

Review of Empirical Studies on Climate Risk—Effects and Activism

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Abstract

This review focuses on major contemporary empirical studies that examine both the physical and regulatory sides of climate risk. These studies explore how climate risk affects firms' operating performance and leverage, stock and bond valuation, cost of capital, and managerial behavior. We also discuss how the effect of climate risk on real estate markets depends on individuals' beliefs about climate change. Furthermore, we summarize papers on climate risk activism and how firms can employ financial devices and technology to mitigate their climate risk. Finally, we make some recommendations for further research areas.

Keywords

Climate Risk, Climate Risk Activism, Climate Risk Mitigation

1. Introduction

We present a review of recent major studies (i.e., from 2020 to 2023) on climate risk with a primary focus on empirical works. We cover both physical and regulatory climate risks. Physical risk refers to potential physical damages of climate change caused by extreme weather conditions such as floods, heat, hurricanes, droughts, storms, and sea level change. Regulatory risk refers to potential damages caused by climate change regulations imposed by the federal and local governments or international treaties such as EPA regulations, the Paris Agreement, and the carbon emissions quota in California. To capture the major studies, we limit papers to those published in top business academic journals included in the list of top 24 journals adopted by UTD in its academic rankings. The purpose of this study is to survey the comprehensive effect of climate risk on individual firms and how managers and shareholders respond to climate risk. Thus, our review is limited to only papers on these subjects. The rationale is that prior stu-

dies have mostly focused on the effect of climate risk on geographic regions (e.g., country, city, and country), and only recently more studies have started to examine the effect on individual firms and the response from managers and shareholders (Huang et al., 2018). Consequently, there is a need for a literature review in this area to summarize the literature development and direct the future studies.

First, we discuss papers that examine the most salient effect of climate risk on public firms, namely operating performance and leverage, stock and bond valuation, and cost of capital, and how this risk influences managerial behavior. These papers reveal the profound impact of climate risk on financial and managerial aspects of public firms and the capital markets. Since firms in the real estate industry are especially affected by the climate risk, we also briefly sample literature regarding the effect of climate risk—and sea level rise in particular—on the real estate markets. Climate risk activism and climate risk mitigation are an emerging practice with much potential and thus we survey papers on these two topics. Specifically, we summarize papers on climate risk activism, including those by shareholders and suppliers. Furthermore, we survey papers examining how firms employ financial devices and technology to mitigate their climate risk. Finally, we make some recommendations for further research areas.

2. Effect of Physical and Regulatory Climate Risk on Public Firms

Operating performance and leverage

We begin our review with a discussion of the literature examining the direct effect of climate risk on firms' performance. Huang, Kerstein, and Wang (2018) find that increasing climate risk is associated with decreased earnings and increased earnings volatility. They further demonstrate that managers incorporate the risk of extreme weather events in decisions, as firms subject to increased risk have higher cash holdings, lower cash dividend payouts, and more long-term debt. This evidence is consistent with firms attempting to mitigate their exposure to climate risk. This paper establishes that i) climate risk directly affects firms' operations, and ii) managers are aware of this and plan for this risk in advance. Both of these effects continue to be discussed in the literature.

Starting with the direct effect of climate risk on firm performance, Addoum, Ng, and Ortiz-Bobea (2020) examine temperature shocks, but find no evidence of temperature-related effects on firms' sales, labor productivity, or earnings, even in industries classified as heat-sensitive (e.g., agriculture, mining, construction, etc.).

On the other hand, Pankratz, Bauer, and Derwall (2023) find that increases in the quantity of very hot days correlates with lower revenue and operating income and higher cost of goods sold and SG&A. They also find that two quarters following a "heat wave," firms increase total wages, implying that firms hire more to compensate for the decreased performance of their workers due to heat, providing further support to the idea that managers incorporate climate risk into

their decision-making process. Further tests reveal that the market does not appear to anticipate these outcomes. Considering the mixed results, the effect of temperature on firm performance is ripe for further research to enhance our understanding.

Continuing the thread of literature tying climate risk to operating performance, Roth Tran (2023) examines the effect of precipitation. She develops a novel weather index using machine learning and finds that rain, snow, and cold weather have negative effects on short-term sales, but that these effects are attenuated for firms with a history of such weather. There is also a decrease in sales for incidents of very hot weather, regardless of the firm's historical experience.

Extending the literature on precipitation risk, Downey, Lind, and Shrader (2023) identify an additional, overlooked economic effect of climate change, namely, increased rainfall volatility due to climate change. They empirically demonstrate that the construction industry faces significant labor adjustment costs to forecasted rainfall—costs which will increase with higher rainfall volatility. This finding underscores the importance of reducing greenhouse gas emissions and mitigating climate change.

Returning to the managerial response, Ginglinger and Moreau (2023) use the Paris Agreement—an agreement in 2015 by 195 countries to constrain global warming to 2°C by the year 2100—as an exogenous shock for firms with increased climate risk. They find that after the Paris Agreement, firms subject to higher climate risk decrease leverage and increase the issuance of equity. Additionally, Ginglinger and Moreau (2023) find evidence of creditors charging increased interest rates to these firms (supply effect) and find stronger results among low-ESG (environmental, social, and governance) firms, which choose to decrease leverage instead of reducing their exposure to climate risk (demand effect). Overall, extant literature finds that climate risk has significant effects on firms' performance and managers' decision-making.

Firm valuation and stock returns

The literature on firm valuation can be loosely grouped into two primary categories. The first stream of literature focuses on investors' bias in reaction to climate-related events, while the second stream studies the climate risk premium associated with a firm's exposure to climate risk.

Starting with investors' bias based on local climate shocks, Alok, Kumar, and Wermers (2020) examine whether money managers are susceptible to salience bias when it comes to climate disasters, i.e., do they over-react to local disasters. Using a difference-in-difference (DID) model, they find that funds located in close proximity to a disaster zone tend to reduce investment in firms located in the disaster zone. There is no similar underinvestment for distant funds or for firms outside the disaster zone, and the rebalancing is not associated with the firms' future earnings. The bias is shown to be costly, in that it reduces returns to these funds.

Following a similar logic, Choi, Gao, and Jiang (2020) hypothesize that people think more about global warming when the weather is warmer, which would

then lead them to focus more on climate change while making investment decisions. Their results show that for any given city, there is an uptick in Google searches about global warming during abnormally warm months in that city. They then demonstrate on a global level that when a city with a stock exchange has an abnormally warm month, firms on that exchange with high carbon emissions suffer lower stock returns, consistent with Choi et al.'s (2020) hypothesis. This is yet another example of local weather causing a salience bias that affects investors.

Another potential cause of investor bias is the media, which can put climate risk at the forefront of investors' minds. Using news articles as a barometer for general climate change concerns, Ardia, Bluteau, Boudt, and Inghelbrecht (2023) develop a robust daily metric using articles from major U.S. news sources. They find that on days with surprise increases in concern over climate change, firms with lower greenhouse gas emissions (green firms) outperform firms with higher greenhouse gas emissions (brown firms) in the stock market, and that these results are primarily driven by a firm's industry. Overall, the literature shows that investors are affected by their own exposure to climate-related events.

Shifting gears into the literature on the pricing of firms' exposure to climate risk, Bolton and Kacperczyk (2021) posit that investors demand a "carbon premium," i.e., they demand higher expected returns for firms with higher carbon dioxide emissions as compensation for the increased carbon emissions risk the firm is subject to. Their conclusion is based on their robust findings of increased stock market returns for firms with higher levels of emissions or higher change in emissions. Extending their previous results, Bolton and Kacperczyk (2023) examine the relationship between stock returns and carbon emissions for over 14,000 companies across 77 countries and find that the carbon premium persists globally for both levels and changes in carbon emissions. The premium is higher for less-democratic countries and for countries with lower levels of renewable energy adoption. The global evidence is particularly compelling. Additionally, they find that the carbon premium spills over from firms' supply chains.

Using the equilibrium model developed in an earlier paper (Pástor et al., 2021), Pástor, Stambaugh, and Taylor (2022) implement two empirical approaches to show that green firms have recently experienced unusually high returns relative to brown firms, but that these returns relate to increased climate-risk concerns and investors' hedging against climate change, and that these firms will have lower future expected returns due to their decreased exposure to climate risk. This result is fascinating, as it captures the market repricing firms based on an increased understanding of climate risk.

In contrast to other studies, which generally focus on firms' carbon emissions, Sautner, van Lent, Vilkov, and Zhang (2023a) use machine-learning analysis of earnings conference calls to calculate a time-varying metric of firms' exposure to various climate change risks, including both physical and regulatory. They have released their metric to the public as an aid for future research. They perform several validation tests of their machine-learning methodology, including corre-

lating their measure with Engle et al.'s (2020) public climate change attention index. Empirically, they find that their metric predicts both green-tech hiring by the firm and the issuance of green patents. In the options market, firms with higher climate change exposure have higher option-implied risks and risk premiums.

In a contemporaneous paper, Sautner, van Lent, Vilkov, and Zhang (2023b) use their climate change exposure metric to study the effect of climate change exposure on risk premium. They document an ex ante risk premium for firms with more exposure to higher climate change due to the uncertainty associated with such changes. Furthermore, the risk premium is associated with upside opportunities of climate change, green innovation, and institutional holdings.

In summary, the literature demonstrates that investors place a higher value on green firms and on firms that are less susceptible to climate risk. However, investors are also subject to biases based on their own exposure to climate disasters, heat, and news about climate change and its associated risks.

Bond valuation: issued by both firms and governments

In addition to climate risk affecting firm valuations, there is a large body of literature on the effect of climate change on both corporate and municipal bond markets. Starting with the corporate bond market, Huynh and Xia (2021) calculate the beta (covariance) of corporate bonds with Engle et al.'s (2020) news-based index of climate change risk. They demonstrate that this beta correlates negatively with future bond returns, and that the effect is exacerbated when climate change news risk is high. This evidence supports the theory that investors use corporate bonds with a high climate-beta to hedge against climate risk. In addition, these results should encourage firms to invest in their environmental performance, as the evidence points to this decreasing their cost of debt.

In a more recent paper, Huynh and Xia (2023) find that when there is a natural disaster, firms in the affected county experience decreases in the price of their stocks and bonds. The prices eventually bounce back, indicating that similar to the findings of investors' bias in the equity market, investors overreact to the news of the disaster in the corporate bond market as well. This overreaction is attenuated for firms with a focus on environmental policies, providing further evidence of the benefits of firms' investments in environmental performance.

But this climate-risk pricing of credit is not confined just to the firm level. Using a modified version of Merton's (1974) credit risk model, Goldsmith-Pinkham, Gustafson, Lewis, and Schwert (2023) find that starting from 2013, municipalities with higher exposure to the risk of rising sea levels face higher interest rates in the municipal bond market than municipalities with lower exposure. Similarly, Painter (2020) finds that counties' cost of debt when issuing municipal bonds is positively correlated with their likelihood to be affected by future climate change. However, this relationship only exists for long-term municipal bonds, whereas for short-term bonds, there is no significant correlation, indicating that investors only price climate risk into long-term bonds. The pricing of climate risk begins following the 2006 Stern Review on climate change, implying that the driving factor behind the climate-risk pricing is investor attention to climate

change.

Taking an even more macro perspective, [Klusak, Agarwala, Burke, Kraemer, and Mohaddes \(2023\)](#) develop a novel climate-adjusted credit rating for countries, which captures the potential effects of climate change on a nation's future creditworthiness. Their findings indicate significant credit downgrades expected to start around 2030, however, these effects are mitigated for countries following the climate policies laid out in the Paris Agreement. Countries that avoid investing in environmental performance are likely to face significantly higher costs of borrowing, in line with research in the corporate bond market (e.g., [Huynh & Xia, 2021](#)).

Overall, the general consensus in the literature is that entities—whether corporate, municipal, or national—that are subject to increased risk related to climate change are also subject to higher interest rates in the bond markets. While there is some evidence of investor overreaction to news of climate disasters, the long-term valuation effects persist. Firms and governments alike would do well to heed the collective wisdom of the markets.

Cost of capital

There is a small body of literature on the related topic of climate risk's effect on cost of capital. [De Angelis, Tankov, and Zerbib \(2023\)](#) develop a theoretical model demonstrating that investors' choice of green investing increases the cost of capital for brown firms, but that this effect is attenuated by increasing uncertainty about climate risks, which would decrease the motivation for firms to invest in decreasing greenhouse gas emissions. Stricter climate regulations increase the impact of green investing, which suggests that there is benefit to increasing environmental regulation.

On the empirical side, [Huang, Kerstein, Wang, and Wu \(2022\)](#) examine bank loans for evidence of the effect of climate risk on loan terms. Using both a measure capturing management's perception of climate risk as well as a measure based on natural disasters, they find that increased climate risk leads to less favorable loan terms (e.g., higher rates and increased likelihood of collateral requirement), highlighting the importance of firms' green investing in lowering their cost of debt.

Managerial (firm) behavior

The final category of literature on the effects of climate risk on firms focuses on firms' response to climate risk and related regulations. A significant portion of this literature highlights the unforeseen consequences of climate regulation. Using California's greenhouse gas emissions cap implemented in 2013, [Bartram, Hou, and Kim \(2022\)](#) show that financially-constrained firms with plants located in California significantly reduce greenhouse emissions in the California plants while simultaneously increasing emissions from plants in other states. [Bartram et al. \(2022\)](#) posit that this is due to these firms' inability to invest in reducing emissions, instead choosing to reallocate production, and by extension, emissions. This is an important finding for policymakers and regulators to keep in mind.

As another example of negative side effects to regulation, [Dang, Gao, and Yu \(2023\)](#) find that following passage of the Nitrogen Oxides Budget Trading Program in 2004, which was designed to reduce greenhouse gas emissions from power plants in parts of the U.S., firms became more fiscally conservative due to the rising cost of electricity. This result is exacerbated for firms subject to increased competition and for manufacturers in electricity-intensive industries.

On the positive side, there is literature that shows that a firm's ownership correlates with its attitude towards climate risk, which can possibly be viewed as an alternative to regulation and its potential second-order effects. [Hsu, Liang, and Matos \(2023\)](#) examine public firms with significant or majority government ownership and find that these firms are more involved in environmental issues than other firms. This effect is more pronounced in countries with less environmental regulation and less energy resources, which highlights a possible path for countries in which regulations are not sufficient to resolve environmental issues.

In a similar vein, [Shive and Forster \(2020\)](#) hand-match EPA data with both public and private firm data, finding that private firms emit significantly less greenhouse gases and are subject to fewer EPA enforcement actions than public firms, although the effect is attenuated for public firms with larger boards and higher mutual fund ownership.

Lastly, with regard to firm disclosures, [Ilhan, Krueger, Sautner, and Starks \(2023\)](#) analyze firms' climate risk disclosure from the investor demand side. A survey of institutional investors reveals a strong preference for climate risk disclosure. Empirically, they find that firms with what the authors refer to as "climate-conscious investors" have significantly higher climate risk disclosures. Since this could be driven by investors' selection rather than their influence, [Ilhan et al. \(2023\)](#) exploit an exogenous shock to investor demand for climate risk disclosure in France in 2015, (Article 173 of the Energy Transition for Green Growth Act requires disclosure of portfolio climate risk by French institutional investors) and show that French firms increase climate risk disclosures, supporting the hypothesis that disclosures are driven—at least in part—by investor demand and highlighting the importance of institutional investors' demand of increased climate risk disclosures.

In summary, while there is a place for climate regulation, the literature makes it clear that regulation may not accomplish what policymakers intend and may even introduce potentially negative side effects. Much care should be taken that policies will have the intended beneficial effect before they become law. As a possible alternative, changing a firm's ownership may induce a stronger proclivity to reducing climate-related risk.

3. Effect of Climate Risk on Real Estate Market

The effect of climate risk on the real estate market is manifested primarily through the concern of sea level rise. Supposedly, sea level rise would endanger the value of real estate property. [Murfin and Spiegel \(2020\)](#) explore whether or

not sea level rise is priced into real estate. Since location is a key factor in real estate value and is highly correlated with the risk of sea level rise, [Murfin and Spiegel \(2020\)](#) exploit the fact that land can move vertically as well. Using data on home sales and *relative* sea level rise, however, they find no evidence of sea level rise affecting real estate prices, in contrast to prior literature ([Baldauf et al., 2020](#); [Bernstein et al., 2019](#); [Giglio et al., 2021](#)).

One explanation for the above finding is that the risk of sea level rise is underestimated by the residents. In an attempt to reconcile the mixed evidence in prior literature of the flood risk premium on the housing market, [Bakkensen and Barrage \(2022\)](#) develop a theoretical model demonstrating how heterogeneous beliefs about flood risk could explain the inconsistent empirical results. Data from a survey of Rhode Island residents shows that many coastal residents underestimate the risk of flooding, providing support for the model's interpretation. After calibrating the model parameters based on the survey findings, they estimate that houses in Rhode Island are overpriced by 6% - 13% due to this flood risk skepticism.

One reason for the underestimate of sea level rise is that some residents are skeptical about climate change. [Baldauf, Garlappi, and Yannelis \(2020\)](#) model homebuyers as deriving utility from living amongst others with similar beliefs, specifically about climate. Using data on home sales in the U.S., they find that houses in areas with residents that tend to be skeptical about climate change sell for approximately 7% more than homes in areas with climate change believers. Furthermore, [Bernstein, Billings, Gustafson, and Lewis \(2022\)](#) demonstrate that registered Democrats are less likely than Republicans to buy properties subject to flood risk due to rising sea levels, presumably due to heterogeneous beliefs about the risks of climate change. In sum, the literature suggests that the effect of climate change on real estate valuation depends on the residents' beliefs about climate change.

4. Climate Risk Activism

Shareholder activism

In recent years, the Big Three (BlackRock, Vanguard, and State Street Global Advisors) have publicly stated their intent to pressure firms in their portfolio to decrease greenhouse gas emissions. [Azar, Duro, Kadach, and Ormazabal \(2021\)](#) provide strong evidence that Big Three investment in a firm is negatively correlated with future carbon emissions, and that the Big Three tend to engage with portfolio firms (especially the firms for which they have large holdings) regarding these emissions. Overall, the findings suggest that institutional investors can influence firms' decisions to reduce greenhouse gas emissions.

In further support of the positive effect of shareholder activism, [Flammer, Toffel, and Viswanathan \(2021\)](#) find that environmental shareholder activism, especially if the shareholders are institutional investors, increases the likelihood of firm climate risk disclosure, and that this increased voluntary disclosure leads

to positive stock market reactions. The finding suggests that transparency on firms' exposure to climate change risk is valued by institutional investors, as it reduces future uncertainty on firms' cash flow affected by climate risk (Alsaifi et al., 2020).

Studies have further shown that institutional investors demand transparency in climate risk disclosure. Specifically, the CDP (formerly known as the Carbon Disclosure Project) offers investors the option of becoming a signatory, giving them access to firms' climate risk data. Since the list of CDP signatories is public, Cohen, Kadach, and Ormazabal (2023) use institutional investors' signatory status as a proxy for climate risk information demand and find that firms' future climate risk disclosure to the CDP is positively correlated with the proportion of ownership by CDP signatories, indicating that investor demand for climate risk information leads firms to increase such disclosures. Additionally, Cohen et al. (2023) find that increased disclosure to the CDP leads to lower greenhouse gas emissions.

Slager, Chuah, Gond, Furnari, and Homanen (2023) explore the factors that determine the success of environmental shareholder activism. Using data from the UN-backed Principles for Responsible Investment, they find that successful shareholder activism is not a one-size-fits-all endeavor. Rather, activists must customize the approach based on each firm's financial capability and ex-ante environmental outlook, which is important for potential activists to bear in mind.

Desai, Lam, Li, and Rajgopal (2023) examine the carbon-reduction commitments of U.S. oil exploration and production companies. On the determinant side, they find that firms with higher ex-ante emissions, with BlackRock ownership, and in the period following Engine No. 1's public suggestion of four climate-friendly directors to Exxon's board are more likely to make such commitments. On average, the market does not appear to react to these pledges.

The above literature shows that institutional investors advocate for lower greenhouse gas emissions and higher levels of climate risk disclosures. However, these studies focus on fund management firms (e.g., BlackRock, Vanguard, and State Street Global Advisors) as institutional investors, and do not test the activism from other major institutional investors, such as public pension funds, which have the political incentives to improve corporate practice in climate risk mitigation and can use publicity as leverage against managers (Guercio & Hawkins, 1999).

Supply chain activism

Suppliers are an important source of greenhouse gas emissions, and firms in many countries are required to disclose the emissions of their suppliers (Diebel et al., 2024). Thus, these firms have incentives to enhance their suppliers' transparency in disclosing carbon emissions publicly. In addition to firms' self-reporting carbon emissions data, CDP has a supply chain program (CDP-SCP) focused on disclosures about emissions from firms' supply chains. Villena and Dhanorkar (2020) use this data to gain insight into the driving factors behind supplier firms' carbon transparency. Their study is based on a sample of 835 suppliers in 41

countries from 2013 to 2015. They also conducted interviews with suppliers to gain more insights. They find that buyer pressure and imitation of competitors are most effective for supplier firms without climate change incentives, but for suppliers with ex-ante incentives, standards set by industry leaders are more effective. Their finding suggests that buyers play an instrumental role in affecting their suppliers' carbon transparency.

Regulatory activism

Regulatory activism refers to advocating for carbon reduction or transparency through regulatory actions. Though many papers have examined the impact of carbon-related regulations on firm valuation, recent studies have focused on the selective enforcement of such environmental regulations (e.g., [Gulen & Myers, 2023](#)). Considering the significance of EPA enforcement, [Heitz, Wang, and Wang \(2023\)](#) look for signs of preferential treatment being given to firms with political connections. They find no significant difference in EPA investigations; however, politically connected firms receive fewer penalties and lower fines than unconnected firms. These effects are more pronounced when the politicians connected to the firm are able to influence the bureaucratic decisions. Additionally, firms that lose their connections face increased regulatory action from the EPA. In sum, these studies suggest that environmental regulations are not enforced uniformly.

5. Firms' Mitigation Activities

It is vitally important for firms to identify climate risk and take mitigation actions to reduce carbon emissions. Prior literature has examined this topic from firms' financing decisions and climate strategy perspectives. Specifically, [Huang, Kerstein, and Wang \(2018\)](#) show that firms in higher climate risk countries build up more cash cushion to prepare for potential cash shortages caused by climate events. [Huang, Kerstein, Wang, and Wu \(2022\)](#) show that firms actively managing climate risk—including adopting climate strategy and having an integrated process to cope with climate change—experience lower negative impact of climate risk on loan contracting.

The recent literature highlights the importance of climate change knowledge in such mitigation actions. For example, [Maksimov, Wang, and Yan \(2022\)](#) show that multinational enterprises have better climate change knowledge and better green technologies due to their global diversification and green certificates, thus enabling them to better identify and seize climate-change related opportunities and address climate risk issues.

More importantly, recent studies have examined how firms can employ financial instruments to mitigate climate risk. First, insurance can be used to cover potential climate events. Climate risk leads to adverse weather risk, which is economically significant in the agriculture industry. Current weather insurance offerings are based on weather indices and often have large basis risk, i.e. they are not properly matched with the weather-induced losses, which leads to minimal demand for such insurance. [Chen, Lu, Zhang, and Zhu \(2023\)](#) develop a

neural-network based insurance that, when applied to Illinois corn production, reduces the basis risk and increases the cost-effectiveness of insurance. The results are promising, suggesting that there may be a viable path for farmers to hedge against the effects of climate risk on weather.

Second, asset portfolios can be built to hedge against climate risk. Given the inherent difficulty in insuring climate risk, [Engle, Giglio, Kelly, Lee, and Stroebl \(2020\)](#) design a hedging approach that dynamically hedges climate change news over time. As part of their approach, they develop two climate change news indices based on textual analysis of newspaper articles. They use these indices to construct dynamically-updating asset portfolios that negatively correlate with climate news. Their results show strong out-of-sample performance, paving the way for future research into using carefully constructed portfolios to hedge against difficult-to-insure risks.

Third, assets with high climate risk exposure can be securitized, and thus the risk can be diversified. For example, [Ouazad and Kahn \(2022\)](#) show that after natural disasters, mortgage lenders have a tendency to increase approvals for conforming loans that can be securitized and sold, thereby reducing their exposure to climate risk. However, [Ouazad and Kahn \(2022\)](#) posit that this may lead to lenders shunting climate change adaptation and propose that Fannie Mae and Freddie Mac price this in to mortgage securities.

Overall, recent literature has proposed several financial instruments to mitigate climate risk exposure for individual firms or certain assets. Nevertheless, it is possible that such mitigation tactics may reduce firms' incentives to reduce carbon emissions.

6. Conclusion and Recommendations for Future Research

The above discussion shows that the literature on climate change has touched on many aspects of the capital markets and firms. The evidence shown by these empirical works demonstrates a tremendous impact of climate change on firms' operations, financing, disclosure, and real economic decisions. The worsening climate change has also negatively affected bond valuation and the real estate markets (although the effect is dependent on the residents' perception of climate change). Consequently, there are widespread activisms to advocate for better green solutions by shareholders and suppliers. Furthermore, firms are adopting financial devices and technology to better cope with extreme weather conditions induced by climate change. Overall, the climate risk has been priced in the equity, debt, and real estate markets, and mitigation of this risk has been in the pressing demand of shareholders—especially institutional shareholders.

In terms of data sources, most literature uses climate events such as heat, drought, and flood to capture the climate change risk. However, climate change risk can go beyond these extreme weather events. Future research can take advantage of recent developments in alternative data sources such as satellite images, transportation data, social media activities, sensor data on temperature and

humidity, etc. These data can help capture the acute physical risk of climate change as well as individuals' perception of climate change.

There are a few areas of climate risk that have attracted little research attention. First, the role of intermediaries, especially financial analysts and underwriters of equity issuance, has not been widely studied yet. These intermediaries play vitally important roles in disseminating information and improving market efficiency. It will be valuable to see how analysts' expertise in climate change affects their assessment of earnings affected by the climate change. Second, shareholder litigation has been an effective way of pushing for governance change and there is some climate-related litigation in the U.S. (Burger & Tigre, 2023), but few papers have examined how it affects the climate management policy for companies. Third, the literature has not paid much attention to the potential adverse selection issue following regulations. For example, do tighter carbon control regulations lead firms to misrepresent their emissions data, or to move the emissions overseas? Studies in this area will be practically important for regulators and practitioners. Fourth, and last, future studies can explore the moderating role of political ideology, religiosity, and culture on the effect of climate risk. Culture plays a major role in influencing an individual's economic decisions, as it affects the norm and moral characters of society (Hilary & Hui, 2009); for example, whether the risk premium of climate risk in the equity markets is moderated by religiosity across the world or political ideology across the states in the U.S.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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