Climate Risk and Corporate Debt Maturity Profiles

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Abstract

Using an international sample covering 2005-2019 period, we find that firm actively structures its debt obligations to mature in a dispersed fashion when exposing to weather-related events. Controlling for time-varying characteristics of both firm and macroeconomic conditions, our results suggest that one standard deviation increase in climate risk leads to four percent of debt maturity dispersion. The findings are confirmed by employing difference-in-differences analysis of firm debt profiles responding to the 2015 Paris Agreement. Our evidence shows that the effects are more pronounced when firms (i) face higher financial constraints, or (ii) operate in the countries with better access to capital market. Taken together, our study sheds light on the joint effect of supply and demand for debt maturity profiles when firms are exposed to a high level of climate risk.

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1. Introduction

Recent literature has highlighted the determining role of weather conditions on firm's operational performance and financing choices. For instance, Brown, Gustafson, and Ivanov (2021) reveal that firms located in natural disaster frequent-hit areas exhibit a high inclination to hold more cash, engage less leverage (Elnahas, Kim, & Kim, 2018) and spend less on long-term investment and innovation (Zhao, Zheng, & Fu, 2022). Shifts in long-term weather patterns are forecasted to not only increase both frequency and severity of extreme natural hazards – physical risk, but also represent a source of external uncertainty due to environmental policies aiming at curving carbon emissions, i.e., transition risk, which exposes firm to difficult positions upon the need of refinancing its debt obligations. For instance, physical damages caused by natural disasters potentially limit firm's borrowing capacity during post-hazard reconstruction due to a reduction of collateral values (Wang, 2023). In order to reduce rollover risk, firms have two options: either relying on government support, which might require a lengthy administrative procedure, or actively managing their debt financing in a more efficient manner such that their debt maturity portfolio spreads out over a time period, i.e., dispersed. Servaes and Tufano (2006) further suggest that Chief Financial Officers, responding to an anticipation that rollover risk could become a significant threat due to limited access to credit markets in the future, tend to avoid large debt issuances maturing concentratedly.

The decision of debt maturity structure requires careful evaluation of the trade-offs between benefits and costs. On the one hand, a dispersed debt maturity portfolio allows firm to better manage its external financing options when market condition is uncertain (Choi, Hackbarth, & Zechner, 2018). In addition to the flexibility of being able to refinance small fractions of its debt obligations scattering over several years, firm with dispersed debt maturity portfolio is entitled to lower bank loans interest due to a reduction of shareholder-creditor conflicts (Chiu, King, & Wang, 2021). On the other hand, the design and maintenance of a dispersed debt maturity may not be a natural choice for these firms. Relative to large and concentrated debt issuances, a dispersed debt maturity portfolio is more costly due to fixed cost component (Altınkılıç & Hansen, 2000), and requires more monitoring efforts. These additional costs may exacerbate impact of rollover risk on firm's refinancing ability in the existence of climate uncertainty.

In this paper, we examine how firms manage their debt maturity profiles when facing a growing external uncertainty environment. In particular, we ask to what extent climate risk affects firm's structure of debt maturity, and whether financial health and capital market efficiency serve as mechanisms via which weather-related uncertainty influences debt maturity structures. Our sample focuses on the firm-level decision of managing debt maturity on a global setting that covers developing countries where the consensus suggests that the most significant consequences of climate change are being experienced (Kling *et al.*, 2021).

We use Global Climate Risk Index (hereafter CRI) developed by GermanWatch to proxy for shifting long-term weather pattern uncertainty. Capturing the country-level losses from extreme weather events, CRI represents the level of exposure and vulnerabilities to extreme weather events (Eckstein, Künzel, & Schäfer, 2021).[1] Merging CRI to accounting data consisting of firms from 41 countries covering 2005 to 2019 period, our sample consists of 199,981 firm-year observations with 27,869 distinct firms. After taking into account for both time-invariant and time-varying characteristics of firm and macroeconomic conditions, we find that weather-related uncertainty induces firm to scatter maturities of its debt obligations over years. In particular, one standard deviation increase in climate risk leads to nearly four percent of debt maturity dispersion. This finding is consistent with Choi, Hackbarth, and Zechner (2018) since dispersing debt maturity profiles is an effective tool allowing firms to mitigate the refinancing risk when market condition is uncertain. Our results are robust using alternative measures of debt dispersion, and different subsampling approaches.

Our mechanism analysis suggests that financial constraint and capital market development are the two channels via which climate risk influences debt maturity portfolio. Using dividend payout as a measure of financial condition, our evidence suggests that one standard deviation increase in climate risk translates to forty three percent more debt maturity dispersed in non-payout firms. Anticipating that firms might face adverse financial condition due to occurrence of weather hazards, management team, instead of paying out dividends, tends to accumulate cash as a safeguard for future climate uncertainty. The finding is consistent with Itzkowitz (2013) and Huang *et al.,* (2017).

We next use KZ as an alternative measure for financial constraint. While financially constrained firms may have stronger incentives to manage their rollover risk by reducing cost stickiness (Li & Zheng, 2020); their counterpart may find it less costly to issue regular debt and gain a better ease to achieve a dispersed debt maturity structure. Our cross-sectional analyses

[1] While calamities occurring between 2000-2019 yielded a total loss of US$2.56 trillion with 475,000 casualties, the estimated costs required to adapt to changing climate can reach to a high of US$500 billion by 2050 (Eckstein, Künzel, & Schäfer, 2021).

indicates that firm with poor financial health has a 20 percent higher debt maturity dispersion comparing to non-constrained firm. In response to potential difficulty in obtaining external funding for future investments when firms are exposed to enhancing weather uncertainty, firm prefers structuring the maturities of its debt obligation in a scattered time intervals when it is financially constrained.

Our next channel via which climate risk affects firm choice of debt maturity profiles is the availability of funding sources. As international trade facilitates financial market development (Beck, 2002) by increasing financial availability, in an open market, firm is able to obtain external fundings to meet its financial needs for investment opportunities (Braun, & Raddatz, 2005). In addition, Bouvard, Chaigneau, and Motta (2015) show that when being exposed to negative aggregate shock, banks increase disclosure to reduce rollover risk. In the same line of argument, since climate uncertainty tends to aggravate rollover risk, firms might exhibit a responsive behaviour of issuing debts maturing in scattering time intervals, given the access to availability of financial slack in an open market. Proxying the external funding availability by *Trade-to-GDP* from Worldbank, we show that one standard deviation increases in climate risk results in an approximate increase of 17 percent of debt dispersion in the high trade-open economy relative to that of the low trade-open economy. In other words, firms located in more developed financial market have more opportunities to employ the dispersed maturity profile strategy when climate risk is high.

So far, our analysis assumes that climate risk is exogeneous to firm operation and financing activities. That is to say, the occurrence of natural disasters is unrelated to firm's financing decisions. Nevertheless, a number of factors, such as firm heterogeneity and industry concentration in different countries, or climatization of firm's behaviour, (i.e., firms take mitigative actions against frequent probability of extreme weather hazards), might obscure our findings. In order to address this issue, we conduct an experiment-like difference-in-differences (DiD) analysis on the debt maturity profiles between high- and low-climate risk firms using the event year of 2015. The choice of the year 2015 is driven by two reasons: (i) the Paris Agreement was signed by 196 countries in 2015, marking the joint supranational effort in addressing climate change, and (ii) the elucidation of Financial Stability Board relating carbon disclosure landscape by establishing the Task Force on Climate-Related Financial Disclosures (TCFD). Both events thus heightened awareness of climate-related risks among firms, bankers, and investors.

Using the same host of firm controls and fixed-effects, our DiD analysis provides consistent evidence showing that firms experiencing a high exposure to climate risk tend to structure their debt maturity profiles in a more dispersed fashion in the post-2015 period. Interestingly, the effect of climate risk is non-monotonic supported by quantile analysis. Running a difference-in-differences on separate climate uncertainty quantiles, we find that the climate risk – debt maturity relation not only switches sign when moving from low to high quantiles, but also becomes more visible in the most extreme quantile. Hence, this evidence lends support to our conjecture that the effect of weather uncertainty on debt dispersion level is more pronounced among firms located in areas with high exposure to weather uncertainty.

We contribute to the recent growing literature on the impact of climate risk on firm behaviour. While a number of studies use temperature (Dell, Jones, & Olken, 2010, Addoum, Ng, & Ortiz-Bobea, 2020, 2023), rainfall (Rao *et al.*, 2022), droughts (Hong, Li, & Xu, 2019), severe winter weather (Brown, Gustafson, & Ivanov, 2021) to identify the effect of weather shocks, our measure of climate risk encompassing a host of natural disasters affecting firm performance (Barrot, & Sauvagnat, 2016, Ozkan, Temiz, & Yildiz, 2023), cash holding behaviour (Javadi *et al.*, 2023), bank loans (Huang, Kerstein, Wang, & Wu, 2022), and market valuation (Berkman, Jona, & Soderstrom, 2024). Building off these studies, we document how climate risk determines firm debt maturity profile management to alleviate the concern of lack of financial capitals in the long run.

Although our study is seemingly similar to Huang, Kerstein, Wang (2018) (hereafter HKW), there are a number of key features differentiating our contributions. First, while both HKW and our study use the same proxy of climate uncertainty to identify the impact of climate risk on firm's financing choice, HKW focus on cash holding and the preference towards long- vs. short-term debt. We, on the other hand, shed light on how firm actively manage its debt maturity profile against the occurrence of natural disasters. Second, our identification strategy employs DiD analysis to eliminate endogeneity issues whilst HKW use instrumental variable approach. Last, we extend our contribution by pointing financial constraints and capital market development being the channels via which climate risk alters the structure of debt maturity.

Second, we enrich the climate finance literature (Hong, Karolyi, & Scheinkman, 2020, Giglio, Kelly, & Stroebel, 2021). Recently emerged but have been receiving increasing attention, climate finance has identified regulatory risk and physical risk are the two most important climate risk to businesses and investors in the coming future (Stroebel & Wurgler, 2021). Climate risk has been empirically documented to influence firm risk (Matsumura, Prakash, & Vera-Muñoz), performance (Ozkan, Temiz, & Yildiz, 2023, Pankratz, Bauer, & Derwall, 2023), financing choice (Huang, Kerstein, & Wang, 2018), capital structure (Ginglinger & Moreau, 2023), to name a few. Our findings complement and extend the literature by suggesting that climate risk affects corporate debt maturity profiles.

Third, our paper enriches empirical and survey research by Servaes and Tufano (2006) regarding debt maturity profile choice. Building off the work of Choi, Hackbarth, and Zechner (2018), we contribute to this literature strand by identifying the unconventional source of rollover risk brought about by shifts in long-term weather patterns. In addition to traditional uncertainties that might inhibit firm's access to debt market, such as financial health (Dangl & Zechner, 2021), business cyclicity (Chen, Xu, & Yang, 2021), cashflow risk (He & Milbradt, 2016), cost of capital (Chiu, King, & Wang, 2021), and so on, both physical and transition risk stemmed from climate change play deterministic role in re-accessing credit risk profile due to non-reversal consequences on the long-term health of both firm and overall financial market. The study further extends the existing understanding of how financial constraints and capital market development channel the relationship between climate risk and corporate debt maturity profiles.

Our findings provide practical implications for government and firms under the increase of climate risk. We call for government attention to have appropriate policies in place assisting firms in the heightening uncertainty environment arisen from shifts in weather patterns. Such effort should reflect a worldwide cooperation, given the global-scale consequence of climate change. Surpassing the traditional form of aids and assistance upon the occurrence of natural hazards, the government should seize the initiative to reduce firm's debt issuance costs in frequent-hit natural disaster areas, enabling firms to have better ability to adapt to the environment by achieving their optimal debt structure portfolio. Such policies can take the form of tax relief or fixed/capped fee on debt issuance.

Our study also points to a potential adaptive measure for managers against the elevating frequency and severity of weather hazards. As climate risk intensifies, firms that prioritise debt dispersion strategies may be better positioned to maintain financial stability. This advantage arises from their ability to refinance maturing debt in external markets, thereby avoiding the need to either forgo profitable investment opportunities or engage in inefficient asset liquidation. This is especially important for financially constrained firms and those located in developing or under-developed regions.

The paper is structured as follows: Section 2 discusses about current literature and hypothesis development. Section 3 presents data construction and methodology. We present our results in Section 4 and mechanisms in Section 5. Section 6 addresses endogeneity issues and Section 7 concludes.

2. Literature Review and Hypothesis Development

2.1 Climate Risk Literature

Climate has been long-established as a predictor of economic growth, industrial output, and productivity (Dell, Jones, & Olken, 2014). Using temperature as a direct measure of weather patterns, Dell, Jones, and Olken (2012) document a reduction of 1.3 percent on average economic growth for every 1ºC degree in poor countries, and further highlight that the effect of temperature is revealed in growth rates, not just levels, and irreversibly persistent even when temperature shock is over. Focusing on the U.S., Colacito, Hoffman, and Phan (2014) document a "*horse race*" effect of temperature shocks between summer and fall, in which the negative temperature-economic growth relationship in the former increases in a faster pace than the negative relation in the latter. Higher temperature is also linked to economic disadvantages in numerous studies (Gallup, Sachs, & Mellinger, 1999, Henderson, Storeygard, & Weil, 2012, Bansal & Ochoa, 2012, Kotz *et al.*, 2021). Contributing to the "climate-output reversal" literature whereby the temperature-out relationship is negative when measured on a per capita basis, but positive on a per area basis (Nordhaus, 2006), Burke, Hsiang, and Miguel (2015) point to the non-linear effect of temperature on global economy, in which productivity reaches its peak at the average temperature of 13ºC and reduces strongly at warmer temperatures. In addition to economic growth, temperature has been adversely linked to agricultural output (Ortiz-Bobea *et al.,* 2021), labour productivity (Niemelä *et al.*, 2002, Dasgupta *et al.*, 2021); and positively related to conflicts (Burke, Hsiang, & Miguel, 2015, Koubi, 2019) and unequal risks among different regions (Hsiang *et al.*, 2017), to name a few.[2]

The 2021 Intergovernmental Panel on Climate Change predicts that the global temperature will increase on an average of 1.5ºC in the 2021-2040 period relative to the pre-industrial levels. Given the well-documented negative impact of temperature on economic growth, Kahn *et al.* (2021) estimate that in the lack of sufficient climate policy, real GDP per capital is expected to

[2] See Dell, Jones, and Olken (2014) for a comprehensive literature review on the impact of climate.

drop more than 7 percent of by 2100, given an increase of 0.04°C per year, bolstering the similar prediction of Burke, Hsiang, and Miguel (2015). Using the business-as-usual emission path, Diez *et al.* (2016) predict a drop of 1.8 percent in global financial assets, in which a loss of USD24.2 trillion stands at 99th percentile climate value at risk. In a most plausible worst case, a portfolio could experience a permanent reduction of 5 to 20 percent when the temperature increase by 4°C in 2030 (Covington & Thamotheram, 2015).

Finance academics, professionals, public regulators and policy economists have reached to a consensus that both regulatory and physical risk stemmed from climate risk represent the most focal source of uncertainty for businesses and investors, especially physical risk is considered the primary concern over the next three decades (Stroebel and Wurgler, 2021). In the recent literature review on climate risk provided by Hong, Karolyi, and Scheinkman (2020) and Giglio, Kelly, and Stroebel (2021), climate risk is increasingly being priced of various financial instruments, including bonds (Huynh & Xia, 2021; Duan, Li, & Wen, 2021), bank loans (Javadi & Masum, 2021), and stock values (Faccini, Matin, & Skiadopoulos, 2023; Huynh & Xia, 2023). Additionally, uncertainties arising from weather patterns are affecting firm performance (Pankratz, Bauer, & Derwall, 2023), real estates (Giglio *et al.*, 2021), and mortgages (Ouazad & Kahn, 2022), among many others.

Prior studies also look at how climate change affects firm's financing choice and performance. Huang, Kerstein, and Wang (2018) show that weather pattern is a determinant of cash holdings and cash dividends for firms located in regions with regular exposure to extreme weather events. In the attempt to explain for the positive relation between cash holdings and climate change exposure, Javadi *et al.* (2023) point to the precautionary motive exhibited by firms to hold more cash to safeguard against the materialisation of climate change. Using firm-level data and forward-looking physical climate risk measure, Ginglinger and Moreau (2023) document that firms exposed to higher physical climate risk tend to use internal financing source and reduce leverage in the post-2015 period. The evidence is the joint effect of firm's optimal capital structure (i.e., demand effect) and higher spread charged by both bankers and bondholders, supported by Javadi and Masum (2021).

2.2 Corporate Debt Maturity Profiles

While the literature on corporate debt maturity is extensive, there is a notable gap in the area of guidance on corporate debt maturity profiles, i.e., dispersed maturity or concentrated maturity profiles. Choi, Hackbarth and Zechner (2018) employ a theoretical framework to demonstrate that the dispersion of debt maturities is a crucial factor in capital structure decisions. In particular, the authors suggest that on the one hand, firms choose to issue a few large debts to avoid high fixed cost of multiple issuances.

On the other hand, in response to the deterioration of secondary market liquidity giving rise to inability to refinance maturing debt obligations, i.e., rollover risk, managers actively structure debt portfolio maturity spreading out over several years. Using the credit rating downgrade of General Motors and Ford Motor Co. in 2005 as an exogeneous shock, Choi, Hackbarth and Zechner (2018) document that firms with debt maturing shortly after the event tend to have low maturity concentration, and that high-leveraged treated observations experience substantial increase in debt maturity. Using a sample of U.S. bank sample covering 2002-2016 period, Chiu, King, and Wang (2021) document a reverse relationship between debt dispersion and interest rate, in which the effect is more pronounced in firms without credit rating. The proxy is also used in the work of Colla, Ippolito, and Li (2020), Ee, Huang, and Cheng (2023), Chu and Kjenstad (2023).

2.3 Hypothesis Development

Previous studies provide evidence suggesting that a reduced firm's profitability due to climate risk might lead to an increase in credit risk for lenders (see *e.g.*, Barrot and Sauvagnat, 2016, Abe *et al.,* 2013, and Park *et al.,* 2013). Given the consensus that climate change materialisation leads to more frequent and severe natural disasters has been reached in hard science, we hence expect that increases in climate risk could potentially deteriorate credit supply of secondary bond market. The increased credit risk due to climate change induces creditors to reduce the credit limit provided to firms with high climate risk or to increase the cost of debt for those firms. This behaviour creates more challenges for the focal firms to refinance their debt.

According to Choi, Hackbarth, and Zechner (2018), a dispersed debt maturity profile is an effective tool to mitigate the refinancing risk. While firm with concentrated debt maturity portfolio benefits economies of scale in terms of fixed transaction costs involving with large debt issuances (Altınkılıç & Hansen, 2000); firms with dispersed maturing debt structure benefits when the probability of market freezes increases. Furthermore, the impact of climate change might not only affect the banks' borrowers in developing countries but also those in developed countries that depend on the supplies and services provided by countries with high climate risks. Acharya *et al.* (2023) also suggest that climate risk deteriorates borrowers' medium-run repayment ability.

Thus, it is possible that firms actively manage their debt maturity profiles as a risk management tool to reduce rollover risk (Chiu, King, & Wang, 2021, Chaderina, 2023), better access to financial availability, lower cost of financing and financial constraints, and lower stock return volatility (Norden, Roosenboom, & Wang, 2016) in the increasing climate risk situation. We, therefore, hypothesise that:

H1a: Climate risk increases debt maturity dispersion.

On the other hand, Huang, Oehmke, and Zhong (2019) provide theoretical framework suggesting that during high cashflow volatility period, among which weather-related events are the causes, firms' debt structure consists of less frequent but larger repayments (i.e., concentrated). Moreover, Kolm, Laux, and Loranth (2018) suggest that highly levered firms might be unable to issue new debts with a dispersed debt maturity structure in place. Therefore:

H1b: Climate risk increases debt maturity concentration.

3. Data And Methodology

3.1 Data

3.1.1 Measure of Climate Risk

Following Kreft and Eckstein (2014), Huang, Kerstein, and Wang (2018), and Ozkan, Temiz, and Yildiz (2023), we use the climate risk data from Climate Change Performance Index published by GermanWatch since 2006. Based on four main indicators, namely the total number of deaths, the sum of loss in US$ inflation-adjusted, the number of deaths per 100,000 habitants, and the losses per unit of GDP, countries are ranked from the most to least impacted by natural disasters. The GermanWatch analysis only considers weather-related disasters, such as extreme temperature extremes, floods, storms, but not the geological incidences, such as earthquakes, volcano eruption, or tsunamis. As a result, the index is more relevant in the context of changing weather patterns that captures worldwide concerns.

Our proxy for climate risk is the Climate Risk Index (hereafter CRI) is then estimated based on different weights assigned to each individual component rank, in which the first two former takes one-sixth, and the two latter takes one-third of the total weight. This is a quantified measure of economic losses due to extreme weather events on a country basis. Additionally, this measure serves as an indicator of potential future extreme weather occurrences.

The CRI is annually calculated for each country based on data of 2 years before the publication each. For instance, the 2018 country ranking uses weather-related incidences occurring in 2016. The GermanWatch also publishes the long-term climate risk index which takes into account data of weather-related events in the previous 20 years, serving as the cumulative measure of climate risk. Given our interest in changing weather patterns, we use the long-term climate risk index, similar to Ozkan, Temiz, and Yildiz (2023). Given the GermanWatch convention that lower climate risk index indicates higher risk, we divided the measure by -100 before carrying our analysis, meaning that higher values indicate higher climate risk.

3.1.2 Measure of Debt Dispersion

Choi, Hackbarth, and Zechner (2018) find that firm actively manages its capital structure against rollover risk by altering debt maturity structure. Follow their construction of debt dispersion measure, we derive our variable of interest by estimating the inverse of debt concentration of debt maturity profiles, similar to Chiu, King, and Wang (2021) and Abotula, and Fairhurst (2022). In particular, after obtaining the detailed debt structure data from Standard & Poor's Capital IQ, we group the principal amounts matured into the nearest integer year. The concentration index based on Herfindahl Index is calculated as follows:

$$\text{HERF}_j = \sum_i w_i^2 \tag{1}$$

In which w_i is the fraction of principals maturing in each year estimated by $w_i = x_i / \sum_i x_i$. The debt dispersion maturity is then estimated as an inverse of Herfindahl Index:

$$\text{Debt Dispersion}_j = 1/\ \text{HERF}_j \tag{2}$$

As a result, if a firm has one outstanding debt issue matured in one-year period from now – i.e., perfectly concentrated, the debt dispersion equals to 1. Subsequently, a firm with four debt issues with equal face values in separate years exhibits the debt dispersion measure of 4.

Nevertheless, the decision to issue debt might be constrained due to the limit of time that a firm is allowed to borrow. For instance, a firm can only issue bond with the maximum maturity period of five or ten years. This will in turn bias the distribution of debt dispersion in our sample. We follow the alternative measure of debt dispersion postulated by Choi, Hackbarth, and Zechner (2018) by considering the maximum debt maturity. Denoting t_j^{max} the longest maturity of the current debt profile, a "perfectly dispersed" maturity profile shares the same maturity of the observed debt structure. However, a constant fraction of principal, $\frac{1}{t_j^{max}}$, is matured in each year. The authors then defined dispersion of debt maturity by taking the negative value of natural logarithm of the average squared difference between the firm's and the "perfectly dispersed" debt maturity profile:

$$\text{Debt Disperse (time)} = -\ln\left[\frac{1}{t_j^{max}}\sum_{i=1}^{t_j^{max}}\left(w_{i,j} - \frac{1}{t_j^{max}}\right)^2\right] \quad (3)$$

3.1.3 Financial Accounting and Macroeconomics data

To control for firm-level characteristics varying over years, we merge our estimated debt dispersion measure to financial accounting data obtained from Compustat. In particular, we control for: (i) *Asset Tangibility* which is the fraction of Properties, Plant, and & Equipment to Total Assets. We expect that firms with more tangible assets will be able to have more dispersed debt maturity since the managers can collateral fixed assets for loans. In addition, in the case of default, debtholders will have higher protection when firms have high level of asset tangibility (Chiu, King, & Wang, 2021). As a result, we expect this variable positively relates to debt dispersion variable. (ii) *Size* is calculated as the natural logarithm of Total assets. Comparing to small firms, large firms have more likelihood to borrow long-term debt due to high credit quality (Diamond, 1991). In addition, due to potential scrutiny from news coverage, large firms tend to disclose more in terms of both financial and non-financial information to the market, thus enhancing information transparency (Datta, Iskandar-Datta, & Raman, 2005). As a result, we expect that asset size will share a positive relation with debt dispersion maturity. (iii) *Return on Asset (ROA)* is a proxy of profitability.

According to the long-standing trade-off theory, firm optimizes its debt amount by balancing the marginal benefit from interest payments for tax deductibility and marginal cost of default of a dollar debt arising. That follows, firm leverage depends on the marginal interest tax shield and/or marginal cost of default. Betton *et al.* (2008) imply high-profit firms will have higher leverage ratios. Nevertheless, Abel (2017), in a modification of the assumption of debt maturity in trade-off theory, proves that profitability exerts a negative impact on the use of debt. Hence, we leave the agnostic relationship to empirical findings. (iv) *Firm's growth opportunity* is proxied by market-to-book (MTB) value ratio. Myers (1977) suggests that firms with high-growth opportunities tend to have more conflict between bondholders and shareholders, and managers resolve this conflict by managing to issue short-term debt maturity (Barclay & Smith, 1995). Nevertheless, in the event of sharp reduction in growth opportunity, firms tend to lengthen its debt maturity structure (Goyal, Lehn, & Racic, 2002), which is due to high issuance costs and roll-over risk relating to short-term borrowings. Similar to ROA, we do not predict coefficient sign of MTB ratio and debt dispersion maturity. (v) *Credit quality* is measured by the standard deviation of ROA within the previous 5 years, similar to Ben-Nasr, Boubaker, and

Rouatbi (2015). As firms with higher profit volatility will have low credit, debtholders will demand higher compensation taking the form of either higher interest rate or shorter maturity. Hence, we predict that credit quality negatively determines debt maturity; and (vi) *Leverage* is calculated as the percentage of Total debt to Total assets. Given the bilateral relationship between leverage and debt maturity, firm with high level of Financial Leverage tend to issue long-term debt maturity to avoid bankruptcy (Wu *et al.,* 2022). As a result, we expect that the coefficient sign is positive.

One concern using the country-level climate risk is that the index might capture other country characteristics, such as financial market efficiency (Ginglinger & Moreau, 2023). We address this issue by controlling for macroeconomic variables obtained from WorldBank, similar to Huang, Kerstein, and Wang (2018). Poeschl (2023) theoretically and empirically proves that debt maturity is pro-cyclical and positively relate to *GDP growth rate*. In addition, Jungherr *et al.* (2022) show that monetary policy determines debt maturity dispersion by altering roll-over risk and debt overhang problem (Dangl & Zechner, 2021). Hence, we include *inflation rate* as a proxy for the effect of monetary policy on the whole economy. Last, unemployment risk can also affect corporate financial position as Devos and Rahman (2018) show that firms tend to hold more cash in the face of increasing concerns among employees regarding unemployment risk. We thus include *unemployment rate* as final proxy for macroeconomic condition.[3] We winsorise all continuous variables at 1 and 99 level to mitigate the outliers problem.

3.2 Methodology

To identify the impact of climate risk on debt policy, we run the following regression:

$$DM_{it} = \alpha + \beta_1 Climate\_risk_{j,t} + \beta_2 X_{1i,t-1} + \beta_3 X_{2j,t-1} + Fixed - effects + \varepsilon_{it} \quad (4)$$

in which DM_{it} is the measure for debt maturity dispersion. $Climate\_risk_{j,t}$ represents the value of climate change exposure at country level j in year *t*. To control for time-changing firm characteristics, we include *Asset tangibility, Total Assets, ROA, Market-to-book, and earnings volatility (ROA standard deviation)*. $X_{2j,t-1}$ is a vector of macroeconomic characteristics, namely *Financial Leverage, GDP Growth, Inflation, and Unemployment rate*. We lag one-year of firm and macroeconomic variables to mitigate the potential endogeneity. To account for both time-varying and time-invariant characteristics, we include year and firm fixed-effects, and cluster standard errors at firm level.

[3] Similar to Huang, Kerstein, and Wang (2018), we also control for country's level environment from Klerman et al. (2011). Nevertheless, our firm fixed-effects subsumes the coefficient so we do not discuss.

3.3 Descriptive Statistics

Table 1 presents the descriptive statistics of all variables in our analysis. On average, long-term *Climate Risk* index stands at -0.587, which can rise up to -0.392 in 75th percentile. Debt dispersion has a mean and deviation of 1.923 and 1.387, respectively. The median value of debt dispersion is close to its average, minimising the skewness concern. The alternative measure of debt dispersion (time) has higher mean of 2.867 with 75th percentile value of 3.492.

Our sample covers firms with average natural logarithm size of 5.74, 6.6 percent ROA, and 1.78 Market-to-book value ratio. The debt-equity ratio is 1:4, and firm borrow up to 33% of its total capital structure at 75th percentile. The mean and median value of standard deviation of ROA are 4.9 percent and 2.8 percent, indicating that our sample mainly covers high credit-quality firms since the distribution is skewed to the right.

Last, in terms of macroeconomic variables, the average GDP growth rate is 3.84 percent with a standard deviation of 2.98 percent. Inflation rate has the means of 0.72 percent with its 75th percentile value of 1.29 percent. The average value of unemployment rate stands at 5.68 percent with standard deviation of 2.79 percent.

Table 2 presents the correlation matrix of our variables. With the highest correlation coefficient of 0.470 between Total asset and Debt dispersion, and the lowest value of -0.473 between standard deviation of ROA and ROA, there should be no concern that our analysis will be biased due to multicollinearity. A quick look on the coefficients in Table 2 shows that both Total assets and Asset Tangibility positively relate to debt dispersion maturity, similar with our expectation. While ROA and Financial Leverage positively relate to our dependent variable of interest, MTB value shows the opposite sign. In terms of macroeconomic variables, both GDP growth and inflation negatively determine debt maturity dispersion; yet unemployment rate shows a positive sign.

In Table 3, we show the distribution of our firm across different countries. The USA leads the sample with a total number of firm-year of 37,387, accounting for 18.65 percent of the whole sample. China contributes 12.54 percent with 25.085 observations. Third is Australia with 19,676 observations. In terms of climate risk, Singapore has the lowest level of risk (-1.585), followed by Finland and Norway (-1.475, and -1.353, respectively). Countries located in Asian region tend to have higher climate risk. For instance, Bangladesh leads the distribution with a climate risk index of -0.239. The Philippines and Vietnam shares the second and third place with -0.246 and -0.271, respectively. Overall, 16 out of 41 countries have a higher climate risk than the sample average -0.587.

4. Results

4.1 Baseline Result

Table 4 presents our baseline results by regressing debt maturity dispersion against proxy of climate risk using both main and alternative measure of debt dispersion variable estimated according to Equation (2) and (3). The statistically significant coefficient in column (1) indicates that firms with a high exposure to climate risk tend to structure their debt maturity profile in a more dispersed fashion. In particular, firm responses to one standard deviation increase in climate risk by designing its debt maturity 4 percent more dispersed,[4] representing an average of 2 percent increase relative to the mean of debt maturity dispersion.

In order to mitigate the concern that the country economic conditions might endogenously drive our findings, we saturate the model with macroeconomic variables in Column (2). Albeit a small magnitude drops, the statistical significance of coefficient at 1% level (0.126) suggests that weather uncertainty risk deterministically scatter debt maturities into many different time intervals. In Columns (3) and (4), we use the alternative measure of debt dispersed maturity estimated in Equation (3) which assumes a perfectly dispersed debt maturity. The persistent evidence of positive significant of climate risk on the maturity of the debt implies that our findings are unsusceptible to variable construction techniques.

On the other hand, the coefficients of control variables in our analysis offer consistent findings to our prediction. First, firms with high proportion of asset tangibility tend to have more dispersed debt profile due to high collaterals that offer better protection for debtholders in the event of bankruptcy (Berger, Frame, & Ioannidou, 2021). Similar with asset tangibility, larger firm spread out its debt maturity structure over a longer timeframe relative to smaller firms since the former has either a lower level of asymmetric information (Shores, 1990, Deshmukh, 2003) or better credit quality (Allayannis & Simko, 2022). Both market-to-book value and leverage positively determine debt maturity structure. While high-growth firms choose to issue long-term debt due to high issuance cost and rollover risk related to short-term debt (Goyal, Lehn, & Racic, 2002) in the former; highly leveraged firms have long debt maturity according to liquidity risk hypothesis (Dang, 2010) in the latter.

Return on asset, on the other hand, has a negative impact on debt dispersion maturity,

[4] 0.144*0.278 = 4%

meaning that higher profitable firms have a more concentrated debt. Documenting the same relationship, Lemma, and Negash (2012) contemplate that according to signalling theory, only profitable firms choose to issue short-term debt as they believe that they are able to refinance in opportunity times, which bad firms cannot imitate. In terms of macroeconomics, we provide consistent results with that of Poeschl (2023) when documenting a positive relationship between GPD growth rate and debt maturity. Last, higher inflation rate leads to shorter debt maturity profile since firms are more exposed to roll-over risk during high interest rate period.

4.2 Result Robustness

We next present our result robustness using different sample exclusion criteria and alternative measures of climate risk in **Table 5**. Given the widespread of firms located in the US (18.65 percent), there is concern that these firms might drive our analysis. We hence exclude US-based firms in Panel A Column (1). Next, EU countries have been adopting cap-and-trade carbon tax since 2005 to address global warming concern. Such differences in effort curving carbon emission exhibited by EU-based firms might lead to a more concentrating effect of climate risk on debt maturity in firms headquartered in EU area. We thus drop all observations with headquarters in either US or EU in Column (2). Last, firms located in more frequently-hit disaster zones might exert stronger effect. We thus prove the of relationship prevalence across all firms by subsequently dropping the top five highest climate risk countries in our sample in Column (3). All the regressions include both firm and country time-varying attributes. Across all three columns, we still document that climate risk positively predicts the dispersion of debt maturity profile, in which the coefficient when dropping top five highest climate risk countries (0.211) has a 46 percent larger magnitude relative to baseline result (0.144), suggesting that the effect of weather uncertainty on debt maturity, rather than concentrating on any countries, are ubiquitous in all areas.

Last but not least, building off discussion of climate risk disclosed in 10-Ks, Berkman et al. (2024) empirically document the explanatory power of their constructed measures on firm valuation. Focusing on the U.S. sample, we proceed by merging Berkman et al.'s proxy to our debt maturity, and performing the analysis using the same fixed-effects and standard errors double-clustered at firm-level. Column (1) in Panel B reveals that the more frequently firm discloses climate risk in its 10-K, the more dispersed its debt maturity. In addition to firm fixed-effects, Column (3) further includes industry-year fixed-effects to account for any events/policies that has industry-wide effect in the U.S., the coefficient magnitude significantly persists.[5] To mitigate potential outliner concern, we log-transform the number of words in Column (2) and (4), and still observe the consistent results.

As mentioned in Ginglinger, and Moreau (2023), one disadvantage of using country climate risk (i.e., GermanWatch) is that the measure might capture some country characteristics. Using the same measure of climate risk, Huang et at. (2018) and Ozkan, Temiz, and Yildiz (2022) allow their observations to respond against climate risk varying in each industry over time. We address this concern in two ways. First, we control for economic conditions by including GDP growth rate, inflation rate, and the unemployment rate as discussed in the methodology section. Second, to limit our analysis to firm-level variation, we control for time-invariant firm characteristics by including firm-fixed effects, in addition to year-fixed effects to account for (industry) time-varying events.[6] Hence, our identification strategy offers a more granular analysis that boils down to firm-level when exposing to different climate risk level. Given the prevalence of climate risk on debt maturity profile in different variable proxies and sample construction techniques, we provide evidence how shifts in long-term weather patterns determine corporate debt maturity design.

5. Mechanisms

So far, our analysis documents how unconventional source of risk contributes to corporate debt policy by showing the positive effect of climate risk on debt maturity structure. In this section, we attribute our findings to firm-level financial constraint and capital market efficiency mechanism via which climate risk influences debt maturity. In particular, we run the following regression:

$$DM_{it} = \alpha + \gamma_1 Climate\_risk_{j,t} * Channel + \gamma_2 Climate_{risk\,j,t} + \gamma_3 Channel + Controls + Fixed - effects + \varepsilon_{it} \quad (5)$$

5.1. Financial Health Condition

5.1.1. Dividend

Guay and Harford (2000) and Jagannathan, Stephens, and Weisbach (2000) empirically provide evidence suggesting that firms, in response to an improvement of financial health condition taking the form of excess of cashflow from operation, choose either to distribute cash dividend

[5] The number of word count is divided by 100 for presentation.
[6] To make sure that we consider any country characteristics varying over years in our analysis, we replace our cluster from firm to country-year in Appendix B – Table 1. We still observe qualitatively the same results showing that climate risk exerts a positive effect on debt dispersion maturity.

or repurchase stocks. Cleary (1999) finds that firms tend to increase payouts during stable and increasing profits. In addition, both WW and KZ index take dividend into account upon estimating firm's financial constraint status. The popularity of payouts suggests that dividend serves as a proxy for firm's financial health condition.

Hitherto, our baseline evidence supports our hypothesis that since climate uncertainty increases rollover risk, firms located in disaster-prone regions purposedly structure the debt maturity profile in a more dispersed fashion. Using a Japanese-listed firm sample, Iwaki and Saito (2022) find that in response to an increasing rollover risk environment, bank-dependent firms that financially constrained firms are more reluctant to pay dividends taking the form of either payouts or share repurchases. Hence, using dividend as a proxy for firm's financial constraint condition, we conjecture that firms choose not to pay dividend due to an increasing rollover risk caused by climate uncertainty. Speaking differently, shifts in long-term weather patterns worsen firm's financial health by increasing the risk of being unable to refinance upcoming debts. That follows, firm responses to the elevating rollover risk by issuing debts maturing in different time bins, i.e., dispersed.

Denoting an indicator variable, *Dividend*, to take the value of 1 if the firm does not pay dividend in year *t*, we interact *Dividend* to our explanatory variable of interest to estimate Equation (4). Columns (1) **of Table 6** includes time-varying firm characteristics, and Column (2) additionally accounts for macroeconomic condition with the fixed-effects similar to baseline Table 4. The significance of interaction term means that one standard deviation increase in climate risk leads to 43 percent more dispersion of debt maturity in non-payout firms.[7] Since climate risk elevates rollover risk, our results indicate that financially constrained firms located in disaster-prone areas tend to structure their debt profile to mature in different time intervals.

5.1.2. Financial Constraints

The next measure for financial constraint is KZ index. Developed by Kaplan and Zingales (1997), the index has been popularly used in prior studies (Lamont, Polk, & Saaá-Requejo, 2001, Li, 2011, Chen & Wang, 2012), in which firm with higher KZ value has more difficulty in obtaining external fundings for operations and investments. Assigning KZ to value of 1 if the firm's KZ index is greater than the sample median, and 0 otherwise, we interact the index dummy with climate risk measure and present the results in Columns (3) and (4) at **Table 6**.

[7] (0.257*0.278)/0.167 = 43%. In the untabular test, the results are the same if we use total dividend.

Following the above line of argument, as climate risk represents a source of uncertainty in the future, firm will manage its risk profile by issuing debts whose maturities scatter over different years to reduce rollover risk, and we expect that the effect will be more pronounced in financially constrained firms. Column (3) and (4) confirm our conjecture. In particular, comparing two firms exposed to the same level of climate risk (i.e., located in the same country), Column (3) show that firm with poorer financial health has a 20 percent higher debt maturity dispersion (0.068+0.066 = 0.134), comparing to non-constrained firm (0.111). The results persist with the same magnitude when we account for macroeconomic conditions in Column (4).

5.2 Capital Market Openness

So far, we have shown that firm financial health channels the effect of climate uncertainty on the dispersion of debt maturity. We next point to the second mechanism, namely capital market openness, via which shifts in long-term weather patterns alters the design of debt maturity. In particular, firms are better off in an open market since they are able to access to external funds to meet financial needs (Braun, & Raddatz, 2005). In addition, international trade facilitates financial market development (Beck, 2002), which leads to more financial availability. This represents an increase in supply of financial resources.

On the other hand, Bouvard, Chaigneau, and Motta (2015) show that when being exposed to negative aggregate shock, banks increase disclosure to enhance financial stability by reducing rollover risk. In the same line of argument, since climate uncertainty tends to aggravate rollover risk, firms might exhibit a responsive behaviour of issuing debts maturing in different time intervals, given the access of financial slack availability in an open market. We therefore expect that firm located in more open economy will have more opportunities to dispersedly structure its debt maturity when climate risk is high.

Proxying capital market openness by assigning an indicative variable of *Trade-to-GDP* to take value of 1 if the country's proportion of trade (import plus export) to total GDP is greater than the world median, and 0 otherwise, we interact the *Trade-to-GDP* to Climate risk, and present the results in **Table 7**. All of the regressions include the firm time-varying and macroeconomic controls and fixed-effects similar to baseline specification.

The statistical significance of both *Trade-to-GDP* and interaction coefficients indicates that firm resided in more open countries is able to design its debt issuances maturing at difference time frames when facing high climate risk. In particular, firms in high-trade openness countries have their debt structured more dispersed than their cohort in less trade openness. Economically, Column (1) translates one standard deviation increase in climate risk to an approximate increase of 17 percent of debt dispersed relative to low trade-open economy.[8] The statistical significance persists when accounting for other macroeconomic conditions in Column (2). We hence provide the evidence suggesting the channelling role of economic openness on firm's debt maturity when the risk of natural disasters occurrence is high.

6. Addressing Endogeneity: Difference-in-Differences Analysis

The above results provide evidence supporting our notion that climate risk leads firm to actively structure its debt maturity portfolio in a more dispersed fashion. Nevertheless, one potential endogeneity that potentially masks our finding is that our analysis might only picks up firm's response towards climate risk in countries with high exposure to natural disasters. Put differently, firms located in high climate risk countries tends to have more dispersed debt maturity relative to their cohort located in low climate risk areas. To address this issue, we design a difference-in-difference analysis, in which we choose the year 2015 to define pre- and post-period.

There are two reasons postulating the choice of 2015. First, the Paris Agreement was signed by 196 countries in 2015, marking the joint supranational effort in addressing climate change. Second, the Financial Stability Board elucidated the carbon disclosure landscape by establishing the Task Force on Climate-Related Financial Disclosures (TCFD) in 2015. Accordingly, TCFD provides framework for firms to assess and determine both challenges and opportunities, given the increasing climate change uncertainty. Hence, the year 2015 marks an important breakthrough in both mitigation effort and firm disclosure relating to climate change. This choice is also consistent with the work of Ginglinger and Moreau (2023). We then estimate the following equation:

$$DM_{it} = \alpha + \beta_1 Treat_{ijt} + \beta_2 Post_{ijt} + \beta_3 Treat_{ijt} * Post_{ijt} + Controls + \varepsilon_{it} \qquad (6)$$

in which *Treat* is an indicator variable taking the value of 1 for firms located in countries that have a climate risk index higher than the that worldwide median, and 0 otherwise. *Post* is a dummy value that is assigned to 1 for the post-2015 period, and 0 for the rest. Thus, our difference-in-differences setting compares the difference of debt maturity dispersion in high- (*Treat = 1*) and low-climate risk firms (*Treat = 0*) during pre- (*Post = 0*) and post-2015 (*Post*

[8] (0.278*0.153)/0.256 = 16.6%

= *1*) period.

6.1. Difference-in-Differences Results

In addition to the main purpose of reducing annual greenhouse gas emission, both Paris Agreement and Task Force on Climate-Related Financial Disclosures are calling for more attention from various stakeholders in factoring climate uncertainty in designing financial products, e.g., debt issuances. We thus expect the rising awareness of climate change in post-2015 period will affect firm's financing decision of issuing different debt maturities.

To be consistent with our baseline analysis, we control for time-varying firm's financial and macroeconomics conditions, in addition to time-invariant characteristics with firm fixed-effects in all our regression.[9] Results in **Table 8** confirm our findings. In particular, we continue to find statistical significance of interaction terms (*Treat* * *Post*) in Column (1) and (2) when using the main debt dispersion maturity variable, or the alternative measure in Columns (3) and (4) at 1% confidence level. The consistent positive coefficient of the explanatory variable proves that climate risk positively determines firm's debt maturity dispersion profile, alleviating the endogeneity concern in our analysis. [10]

6.2. Pre-trend Assumption Validation

While it is plausible to expect that the adoption of either Paris Agreement or Task Force on Climate-Related Financial Disclosures lies beyond firms' control, DiD analysis requires that control and treatment group exhibit behave similarly to each other prior to the event. Speaking differently, there is no pre-trend difference between the two groups in terms of debt dispersion. We validate this assumption by plotting the interaction term of *Treat* and yearly dummies. **Figure 1** confirms our assumption.

Basing off year (t-1) for comparison purpose, we document that there is no diverging trend in the pre-2015 period, which signifies that both control and treatment group move accordingly to each other. On the other hand, a significant jump in year (0) relative to year (t-1) indicates that both group starts behaving differently in terms of debt maturity after 2015. The diverging trend continuing thereafter with a larger magnitude justifies our choice capturing the year from

[9] Similar to baseline, we cluster our standard errors at firm level. However, when clustering standard errors at country-year level to account for any systematic change across the whole country, the results in **Appendix B Table 2** still show that the interaction term is significant at 1% for the main debt dispersion variable.
[10] Using quantile analysis in **Appendix B Table 3**, we also document the non-linear relation since firms located in higher climate risk tend to have more dispersed debt maturity.

which the behavior difference emerges. In combination with Table 8, we therefore provide evidence suggesting that weather uncertainty influences financing decisions by leading firm to issue more dispersed debt maturities.

7. Conclusion

In this study, we provide evidence of how unconventional source of risk determines decision on structuring debt maturity profiles. In particular, we find that managers of firms located in areas with high frequency of suffering natural hazards taking the form of storms, floods, and extreme temperature, etc. tend to prefer issuing more dispersed debt maturities. The underlying motive attributes to the accumulation of financial slack in the face of uncertainty enhancement, and to avoid renegotiation and roll-over risk when using short-term debt. Consistent with our expectation, climate risk exerts a positive effect on debt maturity profile. Our findings supplement to that of Huang et at (2017) by showing that firms take precautionary action towards the uncontrollable source of uncertainty.

To mitigate the concern that out climate risk measure might take up some country characteristics, we include time-varying macroeconomics, in addition to firm, controls in a dense fixed-effects system. Our finding persistency in a difference-in-difference design addresses the potential endogeneity issue that there might be underlying differences in firm characteristics when locating in areas with varying climate risk exposure. Last, we point to both financial heath and capital market openness channelling the effect of weather risk to the dispersion of debt maturity profiles.

This study offers practical implications for both government bodies and firms navigating the escalating threat of climate risk. The paper focuses on the need for governments to implement appropriate policies that support firms in adapting to the heightened uncertainty associated with evolving weather patterns. Given the global nature of climate change's consequences, international cooperation is crucial in this endeavour. The government should seize the initiative to reduce debt issuance costs for firms operating in areas frequently impacted by natural disasters. This would enhance firms' adaptive capacity by enabling them to optimise their debt structure portfolios. Such policies could be implemented through tax relief or fixed/capped fee on debt issuance.

Given the increasing threats from natural disasters due to climate change, firms are more prone to greater operational disruption even in regions with previously low climate risk. As a result, managers should take into account how weather-related events might distort daily operation, which subsequently determines to optimally design debt maturity profiles. As the severity of climate-related risks escalates, firms that prioritise strategies aimed at dispersing their debt maturity profiles may be better equipped to safeguard their financial stability. This advantage stems from their enhanced capacity to refinance maturing debt obligations within external markets. This strategy mitigates the risk of being forced to either forego potential investment opportunities or liquidate assets inefficiently in order to meet debt repayment obligations. This approach holds particular significance for firms facing financial constraints and those operating in developing or underdeveloped economic regions.

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Figure 1: Difference-in-Differences Dynamics

Figure 1 presents the dynamics of *Post#Treat* interaction, in which *Post* is the yearly dummies that take values of 1 for each year, and 0 otherwise.

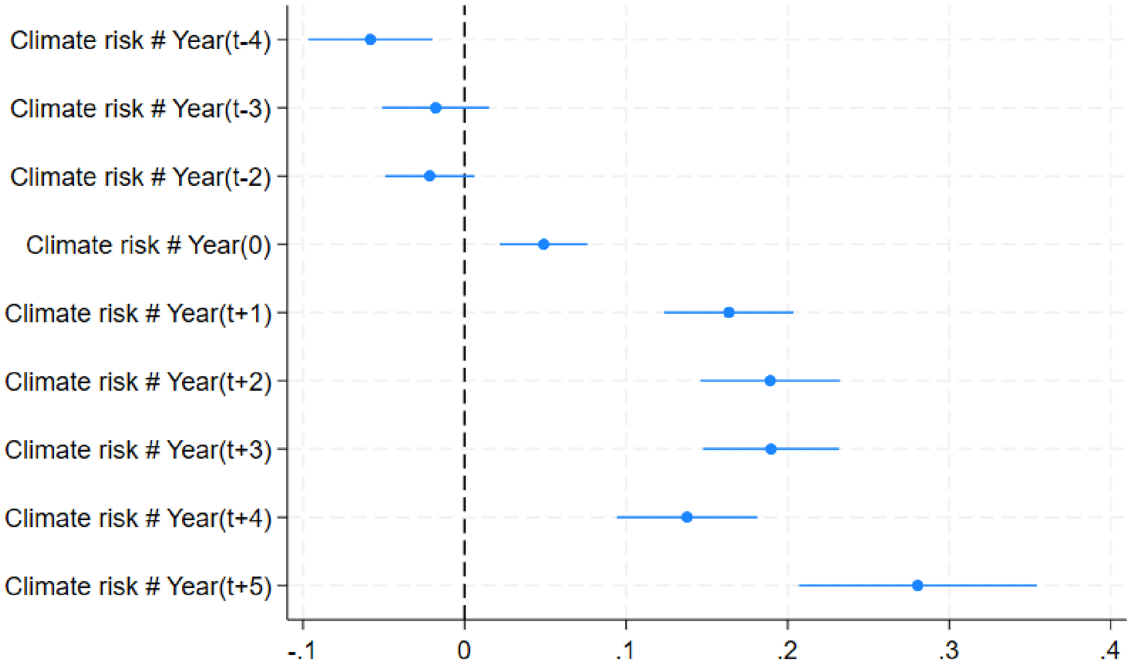

Table 1. Descriptive Statistics

This table reports the descriptive statistics of the study.

Variable	N	Mean	SD	25th	Median	75th
Climate Risk	199,981	-0.587	0.278	-0.727	-0.520	-0.392
Debt Dispersion	199,981	1.923	1.386	1.000	1.414	2.195
Debt Dispersion (time)	199,981	2.867	1.289	1.826	2.635	3.492
Asset Tangibility	199,981	0.301	0.238	0.095	0.259	0.462
Total Assets	199,981	5.738	2.179	4.293	5.678	7.138
Return on Assets	199,981	0.066	0.132	0.031	0.078	0.126
Market-to-book value	199,981	1.780	2.065	0.945	1.203	1.793
Standard Dev. ROA	199,981	0.049	0.065	0.014	0.028	0.054
Financial Leverage	199,981	0.220	0.186	0.068	0.177	0.332
GDP growth	199,981	3.838	2.986	1.842	2.907	6.345
Inflation	199,981	0.723	0.993	0.382	0.830	1.292
Unemployment rate	199,981	5.677	2.789	4.000	4.750	7.650

Table 2: Correlation

This table presents the correlation matrix of independent variables in the study. All variables are winsorised at 1% on both tails to address outliers problem.

Variables	Debt Dispersion	Asset Tangibility	Total Assets	ROA	MTB	S.D. ROA	Financial Leverage	GDP growth	Inflation	Unemployment rate
Debt Dispersion	1.000									
Asset Tangibility	0.090*	1.000								
Total Assets	0.470*	0.000	1.000							
ROA	0.100*	0.124*	0.288*	1.000						
MTB value	-0.044*	-0.040*	-0.227*	-0.132*	1.000					
S.D. ROA	-0.167*	-0.034*	-0.375*	-0.473*	0.231*	1.000				
Financial Leverage	0.151*	0.263*	0.072*	-0.044*	-0.302*	-0.079*	1.000			
GDP growth	-0.111*	0.140*	-0.149*	0.042*	0.084*	-0.016*	0.009*	1.000		
Inflation	-0.038*	0.123*	-0.147*	0.042*	0.030*	0.051*	0.127*	0.366*	1.000	
Unemployment rate	0.046*	-0.067*	0.017*	0.016*	0.016*	0.039*	0.015*	-0.115*	0.142*	1.000

Table 3: Climate Risk Distribution

This table shows the distribution of observation across countries, and corresponding county-level climate risk .

County	Number of firms	Percentage	Cumulative Percentage	Climate Risk
AUS	8,437	4.22	4.22	-0.538
BEL	803	0.40	4.62	-0.774
BGD	964	0.48	5.10	-0.239
BRA	2,745	1.37	6.48	-0.834
CAN	1,699	0.85	7.32	-0.903
CHE	1,113	0.56	7.88	-0.423
CHL	1,619	0.81	8.69	-0.917
CHN	25,085	12.54	21.23	-0.454
DEU	4,410	2.21	23.44	-0.401
DNK	772	0.39	23.83	-1.085
ESP	972	0.49	24.31	-0.482
FIN	929	0.46	24.78	-1.475
FRA	5,789	2.89	27.67	-0.382
GBR	9,798	4.90	32.57	-0.684
GRC	1,091	0.55	33.12	-0.713
IDN	3,768	1.88	35.00	-0.627
IND	18,436	9.22	44.22	-0.369
IRL	469	0.23	44.45	-1.103
ISR	1,808	0.90	45.36	-1.157
ITA	2,571	1.29	46.64	-0.389
JPN	19,676	9.84	56.48	-0.765
KOR	10,575	5.29	61.77	-0.676
LKA	1,593	0.80	62.57	-0.629
MEX	1,096	0.55	63.11	-0.549
MYS	7,853	3.93	67.04	-0.828
NGA	585	0.29	67.33	-1.083
NLD	1,382	0.69	68.03	-0.681
NOR	1,479	0.74	68.77	-1.353
NZL	979	0.49	69.25	-0.810
PAK	2,749	1.37	70.63	-0.343
PER	770	0.39	71.01	-0.610
PHL	1,444	0.72	71.74	-0.246
POL	3,172	1.59	73.32	-0.690
RUS	1,704	0.85	74.17	-0.490
SAU	699	0.35	74.52	-1.140
SGP	4,233	2.12	76.64	-1.585
SWE	1,614	0.81	77.45	-1.197
THA	3,935	1.97	79.42	-0.404
USA	37,287	18.65	98.06	-0.410
VNM	1,732	0.87	98.93	-0.271
ZAF	2,146	1.07	100.00	-0.803
Total	**199,981**	**100.00**		**-0.587**

Table 4: Baseline results

This table present the baseline results. The dependent variable in Column (1) and (2) is firm debt dispersion, and Debt Dispersion (time) in Column (3) an (4). Climate risk is long-term country-level risk according to Germanwatch. All variables are winsorised at 1% on both tails. Firm and macro control variables are lagged 1-year. Standard errors are clustered at firm level. *, **, *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively. Variables are defined in Appendix A.

Baseline Results	**(1)**	**(2)**	**(3)**	**(4)**
	Debt Dispersion		**Debt Dispersion (time)**	
Climate Risk	0.144***	0.126***	0.071*	0.075*
	(0.038)	(0.038)	(0.042)	(0.042)
Asset Tangibility	0.142***	0.131***	0.085**	0.083**
	(0.034)	(0.034)	(0.041)	(0.041)
Total Assets	0.172***	0.172***	0.083***	0.082***
	(0.007)	(0.008)	(0.008)	(0.008)
Return on Assets	-0.093***	-0.095***	-0.121**	-0.122**
	(0.027)	(0.027)	(0.051)	(0.051)
Market-to-book value	0.024***	0.024***	0.012***	0.011***
	(0.002)	(0.002)	(0.003)	(0.003)
Standard Dev. ROA	-0.078	-0.081	-0.232**	-0.225**
	(0.060)	(0.060)	(0.102)	(0.102)
Financial Leverage	0.555***	0.572***	0.328***	0.325***
	(0.028)	(0.028)	(0.034)	(0.035)
GDP growth		0.014***		0.001
		(0.002)		(0.002)
Inflation		-0.017***		0.007*
		(0.003)		(0.004)
Unemployment rate		0.002		-0.014***
		(0.003)		(0.003)
Firm FEs	Y	Y	Y	Y
Year FEs	Y	Y	Y	Y
Clustering at Firm	Y	Y	Y	Y
Adj-R2	0.698	0.698	0.406	0.407
N	199,981	199,981	199,981	199,981

Table 5: Result Robustness

This table present the baseline results. The dependent variable in Column (1) and (2) is firm debt dispersion, and Debt Dispersion (time) in Column (3) an (4). Climate risk is long-term country-level risk according to Germanwatch. All variables are winsorised at 1% on both tails. Firm and macro control variables are lagged 1-year. Standard errors are clustered at firm level. *, **, *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively. Variables are defined in Appendix A.

Panel A: Robustness	**Debt Dispersion**		
	(1)	**(2)**	**(3)**
	Drop U.S.	**Drop U.S. & EU**	**Drop Top 5 Highest Climate Risk**
Climate Risk	0.113***	0.076*	0.211***
	(0.041)	(0.042)	(0.042)
Firm Controls	Y	Y	Y
Macro Controls	Y	Y	Y
Firm FEs	Y	Y	Y
Year FEs	Y	Y	Y
Clustering at Firm	Y	Y	Y
Adj-R2	0.630	0.601	0.712
N	162,694	128,922	189,324

Panel B: Firm-Climate Risk	**Debt Dispersion**			
	(1)	**(2)**	**(3)**	**(4)**
No. of Words	0.005**		0.005*	
	(0.003)		(0.003)	
Ln(No. of words)		0.021**		0.022**
		(0.010)		(0.011)
Firm Controls	Y	Y	Y	Y
Macro Controls	Y	Y	Y	Y
Firm FEs	Y	Y	Y	Y
Year FEs	Y	Y		
Industry-Year FEs			Y	Y
Clustering at Firm	Y	Y	Y	Y
Adj-R2	0.858	0.858	0.858	0.858
N	15,782	15,782	14,967	14,967

Table 6: Financial Health Condition

This table presents how financial health condition channels the effect of climate risk on debt maturity dispersion. *Dividend* takes value of 1 if firm does not pay dividend in year t, and 0 otherwise. *KZ index* takes value of 1 if firm's KZ index is greater than median value, and 0 otherwise. Standard errors are clustered at firm level. *, **, *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively. Variables are defined in Appendix A.

	Debt Dispersion			
	(1)	**(2)**	**(3)**	**(4)**
Climate Risk	0.008	-0.006	0.111***	0.092**
	(0.041)	(0.041)	(0.043)	(0.042)
Dividend	0.167***	0.162***		
	(0.018)	(0.018)		
Climate Risk # Dividend	0.257***	0.251***		
	(0.025)	(0.025)		
KZ Index			0.068***	0.066***
			(0.020)	(0.020)
Climate Risk # KZ Index			0.066**	0.068**
			(0.030)	(0.030)
Firm Controls	Y	Y	Y	Y
Macro Controls	N	Y	N	Y
Firm FEs	Y	Y	Y	Y
Year FEs	Y	Y	Y	Y
Clustering at Firm	Y	Y	Y	Y
Adj-R2	0.698	0.698	0.698	0.698
N	199,955	199,955	199,955	199,955

Table 7: Capital Market Openness

This table presents how Capital market efficiency channels the effect of climate risk on debt maturity dispersion. *Trade-to-GDP* takes value of 1 if country has greater value than sample's population, and 0 otherwise, Standard errors are clustered at firm level. *, **, *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively. Variables are defined in Appendix A.

	Debt Dispersion	
	(1)	**(2)**
Climate Risk	-0.037	-0.083
	(0.053)	(0.054)
Trade-to-GDP	0.256***	0.275***
	(0.029)	(0.030)
Climate Risk # Trade-to-GDP	0.153***	0.188***
	(0.059)	(0.060)
Firm Controls	Y	Y
Macro Controls	N	Y
Firm FEs	Y	Y
Year FEs	Y	Y
Clustering at Firm	Y	Y
Adj-R2	0.699	0.699
N	199,955	199,955

Table 8: Difference-in-Difference Analysis

This table presents the results of difference-in-difference analysis. *Post* takes value of 1 if year is greater or equal 2015, and 0 otherwise. *Treat* is assigned value of 1 if firm's climate risk is greater than median value, and 0 otherwise,. Standard errors are clustered at firm level. *, **, *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively. Variables are defined in Appendix A.

	(1)	**(2)**	**(3)**	**(4)**
	Debt Dispersion		**Debt Dispersion (Time)**	
Treat # Post	0.219***	0.213***	0.043***	0.048***
	(0.017)	(0.017)	(0.016)	(0.016)
Treat	0.051***	0.047***	0.102***	0.102***
	(0.016)	(0.016)	(0.018)	(0.018)
Asset Tangibility	0.107***	0.104***	0.061	0.062
	(0.034)	(0.034)	(0.041)	(0.041)
Total Assets	0.177***	0.178***	0.091***	0.089***
	(0.008)	(0.008)	(0.008)	(0.008)
Return on Assets	-0.099***	-0.101***	-0.127**	-0.128**
	(0.027)	(0.027)	(0.051)	(0.051)
Market-to-book value	0.025***	0.025***	0.013***	0.013***
	(0.002)	(0.002)	(0.003)	(0.003)
Standard Dev. ROA	-0.102*	-0.105*	-0.241**	-0.234**
	(0.060)	(0.060)	(0.102)	(0.102)
Financial Leverage	0.554***	0.562***	0.324***	0.317***
	(0.028)	(0.028)	(0.034)	(0.035)
GDP growth		0.007***		-0.003
		(0.002)		(0.002)
Inflation		-0.003		0.009**
		(0.003)		(0.004)
Unemployment rate		0.005		-0.014***
		(0.003)		(0.003)
Firm FEs	Y	Y	Y	Y
Year FEs	Y	Y	Y	Y
Clustering at Firm	Y	Y	Y	Y
Adj-R2	0.699	0.699	0.407	0.407
N	199,981	199,981	199,981	199,981

Appendix B: Supplementary Tables

Table 1: Baseline results

This table present the baseline results. The dependent variable in Column (1) and (2) is firm debt dispersion, and Debt Dispersion (time) in Column (3) an (4). Climate risk is long-term country-level risk according to Germanwatch. All variables are winsorised at 1% on both tails. Firm and macro control variables are lagged 1-year. Standard errors are clustered at Country-Year level. *, **, *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively. Variables are defined in Appendix A.

	(1)	(2)	(3)	(4)
	Debt Dispersion		**Debt Dispersion (time)**	
Climate Risk	0.144*	0.126	0.071	0.075
	(0.083)	(0.080)	(0.073)	(0.073)
Asset Tangibility	0.142***	0.131***	0.085**	0.083**
	(0.032)	(0.031)	(0.036)	(0.035)
Total Assets	0.172***	0.172***	0.083***	0.082***
	(0.015)	(0.014)	(0.013)	(0.013)
Return on Assets	-0.093***	-0.095***	-0.121**	-0.122**
	(0.027)	(0.027)	(0.051)	(0.051)
Market-to-book value	0.024***	0.024***	0.012***	0.011***
	(0.004)	(0.004)	(0.004)	(0.004)
Standard Dev. ROA	-0.078	-0.081	-0.232**	-0.225**
	(0.052)	(0.053)	(0.090)	(0.089)
Financial Leverage	0.555***	0.572***	0.328***	0.325***
	(0.038)	(0.038)	(0.041)	(0.040)
GDP growth		0.014**		0.001
		(0.006)		(0.006)
Inflation		-0.017**		0.007
		(0.008)		(0.008)
Unemployment rate		0.002		-0.014**
		(0.005)		(0.007)
Firm FEs	Y	Y	Y	Y
Year FEs	Y	Y	Y	Y
Clustering at Country-Year	Y	Y	Y	Y
Adj-R2	0.698	0.698	0.406	0.407
N	199,981	199,981	199,981	199,981

Table 2: Difference-in-Difference Analysis

This table presents the results of difference-in-difference analysis. *Post* takes value of 1 if year is greater or equal 2015, and 0 otherwise. *Treat* is assigned value of 1 if firm's climate risk is greater than median value, and 0 otherwise,. Standard errors are clustered at Country-Year level. *, **, *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively. Variables are defined in Appendix A.

	(1)	(2)	(3)	(4)
	Debt Dispersion		**Debt Dispersion (Time)**	
Treat # Post	0.219***	0.213***	0.043	0.048
	(0.026)	(0.028)	(0.034)	(0.035)
Treat	0.051	0.047	0.102***	0.102***
	(0.042)	(0.040)	(0.039)	(0.038)
Asset Tangibility	0.107***	0.104***	0.061*	0.062*
	(0.028)	(0.027)	(0.035)	(0.035)
Total Assets	0.177***	0.178***	0.091***	0.089***
	(0.013)	(0.013)	(0.012)	(0.012)
Return on Assets	-0.099***	-0.101***	-0.127**	-0.128**
	(0.026)	(0.027)	(0.051)	(0.051)
Market-to-book value	0.025***	0.025***	0.013***	0.013***
	(0.004)	(0.004)	(0.004)	(0.004)
Standard Dev. ROA	-0.102*	-0.105*	-0.241***	-0.234***
	(0.054)	(0.054)	(0.091)	(0.089)
Financial Leverage	0.554***	0.562***	0.324***	0.317***
	(0.035)	(0.036)	(0.040)	(0.039)
GDP growth		0.007		-0.003
		(0.005)		(0.005)
Inflation		-0.003		0.009
		(0.007)		(0.008)
Unemployment rate		0.005		-0.014**
		(0.004)		(0.006)
Firm FEs	Y	Y	Y	Y
Year FEs	Y	Y	Y	Y
Clustering at Country-Year	Y	Y	Y	Y
Adj-R2	0.699	0.699	0.407	0.407
N	199,981	199,981	199,981	199,981

Table 3: Quantile Difference-in-Difference Analysis

This table presents the results of difference-in-difference analysis. *Post* takes value of 1 if year is greater or equal 2015, and 0 otherwise. *Treat* is a dummy variable assigned value of 1 if firm's climate risk is greater than median value, and 0 otherwise. Standard errors are clustered at country-year level. *, **, *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively. Variables are defined in Appendix A.

	(1)	**(2)**	**(3)**	**(4)**
	Debt Dispersion		**Debt Dispersion (Time)**	
Dummy Q2	0.013	0.013	0.019	0.020
	(0.022)	(0.022)	(0.024)	(0.024)
Dummy Q2 # post	-0.090***	-0.092***	-0.090**	-0.091**
	(0.033)	(0.033)	(0.036)	(0.036)
Dummy Q3	0.053	0.055	0.095**	0.086*
	(0.035)	(0.035)	(0.048)	(0.046)
Dummy Q3 # post	0.157***	0.145***	-0.043	-0.038
	(0.033)	(0.034)	(0.046)	(0.049)
Dummy Q4	0.033	0.034	0.015	0.008
	(0.042)	(0.040)	(0.049)	(0.049)
Dummy Q4 # post	0.205***	0.192***	0.091**	0.104**
	(0.040)	(0.042)	(0.043)	(0.044)
Asset Tangibility	0.105***	0.101***	0.067*	0.068*
	(0.028)	(0.027)	(0.036)	(0.035)
Total Assets	0.182***	0.182***	0.091***	0.089***
	(0.013)	(0.013)	(0.012)	(0.011)
Return on Assets	-0.097***	-0.098***	-0.121**	-0.120**
	(0.026)	(0.027)	(0.051)	(0.051)
Market-to-book value	0.026***	0.026***	0.013***	0.013***
	(0.004)	(0.004)	(0.004)	(0.004)
Standard Dev. ROA	-0.099*	-0.101*	-0.230**	-0.223**
	(0.054)	(0.054)	(0.091)	(0.090)
Financial Leverage	0.547***	0.555***	0.321***	0.316***
	(0.035)	(0.035)	(0.040)	(0.039)
GDP growth		0.006		-0.003
		(0.005)		(0.006)
Inflation		-0.008		0.006
		(0.007)		(0.009)
Unemployment rate		0.004		-0.014**
		(0.004)		(0.006)
Firm FEs	Y	Y	Y	Y
Year FEs	Y	Y	Y	Y
Clustering at Country-Year	Y	Y	Y	Y
Adj-R2	0.699	0.699	0.407	0.407
N	199,981	199,981	199,981	199,981

Quantile Difference-in-Difference Analysis

We then move on to identifying whether the different intensity of climate risk has heterogeneous effects on debt maturity structure. In light of agency theory, we expect that firms exposed to higher level of climate risk will be likely to adopt dispersed maturity profiles. Mimicking the DiD analysis but replacing the convention of *Treat* variable, we let an indicator variable take the value of 1 according to four quantiles of the firm's climate risk, in which 1 is the lowest and 4 indicates the highest climate risk. We then interact this indicator variable with *Post* and present our results in Table 6.

The results demonstrate that climate risk has a non-linear effect on corporate debt maturity structure. We use our main and alternative measure of debt dispersion maturity in Columns (1) and (2), and Columns (3) and (4), respectively. Dropping Quantile 1 to avoid the multicollinearity, we find that firms located in higher climate risk tend to have more dispersed debt maturity. In particular, Column (2) shows that the coefficient sign of interaction switches sign from negative to positive value when moving from Quantile 2 to Quantile 3 in terms of climate risk. In addition, the magnitude of *Post * Quantile 4* is 30 percent larger than that of Quantile 3, consistent with our expectation.[11]

Using the alternative measure of debt maturity in Columns (3) and (4), the documented effect of climate risk on debt profiles appears "slower" as the coefficient sign switches when moving from Quantile 3 to Quantile 4 of climate risk. Our findings persist when accounting for macroeconomic conditions in Columns (2) and (4), mitigating the concern the use of country-level risk measure.

[11] The results when clustering standard errors at country-year in Appendix Table 3 are consistent with our main table.