby follows Section 3 in Rapp (2014) for the approximate construction of the VOFF as much as possible. | |
| SIZE | Firm size is the logarithm of one plus Assets – Total [AT]. | COMPUSTAT Annual File - WRDS |
| INV | Corporate investment is the ratio of Capital Expenditures [CAPX] to Assets – Total [AT]. | COMPUSTAT Annual File - WRDS |
| WC | Working capital is the ratio of Working Capital (Balance Sheet) [WCAP] to Assets – Total [AT]. | COMPUSTAT Annual File - WRDS |

| | | |
|---|---|---|
| DIV | Corporate dividend is the ratio of Dividends Common/Ordinary [DVC] to Assets – Total [AT]. | COMPUSTAT Annual File - WRDS |
| OX | Corporate operating expense is the ratio of Operating Expenses – Total [XOPR] to Assets – Total [AT]. | COMPUSTAT Annual File - WRDS |
| R&D | Corporate research and development expenditure is the ratio of Research and Development Expense [XRD] to Assets – Total [AT]. Missing values are replaced by zero. | COMPUSTAT Annual File - WRDS |
| Q | Tobin's Q is the ratio of the sum of a firm's year-end market capitalization and the difference between its Assets – Total [AT] and Common/Ordinary Equity – Total [CEQ] to Assets – Total [AT]: $Q = (AT\text{-}CEQ + PRCC\_F \times CSHO)/AT$. | COMPUSTAT Annual File - WRDS |
| DIV DUMMY | A dividend dummy is a dummy variable that is set equal to one for dividend-paying firms, otherwise it is set equal to zero. | COMPUSTAT Annual File - WRDS |
| PAYOUT_FLEX | Corporate payout flexibility is the ratio of shares repurchase [SRP] to gross corporate payouts [PAYOUT]. SRP is the difference between Purchase of Common and Preferred Stock [PRSTKC] and Preferred Stock - Redemption Value [PSTKRV]. PAYOUT is calculated as the product of Dividends Common/Ordinary [DVC] plus SRP minus the lag value of DVC (Denis & McKeon, 2012). | COMPUSTAT Annual File - WRDS |
| CASH | The ratio of Cash and Short-Term Investments [CHE] to Assets – Total [AT]. | COMPUSTAT Annual File - WRDS |
| MKT_LEV | Market leverage is the product of debt total [DEBT] divided by the sum of DEBT and the market value of equity [MVE]. DEBT is the product of Long-Term Debt – Total [DLTT] and Debt in Current Liabilities – Total [DLC]. MVE is the product of Price Close - Annual – Fiscal [PRCC_F] and Common Shares Outstanding [CSHO]. | COMPUSTAT Annual File - WRDS |
| DPS | The dummy variable is set equal to one for firms located in disaster-prone states. Regarding US News - The Most Disaster-Prone States in the U.S., disaster-prone states include Arizona [AZ], California [CA], Colorado [CO], Florida [FL], Nevada [NV], New Mexico [NM], New York [NY], Oklahoma [OK], Oregon [OR], Texas [TX], Washington [WA], otherwise DPS is set equal to zero. | COMPUSTAT Annual File - WRDS |
| SAPF | The dummy variable is set equal to one for firms located in states with state-led adaptation plans finalized, otherwise, SAPF is set equal to zero. As of 2024, regarding the State Adaptation Progress Tracker by State and Local Adaptation Plans - Georgetown Climate Center, the SAPF dummy includes Alaska [AK], California [CA], Colorado [CO], Connecticut [CT], Delaware [DE], Florida [FL], Maine [MA], Maryland [MD], Massachusetts [ME], New Hampshire [NH], New York [NY], Oregon [OR], Pennsylvania [PA], Virginia [VA], Washington [WA]. Otherwise SAPF is set equal to zero. | COMPUSTAT Annual File - WRDS |
| POST2015 | The time dummy that is set equal to one for the years after the Paris Agreement is a legally | COMPUSTAT Annual |

| | | |
|---|---|---|
| | binding international convention on climate change. It was adopted by 196 Parties at the United Nations Climate Change Conference (COP21) in Paris, France, on December 12, 2015. | File - WRDS |

COMPUSTAT Annual File – Wharton Research Data Services (WRDS) was accessed using the PhD Finance student account h.h.trinh@massey.ac.nz offered by the School of Accountancy, Economics and Finance, Massey University 4442 New Zealand. COMPUSTAT Annual File was extracted as of 2023-06-20.

**Chapter Two - Appendix A2:** Table of frequencies for US states

| State name | Freq. | Percent | Cum. |
|---|---|---|---|
| Alabama | 643 | 0.57 | 0.57 |
| Alaska | 25 | 0.02 | 0.59 |
| Arizona | 1,741 | 1.54 | 2.13 |
| Arkansas | 507 | 0.45 | 2.58 |
| California | 18,583 | 16.47 | 19.05 |
| Colorado | 3,103 | 2.75 | 21.8 |
| Connecticut | 2,562 | 2.27 | 24.07 |
| Delaware | 428 | 0.38 | 24.45 |
| Florida | 5,038 | 4.46 | 28.92 |
| Georgia | 3,323 | 2.94 | 31.86 |
| Idaho | 255 | 0.23 | 32.09 |
| Illinois | 5,257 | 4.66 | 36.75 |
| Indiana | 1,263 | 1.12 | 37.87 |
| Iowa | 510 | 0.45 | 38.32 |
| Kansas | 529 | 0.47 | 38.79 |
| Kentucky | 563 | 0.5 | 39.29 |
| Louisiana | 534 | 0.47 | 39.76 |
| Maine | 142 | 0.13 | 39.88 |
| Maryland | 1,727 | 1.53 | 41.42 |
| Massachusetts | 6,741 | 5.97 | 47.39 |
| Michigan | 2,576 | 2.28 | 49.67 |
| Minnesota | 3,581 | 3.17 | 52.85 |
| Mississippi | 175 | 0.16 | 53 |
| Missouri | 1,673 | 1.48 | 54.48 |
| Montana | 106 | 0.09 | 54.58 |
| Nebraska | 331 | 0.29 | 54.87 |

| | | | |
|---|---|---|---|
| Nevada | 922 | 0.82 | 55.69 |
| New Hampshire | 488 | 0.43 | 56.12 |
| New Jersey | 5,238 | 4.64 | 60.76 |
| New Mexico | 103 | 0.09 | 60.85 |
| New York | 8,676 | 7.69 | 68.54 |
| North Carolina | 2,473 | 2.19 | 70.73 |
| North Dakota | 45 | 0.04 | 70.77 |
| Ohio | 4,067 | 3.6 | 74.38 |
| Oklahoma | 767 | 0.68 | 75.06 |
| Oregon | 1,092 | 0.97 | 76.03 |
| Pennsylvania | 4,839 | 4.29 | 80.31 |
| Rhode Island | 364 | 0.32 | 80.64 |
| South Carolina | 521 | 0.46 | 81.1 |
| South Dakota | 122 | 0.11 | 81.21 |
| Tennessee | 1,765 | 1.56 | 82.77 |
| Texas | 11,320 | 10.03 | 92.8 |
| Utah | 952 | 0.84 | 93.65 |
| Vermont | 83 | 0.07 | 93.72 |
| Virginia | 3,020 | 2.68 | 96.4 |
| Washington | 2,051 | 1.82 | 98.21 |
| West Virginia | 82 | 0.07 | 98.29 |
| Wisconsin | 1,890 | 1.67 | 99.96 |
| Wyoming | 44 | 0.04 | 100 |
| Total | 112,840 | 100 | |

**Chapter Three - Appendix A1: Variables and definitions.**

| Variable | Definition |
|---|---|
| RET | Monthly stock return. Source: Center for Research in Security Prices [CRSP] monthly stock file [MSF]. |
| Ri-Rf | Monthly stock excess return is the difference between stock return [RET] and risk-free rate [Rf] using a 3-Month Treasury Bill Secondary Market Rate, Discount Basis (TB3MS). Source: Center for Research in Security Prices [CRSP] monthly stock file [MSF], FRED, and author's calculation. |
| SL-CCS | Monthly state-level corporate climate sensitivity, indicating a firm's sensitivity to monthly state-level temperature anomaly. The predicted SL-CCS beta captures the sensitivity of a firm's stock to state-level and long-term climate factors with negative or positive temperature anomaly values. Source: Author's calculation using Equation 1 with data archives extracted from the Center for Research in Security Prices [CRSP], NOAA's National Centers for Environmental Information (NCEI), and FRED. |
| SLTA | Monthly state-level temperature anomaly. For each US state, SLTA is calculated as the difference between the current temperature value and its 30-year average or more benchmark temperature value. A positive value of SLTA indicates that the temperature is abnormally warmer than normal. A negative value of SLTA indicates that the temperature is abnormally cooler than normal. Source: raw data archives are extracted from NOAA's National Centers for Environmental Information (NCEI). |
| SIZE | Firm size is measured by the logarithm value of one plus a firm's total assets [ATQ]. Source: COMPUSTAT Quarterly and author's calculation. |
| BM | book-to-market value. The market value of equity (ME) is the product of Price Close – Quarter [PRCCQ] multiplied by Common Shares Outstanding [CSHOQ]. Book value (BM) is calculated as the product of assets total [ATQ], divided by the sum of market value of equity (ME) plus Debt in Current Liabilities [DLCQ] and Long-Term Debt – Total [DLTTQ]. Source: COMPUSTAT Quarterly and author's calculation. |
| LEV | The financial leverage ratio is calculated as the product of Debt in Current Liabilities [DLCQ] plus Long-Term Debt – Total [DLTTQ], divided by assets total quarterly [ATQ]. Source: COMPUSTAT Quarterly and author's calculation. |
| Q | Tobin's Q ratio is calculated as the product of assets total [ATQ], plus the market value of equity [ME] minus Common/Ordinary Equity – Total [CEQQ], divided by assets total. Source: COMPUSTAT Quarterly and author's calculation. |
| CAPEX | Capital expenditure [CAPXY] to assets total [ATQ]. Source: COMPUSTAT Quarterly and author's calculation. |
| TANG | Corporate tangibility is calculated as the fraction of Property Plant and Equipment - Total (Net) [PPENTQ] divided by assets total [ATQ]. Source: COMPUSTAT Quarterly and author's calculation. |

| | |
|---|---|
| ROA | corporate return on assets. ROA is the product of Net Income (Loss) [NIQ], Depreciation and Amortization – Total [DPQ], Income Taxes – Total [TXTQ], and Interest and Related Expenses- Total [XINTQ], divided by assets total quarterly [ATQ]. Source: COMPUSTAT Quarterly and author's calculation. |
| SALE | A firm' sales are calculated as the fraction of revenue [REVTQ] to total assets [ATQ]. Source: COMPUSTAT Quarterly and author's calculation. |
| R&D | Corporate Research and Development Expense [XRDQ] to assets total [ATQ]. Source: COMPUSTAT Quarterly and author's calculation. |
| CASH | Corporate cash holdings are calculated as the fraction of Cash and Short-Term Investments [CHEQ] divided by assets total [ATQ]. Source: COMPUSTAT Quarterly and author's calculation. |
| POLLUTING STOCKS | A dummy variable that is set equal to one for firms' stocks that belong to polluting industries. The polluting industries include Energy [GSECTOR=10], Materials [GSECTOR=15], Industrials [GSECTOR=20], and Utilities [GSECTOR=55], otherwise set equal to zero. Source: COMPUSTAT Quarterly and author's calculation. |
| SAPF | A dummy variable set equal to one for US states with state-led plans finalized for their local/state climate action, otherwise set equal to zero. SAPF captures climate transitional risk in the US states. Source: State and Local Adaptation Plans - Georgetown Climate Center and author's calculation. |
| DPS | A dummy variable set equal to one for disaster-prone states, otherwise set equal to zero. Source: The Most Disaster-Prone States in the U.S.and author's calculation. |

Note: Data subscriptions of stock prices [CRSP] and COMPUSTAT within Wharton Research Data Services (WRDS) are accessed using a licensed account [h.h.trinh@massey.ac.nz] offered for a PhD/Doctoral Finance candidate by the School of Accountancy, Economics and Finance, Massey University, Palmerston North 4442, New Zealand.

**Chapter Three - Appendix A1.1:** Descriptive statistics [excluding Covid-19 period]

| Variable | N | Mean | Min | p50 | Max | SD |
|---|---|---|---|---|---|---|
| RET | 327184 | 0.007 | -0.441 | 0.000 | 0.660 | 0.169 |
| Ri-Rf | 327184 | -3.384 | -8.213 | -3.803 | 0.208 | 2.332 |
| SL-CCS | 312794 | 0.000 | -0.047 | 0.000 | 0.050 | 0.012 |
| SLTA | 322650 | 1.203 | -16.000 | 1.000 | 18.000 | 3.310 |
| SIZE | 265614 | 4.861 | 0.054 | 4.826 | 11.005 | 2.493 |
| BM | 215595 | 1.343 | 0.014 | 0.901 | 9.092 | 1.551 |
| LEV | 247459 | 0.309 | 0.000 | 0.186 | 4.104 | 0.522 |
| Q | 228706 | 2.982 | 0.455 | 1.365 | 51.796 | 6.301 |
| CAPEX | 239243 | 0.035 | 0.000 | 0.015 | 0.343 | 0.058 |
| TANG | 256471 | 0.261 | 0.000 | 0.160 | 0.950 | 0.269 |
| ROA | 258455 | -0.040 | -1.575 | 0.008 | 0.131 | 0.209 |
| SALE | 262022 | 0.222 | 0.000 | 0.162 | 1.160 | 0.231 |
| R&D | 332130 | 0.012 | 0.000 | 0.000 | 0.510 | 0.044 |
| CASH | 262405 | 0.175 | 0.000 | 0.067 | 0.974 | 0.236 |

**Chapter Three - Appendix A1.2:** Descriptive statistics [excluding Covid-19 period and penny stocks]

| Variable | N | Mean | Min | p50 | Max | SD |
|---|---|---|---|---|---|---|
| RET | 288141 | 0.012 | -0.441 | 0.001 | 0.660 | 0.161 |
| Ri-Rf | 288141 | -3.254 | -8.213 | -3.608 | 0.208 | 2.287 |
| SL-CCS | 276101 | 0.000 | -0.047 | 0.000 | 0.050 | 0.011 |
| SLTA | 284195 | 1.230 | -16.000 | 1.000 | 18.000 | 3.320 |
| SIZE | 233447 | 4.879 | 0.054 | 4.864 | 11.005 | 2.492 |
| BM | 190301 | 1.344 | 0.014 | 0.895 | 9.092 | 1.559 |
| LEV | 217735 | 0.308 | 0.000 | 0.181 | 4.104 | 0.525 |
| Q | 201633 | 2.998 | 0.455 | 1.375 | 51.796 | 6.283 |
| CAPEX | 210801 | 0.035 | 0.000 | 0.015 | 0.343 | 0.058 |
| TANG | 225187 | 0.260 | 0.000 | 0.158 | 0.950 | 0.270 |
| ROA | 227066 | -0.040 | -1.575 | 0.008 | 0.131 | 0.209 |
| SALE | 230230 | 0.219 | 0.000 | 0.158 | 1.160 | 0.228 |
| R&D | 292853 | 0.012 | 0.000 | 0.000 | 0.510 | 0.044 |
| CASH | 230664 | 0.178 | 0.000 | 0.068 | 0.974 | 0.238 |

**Chapter Three - Appendix A1.3:** Descriptive statistics by temperature anomaly levels

| | **Negative Anomaly [Abnormal Cooler]** | **Positive Anomaly [Abnormal Warmer]** | **Total** |
|---|---|---|---|
| N | 141,601 (39.1%) | 220,653 (60.9%) | 362,254 (100.0%) |
| RET | 0.005 (0.168) | 0.008 (0.170) | 0.007 (0.170) |
| Ri-Rf | -3.418 (2.365) | -3.034 (2.353) | -3.184 (2.365) |
| SL-CCS | 0.000 (0.012) | 0.000 (0.013) | 0.000 (0.012) |
| SLTA | -1.783 (1.961) | 3.376 (2.282) | 1.303 (3.326) |
| SIZE | 4.858 (2.496) | 4.979 (2.537) | 4.931 (2.521) |
| BM | 1.360 (1.556) | 1.345 (1.586) | 1.351 (1.574) |
| LEV | 0.306 (0.512) | 0.315 (0.538) | 0.311 (0.528) |
| Q | 2.849 (5.994) | 3.107 (6.563) | 3.006 (6.347) |
| CAPEX | 0.036 (0.058) | 0.033 (0.056) | 0.034 (0.057) |
| TANG | 0.263 (0.267) | 0.257 (0.272) | 0.259 (0.270) |
| ROA | -0.036 (0.203) | -0.044 (0.214) | -0.041 (0.210) |
| SALE | 0.226 (0.232) | 0.210 (0.226) | 0.216 (0.228) |
| R&D | 0.011 (0.042) | 0.012 (0.045) | 0.011 (0.044) |
| CASH | 0.172 (0.233) | 0.186 (0.246) | 0.181 (0.241) |

**Chapter Three - Appendix A1.4:** Descriptive statistics by disaster-prone states [DPS]

| | Non-Disaster-Prone States [Non-DPS] | Disaster-Prone States [Non-DPS] | Total |
|---|---|---|---|
| N | 218,119 (60.2%) | 144,135 (39.8%) | 362,254 (100.0%) |
| RET | 0.007 (0.168) | 0.007 (0.171) | 0.007 (0.170) |
| Ri-Rf | -3.113 (2.348) | -3.293 (2.386) | -3.184 (2.365) |
| SL-CCS | 0.001 (0.012) | -0.000 (0.013) | 0.000 (0.012) |
| SLTA | 1.280 (3.546) | 1.336 (2.978) | 1.303 (3.326) |
| SIZE | 5.112 (2.456) | 4.637 (2.598) | 4.931 (2.521) |
| BM | 1.434 (1.635) | 1.217 (1.463) | 1.351 (1.574) |
| LEV | 0.302 (0.511) | 0.327 (0.554) | 0.311 (0.528) |
| Q | 2.756 (5.794) | 3.400 (7.115) | 3.006 (6.347) |
| CAPEX | 0.036 (0.059) | 0.031 (0.053) | 0.034 (0.057) |
| TANG | 0.286 (0.282) | 0.215 (0.243) | 0.259 (0.270) |
| ROA | -0.032 (0.195) | -0.055 (0.231) | -0.041 (0.210) |
| SALE | 0.211 (0.224) | 0.224 (0.236) | 0.216 (0.228) |
| R&D | 0.010 (0.042) | 0.014 (0.047) | 0.011 (0.044) |
| CASH | 0.163 (0.232) | 0.209 (0.252) | 0.181 (0.241) |

**Chapter Three - Appendix A1.5:** Descriptive statistics by state-led adaptation plans finalized [SAPF]

| | Non SAPF | SAPF | Total |
|---|---|---|---|
| N | 313,350 (86.5%) | 48,904 (13.5%) | 362,254 (100.0%) |
| RET | 0.007 (0.171) | 0.007 (0.157) | 0.007 (0.170) |
| Ri-Rf | -3.575 (2.276) | -0.691 (1.029) | -3.184 (2.365) |
| SL-CCS | 0.000 (0.012) | -0.001 (0.012) | 0.000 (0.012) |
| SLTA | 1.187 (3.341) | 2.022 (3.136) | 1.303 (3.326) |
| SIZE | 4.843 (2.492) | 5.728 (2.645) | 4.931 (2.521) |
| BM | 1.355 (1.552) | 1.309 (1.759) | 1.351 (1.574) |
| LEV | 0.304 (0.504) | 0.383 (0.713) | 0.311 (0.528) |
| Q | 2.862 (5.984) | 4.229 (8.765) | 3.006 (6.347) |
| CAPEX | 0.036 (0.058) | 0.018 (0.042) | 0.034 (0.057) |
| TANG | 0.270 (0.272) | 0.155 (0.222) | 0.259 (0.270) |
| ROA | -0.036 (0.200) | -0.082 (0.283) | -0.041 (0.210) |
| SALE | 0.222 (0.230) | 0.162 (0.211) | 0.216 (0.228) |
| R&D | 0.011 (0.042) | 0.016 (0.054) | 0.011 (0.044) |
| CASH | 0.172 (0.233) | 0.259 (0.289) | 0.181 (0.241) |

**Chapter Three - Appendix A2:** State-level corporate climate sensitivity [SL-CCS] and stock returns [RET] excluding penny stocks and the Covid-19 period

| VARIABLES | (1)<br>RET<br>Full sample | (2)<br>RET<br>Negative Anomaly<br>[Abnormal Cooler] | (3)<br>RET<br>Positive Anomaly<br>[Abnormal Warmer] | (4)<br>RET<br>Full sample | (5)<br>RET<br>Negative Anomaly<br>[Abnormal Cooler] | (6)<br>RET<br>Positive Anomaly<br>[Abnormal Warmer] |
|---|---|---|---|---|---|---|
| SL-CCS | -0.246*** | -2.439*** | 0.889*** | -0.266*** | -2.479*** | 0.833*** |
| | (0.037) | (0.076) | (0.047) | (0.050) | (0.101) | (0.064) |
| SIZE | | | | -0.000* | -0.000 | 0.000 |
| | | | | (0.000) | (0.000) | (0.000) |
| BM | | | | 0.000 | 0.000 | 0.000 |
| | | | | (0.000) | (0.001) | (0.000) |
| LEV | | | | 0.000 | 0.004* | -0.001 |
| | | | | (0.001) | (0.002) | (0.001) |
| Q | | | | -0.000 | -0.000 | 0.000 |
| | | | | (0.000) | (0.000) | (0.000) |
| CAPEX | | | | 0.009 | 0.005 | 0.010 |
| | | | | (0.008) | (0.016) | (0.011) |
| TANG | | | | -0.005*** | -0.007* | -0.004* |
| | | | | (0.002) | (0.004) | (0.002) |
| ROA | | | | 0.001 | 0.010* | -0.001 |
| | | | | (0.003) | (0.006) | (0.004) |
| SALE | | | | -0.003 | -0.010** | 0.002 |
| | | | | (0.002) | (0.004) | (0.003) |
| R&D | | | | 0.002 | 0.023 | -0.004 |
| | | | | (0.010) | (0.023) | (0.011) |
| CASH | | | | 0.000 | -0.001 | 0.004 |
| | | | | (0.002) | (0.004) | (0.003) |
| Constant | 0.012*** | 0.011*** | 0.013*** | 0.014*** | 0.015*** | 0.012*** |

| | | | | | | |
|---|---|---|---|---|---|---|
| | (0.000) | (0.000) | (0.000) | (0.002) | (0.003) | (0.002) |
| Observations | 274,045 | 80,261 | 161,307 | 157,273 | 45,189 | 93,337 |
| R-squared | 0.133 | 0.165 | 0.140 | 0.137 | 0.176 | 0.142 |
| Time FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Industry FE | Yes | Yes | Yes | Yes | Yes | Yes |
| SE Clustered | Yes | Yes | Yes | Yes | Yes | Yes |

The table reports linear regressions of stock returns with multiple fixed effects for time (date) and industry (SICCD codes) levels. Robust standard errors are clustered by firm (8-digit CUSIP code) in parentheses. The characters *** p<0.01, ** p<0.05, * p<0.1 indicate the statistical significance at the 1%, 5%, and 10% level, respectively.

**Chapter Three - Appendix A3:** Mediation tests – Polluting stocks excluding penny stocks and the Covid-19 period

| VARIABLES | (1)<br>RET<br>Full sample<br>Excluding Covid-19 | (2)<br>RET<br>Negative Anomaly<br>[Abnormal Cooler]<br>Excluding Covid-19 | (3)<br>RET<br>Positive Anomaly<br>[Abnormal Warmer]<br>Excluding Covid-19 |
|---|---|---|---|
| SL-CCS | -0.206*** | -2.426*** | 0.852*** |
| | (0.060) | (0.124) | (0.074) |
| POLLUTING STOCKS | 0.001 | 0.003* | -0.002 |
| | (0.001) | (0.002) | (0.001) |
| SL-CCS x POLLUTING STOCKS | -0.208* | -0.174 | -0.066 |
| | (0.107) | (0.212) | (0.151) |
| SIZE | -0.000 | -0.000 | -0.000 |
| | (0.000) | (0.000) | (0.000) |
| BM | 0.000 | 0.000 | 0.000 |
| | (0.000) | (0.001) | (0.000) |
| LEV | 0.000 | 0.004** | -0.001 |
| | (0.001) | (0.002) | (0.001) |
| Q | -0.000 | -0.000 | 0.000 |
| | (0.000) | (0.000) | (0.000) |
| CAPEX | 0.009 | 0.005 | 0.010 |
| | (0.008) | (0.016) | (0.011) |
| TANG | -0.006*** | -0.009** | -0.003 |
| | (0.002) | (0.004) | (0.002) |
| ROA | 0.001 | 0.010* | -0.001 |
| | (0.003) | (0.006) | (0.004) |

| | | | |
|---|---|---|---|
| SALE | -0.002 | -0.010** | 0.002 |
| | (0.002) | (0.004) | (0.003) |
| R&D | 0.003 | 0.027 | -0.007 |
| | (0.010) | (0.023) | (0.011) |
| CASH | 0.000 | -0.001 | 0.004 |
| | (0.002) | (0.004) | (0.003) |
| Constant | 0.014*** | 0.014*** | 0.012*** |
| | (0.002) | (0.003) | (0.002) |
| | | | |
| Observations | 157,273 | 45,189 | 93,337 |
| R-squared | 0.137 | 0.177 | 0.142 |
| Time FE | Yes | Yes | Yes |
| Industry FE | Yes | Yes | Yes |
| SE Clustered | Yes | Yes | Yes |

The table reports linear regressions of stock returns with multiple fixed effects for time (date) and industry (SICCD codes) levels. Robust standard errors are clustered by firm (8-digit CUSIP code) in parentheses. The characters *** $p<0.01$, ** $p<0.05$, * $p<0.1$ indicate the statistical significance at the 1%, 5%, and 10% level, respectively.

**Chapter Three - Appendix A4:** Moderation tests – Disaster-prone states [DPS] excluding penny stocks and the Covid-19 period

| VARIABLES | (1)<br>RET<br>Full sample<br>Excluding Covid-19 | (2)<br>RET<br>Negative Anomaly<br>[Abnormal Cooler]<br>Excluding Covid-19 | (3)<br>RET<br>Positive Anomaly<br>[Abnormal Warmer]<br>Excluding Covid-19 |
|---|---|---|---|
| SL-CCS | -0.347*** | -2.610*** | 0.905*** |
| | (0.070) | (0.143) | (0.093) |
| DPS | -0.001 | -0.004** | 0.000 |
| | (0.001) | (0.002) | (0.001) |
| SL-CCS x DPS | 0.158 | 0.261 | -0.136 |
| | (0.100) | (0.203) | (0.128) |
| SIZE | -0.000 | -0.000 | 0.000 |
| | (0.000) | (0.000) | (0.000) |
| BM | -0.000 | 0.000 | 0.000 |
| | (0.000) | (0.001) | (0.000) |
| LEV | 0.000 | 0.004* | -0.001 |
| | (0.001) | (0.002) | (0.001) |
| Q | -0.000 | -0.000 | 0.000 |
| | (0.000) | (0.000) | (0.000) |
| CAPEX | 0.009 | 0.004 | 0.010 |
| | (0.008) | (0.016) | (0.011) |
| TANG | -0.006*** | -0.007* | -0.004* |
| | (0.002) | (0.004) | (0.002) |
| ROA | 0.001 | 0.009 | -0.001 |
| | (0.003) | (0.006) | (0.004) |
| SALE | -0.003 | -0.010** | 0.002 |
| | (0.002) | (0.004) | (0.003) |
| R&D | 0.002 | 0.023 | -0.004 |
| | (0.010) | (0.023) | (0.011) |
| CASH | 0.000 | -0.001 | 0.004 |
| | (0.002) | (0.004) | (0.003) |

| | | | |
|---|---|---|---|
| Constant | 0.015*** | 0.017*** | 0.011*** |
| | (0.002) | (0.003) | (0.002) |
| | | | |
| Observations | 157,273 | 45,189 | 93,337 |
| R-squared | 0.137 | 0.177 | 0.142 |
| Time FE | Yes | Yes | Yes |
| Industry FE | Yes | Yes | Yes |
| SE Clustered | Yes | Yes | Yes |

The table reports linear regressions of stock returns with multiple fixed effects for time (date) and industry (SICCD codes) levels. Robust standard errors are clustered by firm (8-digit CUSIP code) in parentheses. The characters *** p<0.01, ** p<0.05, * p<0.1 indicate the statistical significance at the 1%, 5%, and 10% level, respectively.

**Chapter Three - Table A5**: Moderation tests – State-led adaptation plans finalized [SAPF] excluding penny stocks and the Covid-19 period

| VARIABLES | (1)<br>RET<br>Full sample<br>Excluding Covid-19 | (2)<br>RET<br>Negative Anomaly<br>[Abnormal Cooler]<br>Excluding Covid-19 | (3)<br>RET<br>Positive Anomaly<br>[Abnormal Warmer]<br>Excluding Covid-19 |
|---|---|---|---|
| SL-CCS | -0.277*** | -2.478*** | 0.823*** |
| | (0.051) | (0.104) | (0.067) |
| SAPF | 0.003** | 0.002 | 0.004** |
| | (0.001) | (0.003) | (0.002) |
| SL-CCS x SAPF | 0.197 | -0.036 | 0.167 |
| | (0.221) | (0.451) | (0.251) |
| SIZE | -0.000* | -0.000 | -0.000 |
| | (0.000) | (0.000) | (0.000) |
| BM | 0.000 | 0.000 | 0.000 |
| | (0.000) | (0.001) | (0.000) |
| LEV | 0.000 | 0.004* | -0.001 |
| | (0.001) | (0.002) | (0.001) |
| Q | -0.000 | -0.000 | -0.000 |
| | (0.000) | (0.000) | (0.000) |
| CAPEX | 0.009 | 0.005 | 0.009 |
| | (0.008) | (0.016) | (0.011) |
| TANG | -0.005*** | -0.007* | -0.004 |
| | (0.002) | (0.004) | (0.002) |
| ROA | 0.001 | 0.010* | -0.001 |
| | (0.003) | (0.006) | (0.004) |
| SALE | -0.003 | -0.010** | 0.002 |
| | (0.002) | (0.004) | (0.003) |
| R&D | 0.001 | 0.023 | -0.005 |
| | (0.010) | (0.023) | (0.011) |
| CASH | 0.000 | -0.001 | 0.004 |
| | (0.002) | (0.004) | (0.003) |
| Constant | 0.014*** | 0.015*** | 0.011*** |

| | | | |
|---|---|---|---|
| | (0.002) | (0.003) | (0.002) |
| | | | |
| Observations | 157,273 | 45,189 | 93,337 |
| R-squared | 0.137 | 0.176 | 0.142 |
| Time FE | Yes | Yes | Yes |
| Industry FE | Yes | Yes | Yes |
| SE Clustered | Yes | Yes | Yes |

The table reports linear regressions of stock returns with multiple fixed effects for time (date) and industry (SICCD codes) levels. Robust standard errors are clustered by firm (8-digit CUSIP code) in parentheses. The characters *** p<0.01, ** p<0.05, * p<0.1 indicate the statistical significance at the 1%, 5%, and 10% level, respectively.

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