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Finance and Climate Change Risk: A Review of the Literature

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Abstract: Climate change poses a significant threat to financial stability and has the potential to trigger global systemic financial risks. Therefore, the relationship between climate change and finance has become a focal point for scholars, financial institutions, and policymakers. The impact of climate change risks on the decisions made by enterprises and financial institutions underscores the need for strengthened research efforts in policy, technology, markets, and other relevant areas to mitigate these risks and uphold the stability of the financial system. This paper undertakes a review of the literature on climate change risk published in leading finance journals, examining diverse perspectives such as public belief, corporate finance, asset pricing, theoretical models, and policy supervision. By identifying key research directions in this field, the paper aims to provide valuable insights to support countries in promoting the transition to a low-carbon economy and maintaining financial system stability in the face of climate change challenges.

1. Introduction

Climate change risk can be divided into transition risk and physical risk, which are the two main transmission channels of climate change risk to the financial sector. Firstly, climate change can affect financial stability by causing direct damage to economic activity through more frequent and severe natural disasters. Secondly, financial markets may be adversely affected by uncertainties about the timing and pace of the transition to a low-carbon economy, including the implementation of related policy measures, as well as the potential impact of disruptive technological advancements on asset prices in carbon-intensive industries.

When physical risks materialize, such as sea-level rise, drought and hurricanes, the potential for sudden impairment losses increases in climate-risk-sensitive areas. This could lead to the devaluation of collateral and assets for numerous financial institutions, especially with insurance liabilities being particularly vulnerable to the frequency and severity of climate and weather-related events. Regarding transition risks, unexpected policy measures or rapid changes in consumer preferences could result in abrupt declines in asset prices for affected companies and industries. The lack of reliable and comparable information on climate-sensitive exposures by financial institutions or investors could create uncertainty and lead to pro-cyclical market dynamics, including a significant sell-off of carbon-intensive assets and potential liquidity problems. In addition, an accelerated transformation of policy, technology, and market responses would have the greatest potential to reduce the profitability of

carbon-intensive enterprises, increase their default risk, and eventually change the capital requirements and risk weights of banks' exposures. The sovereign default risk of countries with a dominant share of carbon-intensive industries is also likely to increase.

In the last few years, the empirical and theoretical literature on climate change risk pricing and hedging, investor risk awareness and strategies, and the impact of climate change risks on investment decisions of companies, financial institutions, and sovereign entities has broadened the research horizon. There is also a growing awareness among policymakers that finance is part of the solution to the challenge of climate change. This paper reviews the literature on climate change risk published in top finance journals in recent years, aiming to give a brief introduction and summary of current research in related fields.

2. Climate change risk and public belief

Public belief plays a key role in financing new technologies that mitigate climate change and in setting the price of climate-sensitive assets. Therefore, studying the beliefs of investors, financial institutions, and corporate executives is essential when assessing and pricing climate change risk.

Stroebel & Wurgler (2021) [1]conducted a survey involving over 800 finance academics and professionals on climate issues. Respondents identified regulatory activities, or transition risks, in the transition to a low-carbon economy as the most significant climate risk for businesses and investors over the next five years. However, they identified physical risks as the predominant risk over the next 30 years. The vast majority of respondents believe that current asset prices underestimate climate risk. Meanwhile, those who believe that climate risk is not adequately reflected in the stock market also generally consider the risk to be underrepresented in the real estate and insurance markets. Krueger et al. (2020) also indicated that many institutional investors believe that stock valuations in certain sectors do not adequately reflect climate risk.[2] Furthermore, Stroebel & Wurgler (2021) observed notable differences among respondent populations. When comparing different occupational roles, private market participants were 22% more likely than academics to believe that climate risks were underestimated (73% of respondents in the private sector versus 51% of academics). By contrast, academic researchers are more likely to believe that these risks are accurately priced, possibly due to financial academics' greater faith in market efficiency.[3]

Choi et al. (2020) discovered a disparity between public belief and scientific consensus, noting that the impact of climate risk is often disregarded as the public tends to focus on high-profile weather events and personal experiences. However, when local temperatures experience abnormal increases, individuals alter their beliefs and respond accordingly. This shift in belief is reflected in stock prices and trading activity. For instance, during months with unusually high temperatures, Google searches for the term “Climate change” in the region tend to surge. Additionally, a significant number of retail investors tend to divest from carbon-intensive stocks, resulting in lower stock returns for carbon-intensive companies compared to low-emission companies. Painter (2020) further highlighted that investors would consider the risk of climate change on fixed-income assets in their portfolios, underscoring the significance of climate change as a factor influencing investment decision-making.[4]

Although institutional investors typically prioritize financial, legal, and operational risks over climate risk and may not respond to unusual local temperatures accordingly (Krueger et al. , 2020) [5], research by Alok et al. (2020) indicates that professional fund managers tend to overreact to significant climate disasters occurring in their immediate vicinity. This overreaction leads them to reduce their exposure to stocks affected by the disaster to a greater extent compared to managers located further away. Alok et al. (2020) also observed that such overreaction could incur costs for investors.[6]

Garel & Petit-Romec (2021) examined the cross-sectional returns of equities during the COVID-

19 shock to investigate investor perceptions and expectations regarding environmental issues. The findings reveal that companies implementing responsible strategies on environmental issues experience higher returns on their stocks. This impact is primarily attributed to initiatives addressing climate change, such as emission reductions. The effect was particularly pronounced for companies with a higher ownership percentage by long-term investors and was not evident before the shock. Consequently, the impact of COVID-19 did not shift investors' focus away from environmental issues; instead, it further underscored investors' sense of responsibility toward environmental concerns.[7]

3. Climate change risk and corporate finance

We need to enrich the literature on the impact of climate change on corporate finance by examining the importance of carbon risk in corporate acquisitions. Bose et al. (2021) noted that in countries with weak environmental regulatory standards, companies with high carbon emissions are more inclined to acquire overseas targets. In a complementary study, Hickey et al. (2021) scrutinized the effectiveness of European regulations in achieving net-zero carbon emission targets. Their research augmented the existing literature on carbon risk at the enterprise level, including discussions on stranded assets, impairment risk, and the capacity of utilities to manage significant energy resources. Furthermore, Hickey et al. (2021) established a framework to evaluate the ability of enterprises to uphold financial sustainability during the transition period, ensuring that companies have adequate time to prepare for mandated phase-outs. Both studies underscored that climate change will affect various aspects of corporate financial management, necessitating further research in this domain. Specifically, there is a pressing need to comprehend how financial policies can facilitate companies in internalizing the social costs of carbon and effectively managing the climate risks inherent in business operations and supply chains.[8-12]

Addoum et al. (2020) by establishing a detailed temperature exposure data panel for large businesses across the U.S. to estimate how temporary temperature shocks in specific geographic locations affect sales and production levels. Their study aimed to analyze the impact of temperature on business sales. Addoum et al. (2020) found that the per capita impact of rising temperatures on business sales and production levels is nearly negligible, indicating that businesses possess the capability to adapt to these temporary shocks. However, a caveat from its conclusions is that long-term shifts in temperature can and do elevate the risk of extreme weather events, and for this reason, extrapolation from short-term temperature changes might pose potential challenges. Furthermore, the study suggested that companies in developed countries are generally less susceptible, on average, to the impacts of extreme temperatures.[13-16]

Shive & Forster (2020) conducted studies utilizing greenhouse gas emissions data, revealing that independent private companies are less inclined to pollute the environment or face penalties from the United States Environmental Protection Agency (EPA) compared to public companies. This observation suggests that ownership structure, agency issues, and other related factors may influence enterprises' responses to climate risk. However, after controlling for industry, time, location, and various company characteristics, the study found no significant difference in this regard between private-equity-invested firms and public firms. Furthermore, Shive & Forster (2020) identified a negative correlation between emissions and mutual fund ownership as well as board size in public firms, suggesting that heightened internal oversight within enterprises may help mitigate pollution externalities.

Huynh et al. (2020) found a significant positive correlation between drought climate risk and the cost of equity capital, indicating that enterprises affected by severe drought face a higher cost of equity capital compared to unaffected enterprises, with a difference of 92 basis points. Additionally, the study found that both the duration and intensity of drought exacerbate the risk premium for

enterprises. However, for firms with diversified investments, operations, and ample cash holdings, the impact of drought on expected earnings was significantly mitigated. The results show that investors are demanding higher returns from drought-affected companies, and their research provides insights into how companies can mitigate the impact of drought on their cost of capital.

Climate change risk also exerts a substantial influence on the market value of companies. Ramelli et al. (2021) studied the "Greta Thunberg" effect of the first global climate strike and found that the unexpected success of the strike led to a decline in the share prices of carbon-intensive companies in Europe. Similarly, Rao et al. (2022) demonstrated that firms highly sensitive to rainfall conditions experience a significant drop in market value following periods of excessive or inadequate rainfall. Furthermore, Bolton & Kacperczyk (2021) identified a positive correlation between carbon emissions and stock returns. This implies that companies with higher carbon emissions offer a higher return on equity to compensate for carbon risk. Moreover, Engle et al. (2020) found that companies with lower exposure to climate risk tend to yield higher stock returns during periods characterized by negative news about climate change.

Huang et al. (2021) introduced a quasi-natural experiment to investigate the repercussions of the clean air initiative launched by the Chinese government in 2013. Through the analysis of over a million loans, they observed a notable increase in defaults among borrowers in highly polluting industries, suggesting that stricter environmental regulations may exacerbate corporate balance sheet vulnerabilities and potentially impact the overall financial system. Similarly, Javadi & Masum (2021) conducted an empirical study revealing that bank lending spreads are substantially elevated for companies located in regions that are more affected by adverse climate change.[17-19]

4. Climate change risk and asset pricing

Given the macroeconomic impacts of climate change, asset prices are expected to exhibit heightened sensitivity to climate risks affecting their cash flows (Hong et al., 2020). Climate risks in asset markets, including stocks, real estate, and insurance, are prominent, with a substantial body of literature demonstrating that equity, bond, real estate, and derivatives markets have integrated climate risk into asset prices. Additionally, research by Ilhan et al. (2021) suggests that pricing in options markets reflects uncertainty in climate policy. However, the extent to which asset prices accurately reflect climate risk has garnered increasing attention. This issue is not only significant due to its policy implications (Anderson et al., 2019), but also because it pertains to the fundamental question of the empirical determinants of asset prices. Yet, there remains limited research examining whether asset prices adequately capture climate risk and whether the pricing is rational. Nevertheless, there have been scholars who have made contributions in this area.

Hong et al. (2019) focus on climate risk associated with drought and examine whether stock markets adequately price the risks exacerbated by climate change. Their research utilizes the Palmer Drought Severity Index (PDSI) to measure a country's long-term drought levels, shows that stock markets are inefficient at informing about long-term drought, and stock prices do not adequately reflect drought risks. By employing a three-year moving window average of PDSI, the study demonstrates that prolonged dry spells in a country are predictive of decreased profitability ratios and stock returns for food companies within that country. Furthermore, a portfolio comprised of food company stocks exhibits lower returns, with these forecasts being particularly pronounced in countries with historically mild climates and fewer instances of droughts. The findings also confirm regulators' concerns regarding the inadequate response of markets to climate risks and advocate for further examination of the value of corporate disclosure of such risks.

Ehlers et al. (2022) merged syndicated loan data with information on the carbon intensity of borrowers across different sectors, measured by CO2 emissions per unit of GDP, and found that there

has been a significant “Carbon premium” on loans since the implementation of the Paris Agreement, extending beyond carbon-intensive industries. However, they noted that the level of risk pricing remains relatively low, given the actual circumstances of the borrower, as only carbon emissions directly attributable to the company are priced, while activities such as indirect emissions are not taken into account.

Painter (2020) found that regions that are more likely to be affected by climate change face higher underwriting costs and higher yields when issuing long-term municipal bonds compared to regions less vulnerable to climate change. However, this discrepancy is not evident in the issuance of shorter-term municipal bonds, which means that only the pricing of longer-term bonds incorporates climate change risk in the bond market.

Schlenker & Taylor (2021) compared derivatives prices based on future weather with CMIP5 climate model forecasts and weather station observations from eight U.S. cities from 2001 to 2020. They found that derivatives prices responded to both short-term weather forecasts within two weeks and long-term climate warming trends. For long-term climate trends, derivatives prices aligned with both model predictions and weather station observations. When examining the spatial and temporal heterogeneity of climate trends, futures prices were found to be more consistent with climate model data, suggesting that market participants’ expectations are closely tied to scientific predictions rather than recent observations. On the other hand, Ilhan et al. (2021) identified the impact of climate policy uncertainty on options markets, and found that for carbon-intensive companies, the cost of protective options against downside risks is higher, a trend exacerbated by increased public concern about climate change.

Giglio et al. (2021) found that as the public becomes more aware of climate risks, the premium for location advantages, such as sea-view rooms, gradually diminishes. This finding aligns with similar conclusions drawn by Baldauf et al. (2020) and Bernstein et al. (2019). Baldauf et al. (2020) used a set of real estate transaction data to measure the impact of flood expectations and local public beliefs about climate change on house prices. They found that compared to counties that deny the impact of climate change, home prices in districts perceived to be affected or expected to be flooded are discounted, indicating significant differences in public beliefs across regions. In contrast to the study by Murfin & Spiegel (2020), Baldauf et al. (2020) highlighted the importance of public perceptions of climate risk in influencing how and whether assets are priced.

Murfin & Spiegel (2020) conducted a study utilizing real estate transaction data with residential elevations, which they matched with tidal data to examine whether house prices reflected different sea-level rise risks. Notably, they employed the rate of land subsidence-rebound as an indicator of the expected rate of regional relative sea-level rise, effectively separating the effects of sea-level rise from the hedonic value of property height. In contrast to studies such as Bernstein et al. (2019) and Baldauf et al. (2020), Murfin & Spiegel (2020) found that the price effect of climate change on real estate is limited, possibly due to public optimism regarding sea-level rise or the slowdown in the upward trend, coupled with the possibility of receiving bailouts. In other words, if public perception of climate risk is not fully considered and only the combination of sea-level rise and house prices is examined, the impact of sea-level rise risk on house prices may appear weak.

Nguyen et al. (2022) showed that lenders impose higher mortgage rates on properties facing greater risk of sea-level rise. This risk premium is not evident in short-term loans and remains independent of the borrower's short-term default or creditworthiness. Moreover, the risk premium for sea-level rise is lower when climate change outcomes are less pronounced and where the effects of climate change are denied. In general, mortgage lenders perceive sea-level rise risk as a long-term concern, and public attention and belief in climate change may hinder its integration into pricing in the housing mortgage market. Similarly, Bakkensen & Barrage (2022) developed a dynamic housing market model to explore the heterogeneity of flood risk beliefs, in particular, public misconceptions about

flood risk play a role in explaining current and future pricing dynamics in the U.S. coastal housing market.

5. Climate change risk and theoretical model

Traditional financial risk models may not adequately capture climate-related financial risks (Bolton & Kacperczyk, 2021). To address this, Engle et al. (2020) developed a climate news index, which integrates media platform reports on climate change through text analysis. They used this index to build a dynamic trading strategy, enabling enterprises to obtain significant returns on investment in the face of negative climate risks. On the other hand, Giglio et al. (2021) used the probability of climate disasters to refer to climate risk, which is affected by the length of its lag period and the level of economic activity during that period.

Ouazad & Kahn (2022) developed a mortgage pricing model incorporating information asymmetry, home location selection, and mortgage default dynamics. The key point of their study is that the risk of climate catastrophe impacts lenders' earnings far beyond other default factors, such as personal unemployment or divorce, which do not affect foreclosure proceeds. Through out-of-sample simulation, the model evaluates the effect of increased probability of climate disaster risk on mortgage application approval rates, original mortgage securitization rates, location choices, and default rates.

Barnett et al. (2020) estimated the social cost of carbon by integrating asset pricing methods and decision theory, while uncertainty about the impact of climate change on human welfare and inherent uncertainty in economic models must be addressed. The model reveals that the interaction between these uncertainties is multiplicative, resulting in a significant impact on the social cost of carbon when both of them are prominent. They also highlighted that the social cost of carbon could be significantly overestimated due to investor ambiguity aversion and model misspecification.

With the growing demand for carbon emission reduction and environmental awareness, studies have increasingly shown that investors consider climate risk in their investment decisions. Pedersen et al. (2021) focus on the econometric and statistical analysis of ESG portfolio selection and asset pricing, introducing the concept of ESG-SR efficient frontier for the first time. On this basis, Pedersen et al. (2021) explore the equilibrium asset pricing model incorporating ESG factors and extend the analysis to the Capital Asset Pricing Model (CAPM) after adjusting asset returns to satisfy the ESG criteria.

Pástor et al. (2021) developed a pricing model that incorporates the ESG standard. In the equilibrium state of the model, the expected return of green assets is low because investors prefer to hold them, viewing them as a hedge against climate risks. Green assets outperform other assets when they have a positive shock on the ESG factor, which reflects the change of investors' views on green assets. Pástor et al. (2021) believes that sustainable investment will have a positive social impact, encouraging companies to adopt more environmentally friendly practices, consequently leading to a shift in physical investment toward green businesses.

6. Climate change risk and policy supervision

Huang et al. (2021) and Javadi & Masum (2021) have both highlighted the importance of climate finance in banking and financial regulation, given that there are still differing views on whether central banks should take climate change into account in their policies, further research is still needed to better understand the direct and indirect impacts of a “Green monetary policy” and the potential ramifications for the banking system in the face of climate-related shocks. Central banks could explore leveraging reserve assets to manage climate risk, with green financial instruments emerging as complementary tools for foreign exchange reserve management (Bolton & Kacperczyk, 2021) .

But policies aimed at mitigating climate risks may be ineffective because of regulatory arbitrage

by companies. Bartram et al. (2022) employed the DID method to study the impact of California's cap-and-trade program on U.S. factory-level data and found that financially constrained companies subject to the program tend to shift their carbon emissions and output to other states, there they have similar underutilized factories, while unfettered companies do not make such adjustments. The results show that unrestrained enterprises do not reduce their total emissions, whereas restrained enterprises increase their total emissions after the implementation of the cap-and-trade scheme, which undermines the effectiveness of the policy. Bartram et al. (2022) argue that if climate policies fail in one region, their effectiveness on a global scale may be called into question.

Bartram et al. (2022) suggested two aspects for climate policy consideration. First, climate policy should be coordinated across jurisdictions because of the geographical diversity of business operations. Secondly, given that financially constrained businesses have a stronger incentive to redistribute carbon emissions, policymakers could explore differentiated subsidies, such as tax incentives, to mitigate distortions in the implementation of climate policies.

7. Prospect of research

To help businesses, financial institutions, and policymakers better manage climate change risks, future research in this area could focus on the following five areas.

First, financial institutions need to enhance the transparency of climate risk information and establish comprehensive databases. As a novel form of financial risk, the scarcity of data is a challenge in current research efforts. A thorough understanding of businesses' and financial institutions' exposure and vulnerability to climate-related risks is crucial to accurately pricing climate risks. While existing research predominantly focuses on developed markets due to their relatively robust information disclosure mechanisms, it's essential to acknowledge that developing countries often face more pronounced challenges in this regard. In developing countries, central banks and financial regulators hold a prominent position in the financial system, there's a compelling case for these institutions to take a more proactive role in promoting information transparency and database construction.

Second, financial institutions must bolster their capacity for climate risk modeling to enhance the accuracy of climate risk quantification and assessment. It's crucial to recognize that various models and parameter settings can directly influence assessment outcomes. Currently, there remains significant variability in the assessment of transition risks, physical risks, and the social costs of carbon. By investing in advanced modeling techniques and refining parameter settings, financial institutions can better understand and anticipate the diverse range of climate-related risks faced by businesses and financial markets, thereby enhancing their ability to develop effective risk management strategies.

Third, financial institutions need to prioritize examining the impact of divestment and stranded assets on financial stability. Divestments typically concentrate within specific sectors, notably oil and gas, utilities, and automobiles. Institutional investors may have already removed high-carbon risk companies from their portfolios due to climate risk considerations (Bolton & Kacperczyk, 2021) . These divestments, combined with litigation risk and regulatory lobbying, would lead to significant asset stranding risks and could trigger a "Green swan" event. By assessing and addressing these risks proactively, financial institutions can enhance their resilience to potential shocks and contribute to the transition towards a more sustainable financial system.

Fourth, it's imperative to consider the impact of climate change on urban finance. Climate change poses a substantial threat to the financing and debt-servicing capacity of urban finance, and severe extreme weather events can inflict damage on urban infrastructure, thereby exacerbating urban budget constraints. By incorporating climate change considerations into urban financial planning,

stakeholders can better prepare for and respond to the challenges posed by climate-related events, ultimately safeguarding the financial stability and sustainability of urban economies.

Fifth, it's essential to explore green financial instruments and financial innovations related to climate change. Green finance instruments and financial markets, such as green credit, green bonds, carbon taxes, and carbon markets have been introduced to address climate change. However, the effectiveness of these instruments in promoting enterprise green transformation remains inconclusive due to inconsistencies in research findings. With more information disclosure and the development of empirical methods, these areas will become increasingly important research directions.

8. Conclusion

This paper reviews recent research on climate change risk in top financial journals, with a focus on its implications for public belief, corporate finance, asset pricing, theoretical models, and policy supervision. The studies found that climate risk poses a threat to financial stability, there is a gap between public belief and scientific consensus on climate risk, and investors are increasingly concerned about climate risk. In addition, climate change risks have an impact on the investment decisions of enterprises and financial institutions, necessitating strengthened efforts in policy, technology, market research and other aspects to reduce the impact of climate change risks on the financial system. The studies also highlighted the influence of ESG factors on asset pricing models, including the Capital Asset Pricing Model (CAPM), emphasizing the importance of incorporating climate risk into policy regulation. Future research directions could include enhancing the transparency of climate risk information, bolstering climate risk modeling capabilities, investigating the impacts of divestment and asset arbitrage on financial stability, exploring the ramifications of climate change on urban finance, and further exploring the application of green financial instruments and financial innovations related to climate change mitigation.

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