Climate risk and capital structure*

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JEL Classification: G18, G2, G32, Q54
Keywords: Capital structure, leverage, credit rating, climate risk, natural disasters

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1. Introduction

Compared to the temperature in preindustrial times, the world has warmed by 1°C on average. Global temperatures are still trending upward, with an increase of 2 to 4° expected by 2100. Climate change has dramatic effects in the forms of sea level rise and weather-related natural catastrophes, such as droughts, storms, heat waves, floods, and heavy rainfalls (Stern, 2008). The consequences of climate risks for investors are difficult to assess and to hedge.[1] In 2015, Mark Carney, the former chair of the Financial Stability Board (FSB), stated that investors face potentially substantial losses from climate change consequences in terms of physical risks, liability risks and transition risks, which may be an issue for financial stability.[2] These climate risks may lead to a reassessment of the value of a large range of firms' assets (plants, property, and equipment) and to increased operational costs, such as relocation costs and insurance costs, resulting in lower profits and reduced repayment capacity.

In this paper, we use a new firm-level measure to examine whether the physical climate risks faced by a firm have an impact on its capital structure. We hypothesize that firms exposed to greater climate risk face larger expected distress costs, which, in a static tradeoff framework, involves a reduction in their optimal leverage. We find strong support for the conclusion that greater climate risk leads to lower leverage in the post-2015 period, i.e., after the Paris

[1] See, for example, Andersson, Bolton, and Samama (2016a and 2016b), Daniel, Litterman, and Wagner (2016), Giglio et al. (2018), Hansen, Brock, and Barnett (2018) and Engle et al. (2018).

[2] Carney also underlined an urgent need for standard measures and disclosure of climate risks and established an industry-led group (Climate Disclosure Task Force) to design and deliver these standards (Carney, 2015). Several initiatives providing information on climate issues already existed (Carbon Disclosure Project, UN principles for Responsible Investment) but were fragmented and difficult to compare. See also European Commission (2018) guidelines, available at http://europa.eu/rapid/press-release_IP-18-1404_en.htm

Agreement (COP21), a historic global climate deal to limit warming to 2°C by 2100, which was signed by 195 countries in December 2015.

To measure physical climate risk, we rely on the "Climate Risk Impact Screening" (CRIS) methodology, developed by a French company, Carbone 4, with support from several institutional investors and public agencies, including the French Development Agency (AFD) and Caisse des Dépôts et Consignations (CDC). The CRIS risk rating is a forward-looking measure that captures the increased risk due to the increased intensity or frequency of climate-related hazards in the future due to global warming compared to historical reference average hazards. The analysis uses three emissions scenarios developed by the United Nations (low, medium and high) and two time horizons (2050 and 2100). For each company of the MSCI World Index, climate risk grades are quantified based on risk projections from the World Bank Climate Portal, the geographical division of activities, country-specific vulnerabilities and industry-specific vulnerabilities. Seven levels of subrisks are examined: three chronic hazards (increase in average temperature, changes in rainfall patterns, and sea level rise) and four acute hazards (heat waves, rainfall extremes, droughts, and storms).

We begin our empirical analysis by estimating the relationship between a firm's leverage ratio and the CRIS measure of climate risk. Specifically, we regress the observed debt ratios of firms belonging to the MSCI World Index over the period 2010-2017 on climate risk measures for each firm, in addition to country, industry and year fixed effects, and several other control variables. We find that an increased overall climate risk reduces firms' leverage in the post-2015 period. We then examine the impact of subrisks on leverage and find that acute risks, those leading to natural disasters (droughts, storms, heat waves), are the main drivers of the leverage decrease. Sea level rise has also a significant negative effect on leverage. Our results are both statistically and economically significant. The patterns that we observe in our baseline tests remain after various robustness checks involving changes in empirical specifications, variable construction methods and sampling restrictions.

However, climate risk could also be a component of the overall corporate credit risk; therefore, credit rating agencies (CRAs) should include it in their risk assessment, with credit ratings also reflecting climate risk. Rating agencies are increasingly aware of the need to incorporate the risks and opportunities associated with environmental and climate (E&C) factors into their corporate credit ratings. For example, Standard and Poor's examined 9000 updates between July 2015 and August 2017 to gage how these factors have featured in S&P global ratings' corporate credit analysis.[3] E&C factors were an important consideration in the analysis in 717 cases and a driver for rating changes in 106 cases. Interestingly, of the examples that have an environmental or climate factor that was key to a rating change in the S&P analysis, most are linked to physical climate risks.[4] However, our results suggest that credit ratings do not reflect all the information related to climate risk. In all our tests, we control for credit ratings and find that the CRIS grades provide additional information that is not already embedded in credit ratings. We also find that our measure of climate risk does not impact credit ratings, controlling for the usual determinants of credit ratings.

The reduction in leverage we observe may result from the demand side or from the supply side. On the one hand, firms becoming aware of their climate risks and the consequences of those risks on the expected cost of financial distress may lower their demand for debt. On the other

[3] https://www.spratings.com/documents/20184/1634005/How+Environmental+And+Climate+Risks+And+Opportunities+Factor+Into+Global+Corporate+Ratings+-+An+Update/5119c3fa-7901-4da2-bc90-9ad6e1836801

[4] However, a S&P note specifies that "we made a conscious decision not to look for climate change risks specifically because of the difficulty of attributing any given weather event to climate change alone."

hand, bondholders and bankers may be willing to reduce their exposure to climate risks by limiting the amount of debt they lend to high-climate-risk firms. To disentangle demand and supply reasons for the reduction in leverage, we first examine the case of France, where a 2015 law[5] required French bankers and institutional investors to disclose their climate risks and investment policies related to climate and environmental issues. Due to home bias in lending and investing (see, for example, Grinblatt and Keloharju, 2001, and Butler, 2008), French bankers and investors own a relatively larger share of French firms' loans and bonds than their share of the global portfolio. We should therefore observe a larger impact of climate risk on leverage for French firms after 2015. We run a difference-in-difference test between French companies subject to the new regulation after 2015 and non-French companies that are not affected. We find that greater climate risk implies a reduction in leverage that is almost two times higher for French firms than non-French MSCI World Index firms. This result suggests that the reduction in leverage is at least partly due to supply effects.

To explore the supply side effect further and to distinguish between banks and bondholders, we run a second test, focusing on firms without credit ratings. We assume that these firms (34% of our sample) do not have access to public debt markets. We find that, for these companies, whose debt is entirely bank debt, leverage decreases more with climate risk in the period after 2015 than for firms with access to the bond market. Overall, our findings suggest that the reduction in debt related to climate risk is shared between a demand effect and a supply effect. The supply effect is greater for banks than for bondholders.

[5] Article 173-VI of France's Law on Energy Transition for Green Growth (LTECV). The law was adopted in August 2015 and entered into force on the 1st of January 2016.

Our paper contributes to several strands of research. First, this research is related to the literature on climate change and its impacts on firms and investors. Macroeconomic literature provides a great deal of evidence of global warming and extreme natural events affecting agricultural output, industrial output, energy demand, labor productivity, health, conflict, political stability and economic growth.[6] Evidence on a microeconomic level gives rise to a recently growing literature. Bernstein, Gustafson and Lewis (2018) find that coastal properties exposed to projected seal level rise (SLR) sell at an approximately 7% discount relative to otherwise similar properties. This SLR exposure discount is primarily driven by properties unlikely to be inundated for over half a century, suggesting that it is due to investors pricing long horizon SLR costs.[7] This result highlights how climate risk discounts asset values and potentially reduces their pledgeability, which in turn may be part of the explanation of the leverage reduction we document in our study. A few papers try to understand the role of financial markets in pricing climate risks, with divergent results. According to Bansal, Kiku, and Ochoa (2016), long-run climate risks, as captured by temperature, are priced into the market. However, most papers find that investors do not price climate risks, at least in the short or medium term. For example, using the Palmer Drought Severity Index to estimate countries' vulnerability to droughts, Hong et al. (2019) show that equity markets do not anticipate the effects of predictably worsening droughts on agricultural firms until after they materialize. Another example of investors' lack of anticipation is related to the limiting of total carbon emissions, which will leave the majority of fossil fuel reserves as "stranded assets" (McGlade and Ekins, 2015), whereas the Carbon Tracker

[6] See, for example, Dell et al. 2009, 2012, 2014, Hsiang and Jina (2014), Jongman et al. (2014), Jones et Olken (2010).

[7] On the impact of sea level rise on real estate, other results are less clear cut. See, for example, Baldauf, Garlappi and Yannelis, 2018, who find that houses projected to be underwater in "believer" neighborhoods tend to sell at a discount compared to houses in "denier" neighborhoods.

Initiative (2013) highlights that listed oil, gas, and coal companies still largely invest in locating and developing new fossil fuel reserves. Batten, Sowerbutts, and Tanaka (2016) analyze the market reaction to climate change news over the period 2011-2016. The authors find an insignificant effect on the abnormal return of oil and gas companies, which could reflect investors' difficulties in assessing the impact of climate policies on the share price of these firms. Berkman, Jona and Soderstrom (2018), using a firm-specific climate risk measure based on textual analysis, find that firm value is negatively related to climate risk.[8] Ilhan, Sautner and Vilkov (2018) estimate the effects of carbon emissions on downside risk as the tail loss reflected in out-of-the-money put options for firms in the S&P 500 between 2010 and 2017. Measuring downside risks, which reflect negative price fluctuations, is a way to capture investors' risk perceptions.[9] The authors find that higher carbon emissions increase downside risk, especially for firms in high-emission industries, at times when investor attention to global warming is high, and for firms with larger institutional ownership. In a survey of institutional investors regarding their perceptions of climate risks, Krueger, Sautner and Starks (2018) underline that they find climate risks difficult to price and hedge. Respondents believe that equity valuations do not fully reflect the risks from climate change, although the overvaluations seem to be concentrated in certain industries.[10]

[8] Other papers examine growth and operating performance. For example, Barrot and Sauvagnat (2016) examine the impact of natural disasters on sales growth. They find that disasters negatively affect both the sales growth of directly exposed firms and their largest customers.

[9] See, for example, Ang, Chen and Sundaresan, 2012.

[10] Briere, Pouget and Ureche (2018) find that institutional investors may have different views about climate risk. Examining votes at general meetings on resolutions filed by shareholders to impose externality-related policies on corporate management, they find that Norway Fund often votes in favor of climate change mitigation policies, despite management's negative recommendations, whereas BlackRock is less engaged in favor of climate favorable policies.

Second, our research also contributes to the literature on the impact of climate risks or climate events on credit risks and financial policies. Painter (2018) examines municipal bonds and finds that counties more likely to be affected by climate change pay more in underwriting fees and initial yields. Delis, De Greif and Ongena (2018) use syndicated loan data and find that, before 2015, banks did not price climate policy risk. After the Paris Agreement in December 2015, however, the risk is priced, meaning that banks are aware of the climate policy issue and have started pricing the relevant risk post-2015. To measure climate risk, the authors use data on fossil fuel reserves from firms' annual reports and generate a firm-year measure of climate risk from the product of relative reserves and one of the climate change country-year indices. Our approach focuses on leverage and uses an overall assessment of climate risk for all firms belonging to the MSCI World Index, not only firms with fossil fuel reserves. However, it is notable that the pricing of climate risk is effective in the post-2015 period, and not before, which also converges with our result that leverage is impacted only after 2015. Elnahas, Kim and Kim (2018) investigate the impact of natural disasters on the leverage of U.S. firms. The authors find that the average leverage of firms headquartered in areas exposed to natural disasters is lower than that of counterparts in areas less subject to natural disasters. Their results show that, once disaster risks materialize, firms adjust their leverage. In our paper, we rely on a forward-looking climate risk measure and find that, after 2015, the risk related to climate change, even if not materialized yet, leads to a reduction in the leverage of the world's largest firms.

Further, climate events are used as exogenous shocks in several papers. For example, Massa and Zhang (2011) exploit the event of Hurricane Katrina to examine the impact on subsequent debt financing for exposed firms. The authors find that the Katrina shock led firms to shift from bond financing to bank financing due to the liquidation of bond holdings by property and reinsurance companies exposed to Katrina, but they do not find any significant effect on the leverage of firms. However, the documented effect is a short-term effect of the climate event and not a long-term effect of overall exposure to future climate risk. Dessaint and Matray (2017) study how managers respond to hurricane events when their firms are located in the neighborhood of the disaster area. Even though the actual risk remains unchanged, managers increase corporate cash holdings and express more concerns about hurricane risk in 10-Ks/10-Qs. Over time, the perceived risk decreases, and the cash reverts to the prehurricane level. The authors interpret their findings as the result of managers' behavioral biases. However, they observe data before 2008, a period when less attention was paid to climate changes. Further, long-term risk affects cash holdings less than leverage because some firms are able to issue bonds with maturities of up to 100 years (see Badoer and James, 2016).

Third, our paper is also related to the literature examining the impact of corporate social responsibility (CSR) issues on capital structure and the cost of capital. Chava (2014) relates environmental issues measured by KLD criteria (currently MSCI ESG) and the cost of equity and debt and finds that firms causing environmental externalities (e.g., toxic waste) have higher equity and debt costs. Similarly, Chang et al. (2018) find that firms with greater environmental liabilities maintain lower financial leverage ratios, with a lower fraction of bank debt in total debt. This result is consistent with our finding that banks seem more likely than bondholders to reduce their loans in response to an increase in climate risk. Amiraslani et al. (2017) find that, during the 2008-2009 financial crisis, high-CSR firms were able to raise more debt at lower spreads, better credit ratings and longer maturities. Sharfman and Fernando (2008) find that improved environmental risk management is associated with lower capital costs and allows for more leverage. El Ghoul et al. (2011) find that firms with better CSR scores exhibit more inexpensive equity financing. Brandon and Krüger (2018) show that portfolios of institutions with longer investment horizons exhibit greater sustainability and that risk-adjusted performance is positively related to sustainability, primarily through a reduction in portfolio risk.

The rest of the paper is structured as follows. In section 2, we present the institutional context of climate risk and our hypotheses. In section 3, we present our climate risk measures and our dataset. We analyze our empirical results in section 4, and section 5 concludes.

2. Hypothesis development

2.1. The effect of climate risk on leverage

Static tradeoff theory (see, for example Fischer, Heinkel, and Zechner, 1989 and Leland, 1994) predicts that it is optimal for firms to borrow more when they are subject to lower debt issuance costs, higher corporate taxes, lower bankruptcy costs, higher liquidation value of assets and lower profit volatility. A large number of empirical studies document evidence supporting static tradeoff theory and the existence of a target debt level (see, for example, Titman and Wessels 1988, Rajan and Zingales, 1995, Graham, 1996, Hovakimian, Opler, and Titman, 2001, and Hovakimian, Hovakimian, and Tehranian, 2004).[11]

Climate risk can have an impact on the probability of failure and on the costs associated with a possible failure. Thus, the value of the firm's assets may be reduced if they are located in areas that are subject to significant climatic risks. The impairment may be related to assets' destruction by an extreme climatic event. In addition, a loss in assets' market value may result

[11] For a review of empirical capital structure research, see Graham and Leary, 2011.

from the inability to sell these assets to an acquirer due to the increased climate risks. Insurance companies can partly mitigate the first kind of costs but do not cover the second.

Our first hypothesis is, therefore, that firms exposed to greater climate risk face larger expected distress costs, which, in a static tradeoff framework, involves a reduction in their optimal leverage.

2.2. Climate risks: why is 2015 a key year for climate risk awareness?

Even though the United Nations Framework Convention on Climate Change (UNFCCC), adopted in 1992, establishes the general legal framework for international climate change action, it was not until 1997 that countries agreed on quantified emissions limits for developed countries for the first commitment period of the Kyoto Protocol (2008-2012). However, as Andersson et al. (2016b) underline, businesses respond to rules imposed on them by governments by managing their operations as best they can, which resulted in little progress in the field of climate change mitigation. In contrast, 2015 was a pivotal year in taking climate change into account, as economic actors decided to take up the issue. In 2015, the FSB established the Task Force on Climate-related Financial Disclosures (TCFD) to develop recommendations for more effective climate-related disclosures that could "promote more informed investment, credit, and insurance underwriting decisions" and, in turn, "would enable stakeholders to understand better the concentrations of carbon-related assets in the financial sector and the financial system's exposures to climate-related risks." Further, the Paris Agreement, signed in December 2015, applies for the first time to all countries, including large developing countries with large emissions, such as India and China. One of the core aims of the Paris Agreement was to make all financial flows consistent with a pathway towards low-emissions, climate-resilient development.

The Agreement sends a strong signal that all finance, both public and private, needs to be directed towards the climate challenge. This achievement can be attributed to a new bottom-up approach centered around intended nationally determined contributions (INDCs), including all economic actors. Several initiatives have since been developed to increase investors' awareness of the climate risks they are exposed to. However, the assessment of climate risk at the firm level is not easy, as it depends both on geographical factors and on vulnerability factors specific to the firm's activity. In this study, we use new data developed by a French firm, Carbone 4, which integrates these factors by breaking down the firm's activity into geographical and industrial segments and assessing the future climate risk for each country-industry pair. To the extent that the many recent climate change initiatives have increased investor attention to climate risk, we assume that the effects of climate risks on capital structure will be more pronounced in the period after 2015.

2.3. Climate risk and leverage: demand or supply effect?

Climate risks may have an impact on leverage on the demand side: managers becoming aware of the risk associated with climate changes decrease their leverage in order to lower the costs of financial distress. On the other hand, lenders becoming increasingly aware of climate risk and subject to more stringent regulations and disclosure requirements may reduce loans to high-climate-risk firms. To disentangle demand and supply factors, we conduct two empirical tests.

In the first test, we examine the case of France, where a specific law required all bankers and institutional investors to disclose their climate risks and investment policies related to climate and environmental issues for all asset classes. Article 173 of France's Law on Energy Transition for Green Growth, adopted in August 2015,[12] establishes new reporting requirements for financial and nonfinancial firms to improve the quality of information disclosure and foster the internalization of climate issues by firms and financial institutions. This law requires banks to enrich their risk reporting by adding their analysis of climate-related financial risks and enumerates the risks that are subject to prudential control and that must be "highlighted in stress testing carried out on a regular basis." The law is aimed at encouraging credit institutions to think more carefully about the challenges of climate change for their activities. The law also targets institutional investors and asset managers who are required to report how they take account of environmental, social and governance (ESG) criteria in their investment policy, with greater detail on climate-related aspects. These provisions enable the financial sector to better understand the climate issues related to its activities and to take a more effective role in consistently reallocating capital with the risk associated with climate change. In addition, the quality of companies' own climate reporting has thus become crucial for attracting investors that follow a climate approach.

This new regulation provides a unique opportunity to examine whether lenders subject to increased transparency requirements regarding their climate risks will decide to reduce the supply of debt to high-climate-risk companies. The regulation applies to French institutional investors and banks. We hypothesize that the effect of climate risk on leverage is greater for French companies in the post-2015 period than for similar non-French companies due to a supply effect.

In the second test, we examine the impact of climate risk on the leverage of firms according to their access to the public debt market to disentangle whether climate risks have a different effect on lending by bondholders and bankers. We assume that, due to a closer

[12] The law was adopted in August 2015, the implementation decree occurred in December 2015, and it entered into force on the 1st of January 2016.

relationship with companies the often common location of head offices and operational units, banks have a better knowledge of the climate risks to which a firm is exposed. Therefore, the impact of climate risk on leverage should be larger for firms whose debt is solely bank debt.

3. Data

3.1. Physical climate risk measures

To tackle the issue of better disclosure of climate risk, the FSB, upon the request of G20 countries, established the TCFD in December 2015. One year later, the task force issued a set of recommendations, outlining two major categories of climate-related risk: transition risks (related to carbon and mitigation issues) and physical risks (related to impacts and adaptation issues). Several data providers (for example, RepRisk, MSCI ESG) focus on transition risk and CSR in relation to environmental externalities. However, these data providers do not provide data on the exposure of firms to the physical consequences of climate change.

In this paper, we use the CRIS methodology, which was developed by a French firm, Carbone 4, in cooperation with several financial institutions.[13] The CRIS measures aim at assessing the climate-related physical risks facing companies and their business units in the future. Thus, rather than focusing on externalities produced at the firm level, CRIS data capture externalities incurred at the firm level. Each climate risk rating is a function of location-specific climate hazards and sector-specific vulnerabilities. Industry information comes from GICS, ICB and NAICS codes. The geographical division of activities is based either on sales, on tangible assets, or on a combination of both, depending on the low, high or medium capital intensity of the

[13] More information is available on www.crisforfinance.com/en/.

sector to which the company belongs. Geographical information depends on the granularity of the information disclosed by the companies. Six of the seven largest countries (Brazil, Canada, China, India, Russia, USA) are further divided into 4 subcountries. At its broadest level, climate risk is measured through an index aggregating 7 hazards: 4 of these are acute (extreme) hazards – heatwaves, rainfall extremes, drought, and storms – and 3 are chronic hazards – increases in average temperature, changes in rainfall patterns and sea level rise.

The CRIS measures are split into two time horizons (2050 and 2100) and three intensity cases (low, medium, high), reflecting the Intergovernmental Panel on Climate Change (IPCC) scenarios, which are formally named Representative Concentration Pathways (RCP).[14] The CRIS risk rating does not capture the absolute risk from future climate or weather but does capture the increased risk due to the increase in the intensity or frequency of the climate-related hazards in the future due to global warming compared to historical reference average hazards. Final ratings are attributed on a scale of 0 to 99, and the higher the rating is, the greater the risk. As the rating scale is relative, a low rating does not necessarily imply low risk in absolute terms but rather means that the risk is in the lower part of the gradient in relative terms. For a company with multiple business segments (various sectors in various countries), for each hazard, the risk rating is based on the weighted arithmetic mean of all the risk ratings calculated for each of the company's business segments for this same hazard. Weighting is proportional to the breakdown of the company's revenue or fixed assets (if capital intensive) in its various segments. For each

[14] The RCPs include a stringent mitigation scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0) and one scenario with very high GHG emissions (RCP8.5). Scenarios without additional efforts to constrain emissions ('baseline scenarios') lead to pathways ranging between RCP6.0 and RCP8.5. The RCP2.6 scenario's feasibility is, at this point in time, seriously in question. Therefore, the CRIS measures rely on the RCP4.5 (low), RCP6.0 (medium) and RCP8.5 (high) scenarios.

hazard, the risk rating of a specific sector in a specific country is a combination of the hazard rating of the country and the vulnerability rating of the sector.

In this paper, for the sake of clarity, we use a unique CRIS rating corresponding to the 2050 horizon and medium intensity risk. As our purpose is to examine the impact of climate risk on leverage, the 2050 horizon seems relevant: analyzing bond issues of more than $200 million available in Thomson-Reuters, we find that only 6.8% of the offerings have a maturity greater than 30 years and 0.2% have a maturity over 70 years. In our robustness checks, we also use the 2100 horizon and low/high intensity risks, and the results are qualitatively unchanged.

The CRIS ratings cover the sphere of the MSCI World Index for 2016. As the climate risk is determined on the basis of a 2050 horizon, we assume that this risk remains stable over the period studied (2010-2017) and that the company's activities and locations do not undergo major changes over the period. After excluding financial firms and observations with missing data (see below), we are left with 1212 firms.

Table 1, Panel A presents the descriptive statistics for the climate risk CRIS ratings. The average overall rating is 35.161 (median = 36.994). The average rating for subrisks varies from 16.168 for rainfall patterns to 44.197 for storms. Column 4 indicates a standard deviation of 10.833 for the overall rating, while subrisks have a standard deviation going from 6.989 (rainfall patterns) to 15.796 (heavy rainfalls).

3.2. Credit ratings

Credit ratings at the issuer level are obtained from Thomson-Reuters. This variable is based on the S&P Long-term Issuer Rating when available. If this rating is not available, we rely on Moody’s Long-term Issuer Rating and, eventually, on Fitch’s Long-term Issuer Default Rating if both previous measures are missing. Similarly to Baghai et al. (2014), we linearize these ratings from 1 to 20. Investment grade ratings are coded between 11 and 20, whereas high yield ratings are coded between 1 and 10. Missing ratings are coded 0.

Of our firm-year observations, 66% are rated and, therefore, potentially have access to public debt markets, reflecting the fact that the sample is composed of the world's largest listed companies belonging to the MSCI World Index. The average credit rating is 9.3 (median 10), which corresponds to an S&P grade of BB (9)/BB+ (10).

3.3. Financial and accounting data

The financial and accounting data are from Compustat North America and Compustat Global. We match the companies covered by the CRIS grades with the data available in Compustat for fiscal years 2010 to 2017, which yields 11,836 firm-year observations. Relying on 2-digit SIC codes, we exclude SIC codes 60 to 69, as financial firms are subject to special regulations concerning their capital structure. Missing values for long-term debt, EBIT, R&D expenses and issuer ratings are set to zero. Missing ages are set to 1 in order to use the natural logarithm. This assumption is noncritical, as only 71 observations have missing values of long-term debt. We have 3 additional observations with missing EBIT. We exclude observations with missing values of operating expenses and those for which we were unable to compute Tobin's Q. Therefore, we are left with 9,138 firm-year observations, covering 1,212 firms. These figures are sound as, on the one hand, 1,604 firms are covered by CRIS; and on the other hand, the MSCI

World Index covers approximately 1,600 firms, with 16.33% of them belonging to the financial sector.[15]

Our main measure of leverage, for firm *i* in year *t*, is a book leverage variable, which is defined as follows:

$$LTDebt/TotAssets_{it} = \frac{DLTT_{it}}{AT_{it}};$$

where $DLTT_{it}$ is the amount of long-term debt exceeding a maturity of one year and AT_{it} is the book value of total assets. We exclude debt in current liabilities because of the long-term nature of climate risks.

Similarly, we define the market leverage, for firm *i* in year *t*, as follows:

$$LTDebt/MVAssets_{it} = \frac{DLTT_{it}}{AT_{it} - CEQ_{it} + PRCC\_F * CSHO}$$

if the firm is covered by Compustat North America, and

$$LTDebt/MVAssets_{it} = \frac{DLTT_{it}}{AT_{it} - CEQ_{it} + PRCCD * CSHOC}$$

if the firm is covered by Compustat Global.

All the variables computed from Compustat are winsorized at the 1% level to prevent the effect of potential outliers. Country fixed effects are based on headquarters locations and industry fixed effects are based on 2 digit SIC codes.

In Table 1, Panel B, the means (medians) of various firm characteristics are reported for the full sample and are disaggregated between low- (below median) climate-risk and high- (above median) climate-risk firms. The average long-term book leverage is 21.3%. High-climate-risk

[15] https://www.msci.com/documents/1296102/1362201/MSCI-MIS-World-Brochure-May-2018.pdf/8f4db460-a0cb-d845-226b-fe2472b3dc08

firms (average CRIS rating of 43.8) are less leveraged (19%) than low-climate-risk firms (average CRIS rating of 26.5) (23.6%). Market leverage is also significantly lower for high-versus low-climate-risk firms, even if the difference is smaller (13.4% versus 15.1%). High-climate-risk firms are larger, have more tangible assets, have more R&D expenses and have a lower Tobin's Q than low-climate-risk firms. Of high-climate-risk firms, 35.4% do not have a credit rating, compared to 33.0% for low-climate-risk firms.

4. Empirical results

4.1 Leverage and climate risk

Descriptive statistics show that firms with high climate risk are less highly leveraged. It may be that firms with high climate risk are also those that find debt less valuable. However, as these firms are larger and have more tangible assets, the theory predicts that they should demand more debt, which suggests that they are not in a situation in which they would attach less value to debt. Based on the literature of capital structure determinants, we regress the firm's leverage on a set of firm characteristics, including credit ratings and climate risk measures. Clustering effects could bias the statistical significance of the results because of cross-sectional dependence. Thus, in estimating our regressions, we apply the procedures described in Petersen (2009) to adjust standard errors for clustering by firm.

Our results confirm the previous work on capital structure.[16] Firms with more tangible assets, measured by a firm's property, plant and equipment to total asset ratio, have a higher debt ratio. In contrast, intangible assets, measured as research and development expenses scaled by

[16] For example, Titman and Wessels, 1988, Rajan and Zingales, 1995, Graham, Lemmon, and Schallheim, 1998, Hovakimian, Opler, and Titman, 2001, and Strebulaev & Yang (2013).

total assets, reduce the firm's leverage. More profitable firms (EBIT/total assets) and firms with a higher proportion of operational expenses are less leveraged (Table 2, Panel A). When market values are considered (Table 2, Panel B), these results remain similar, but leverage further increases with size, confirming previous results that larger firms are less risky or incur lower issue costs. In addition, firms with higher Tobin's Q values are less leveraged, reflecting their greater risk and potential for growth. Further, by including industry dummies and year dummies, we can completely control for any determinant of leverage that is constant within a year or an industry.

Controlling for these fundamental differences between firms, as well as year and industry fixed effects, we find that increased physical climate risk reduces leverage: a 10-point increase in the overall risk rating is associated with a 3% decrease in the long-term book debt ratio (Panel A, column 1) and a 1.45% decrease in the market debt ratio (Panel B, column 1). 2015 was a pivotal year for taking climate risk into account, resulting from the Paris Agreement (COP21) and the implementation of the TCFD. Therefore, we also examine whether the impact of climate risk on leverage changed after 2015 by interacting our climate risk measure with a dummy variable equal to one for the post-2015 period. We find that, indeed, after 2015, a 10-point increase in climate risk reduces debt by an additional 1% (book value, Panel A, column 2) or 0.4% (market value, Panel B, column 2).

Our estimates have thus far ignored the location of the headquarters of the firm. It could be that our climate risk variable reflects the climate characteristics of the country in which the firm is located as well as other determinants of leverage that are constant within a country given its institutional and tax characteristics. We therefore further include country dummies to verify that climate risk is not a proxy for a firm's headquarters location. We find that, until 2015, the effect of climate risk on leverage vanishes when country dummies are included in the regressions. However, after 2015, the effect is still there, suggesting that, in addition to country characteristics, there is an incremental climate risk factor that reduces leverage by 1% for a 10-point increase in climate risk (book leverage, Panel A, column 3) and 0.4% (market leverage, Panel B, column 3). This effect is economically significant, as it represents 5% of the leverage when measured in book value and 3% when measured in market value.

Climate risk could also be a component of the overall corporate credit risk. Graham and Harvey (2001) find that, for CFOs, credit ratings are their second highest concern when determining their capital structure. If credit ratings already reflect climate risk, adding climate risk variables would not provide any additional information to the determinants of leverage. To verify that our climate risk measure is not a mere proxy for credit risk, we add two independent variables. The first is a dummy variable that is equal to 1 if the firm is not rated by any of the three major rating agencies: Standard and Poor's, Moody's and Fitch. The second is a variable linearizing the credit ratings from 1 (DDD) to 20 (AAA) for firms that benefit from a rating and zero otherwise. Confirming previous results (Faulkender and Petersen, 2005), we find that firms without a credit rating are significantly less leveraged (-17% in book leverage, and -9% in market leverage). We also find that firms with more favorable ratings are less leveraged than firms that are poorly rated. Including these two variables in our regressions does not change our results. The magnitude of the coefficients of our climate risk variable remains similar (Table 2, Panel A, columns 4 to 6, for book leverage, and Panel B, columns 4 to 6, for market leverage). Our finding may also result from a reverse causality between credit rating and leverage. To address this potential problem, we use an instrumental variables approach. In the first stage, we estimate the endogenous variables (no grade and issuer grade) as a function of the exogeneous variables in the second stage plus two additional instruments. We instrument our credit rating variables by their means for groups by year/sector/country. These instruments are correlated with our credit rating variables, but it is unlikely that the debt level of a given firm will depend on the average rating of the sector for a given year and country once fixed effects are taken into account. Again, our results are confirmed and the magnitude of the coefficients of the climate risk measure remains similar (Table 2, Panel A, column 7, for book leverage, and Panel B, column 7, for market leverage).

These findings suggest that our CRIS climate risk measure provides an additional risk factor that has an impact on leverage after 2015 and that is not already included in credit risk ratings. After the strong signals sent to all participants in the financial system in 2015 regarding the necessity to develop climate-related disclosures and better understand their exposure to climate-related risks, both managers and investors became more aware of climate risks, which, in turn, can explain the reduction in leverage we observe.

4.2. Acute risks and chronic risks

CRIS climate risk ratings combine information on seven direct climate hazards: three chronic hazards (increases in average temperature, changes in rainfall patterns, and sea level rise) and four acute hazards (heat waves, droughts, rainfall extremes, and storms). For each hazard, the rating is based on the analysis of information on the magnitude, duration and frequency of the hazard (particularly relevant for acute hazards). To build a rating of 1 to 99 for each climate variable and each country, the relative changes are first extracted in the future time horizons compared to the historic reference period and then normalized across all scenarios and time horizons. These direct hazards are associated with information on the risk-aggravating context to capture indirect hazards. For example, the impact of heavy rainfall is larger when the proportion of high slopes in the area is high because of increased landslide risks. Extreme droughts lead to water scarcity but also wildfires.

We examine the impact of each of these 7 climate subrisks on the leverage of firms. Since the risk variables by category are normalized, their values are of the same magnitude as the overall rating. Therefore, the regression coefficients reflect the relative impact of the risk variables on debt but not the weight of each risk in the total risk to explain the climate impact on debt. The results in Table 3 indicate that the four acute risks have a significant negative impact on leverage over the whole period, without including country fixed effects in the regressions, and after 2015 when country fixed effects are considered. The magnitude of the effect is comparable across subrisks. A 10-point increase in the subrisk rating is associated with a 1.5% decrease in the long-term book debt ratio for storm risk, 1.9% for heavy rain risk and 2% for drought and heat waves risks. When controlling for country fixed effects, the impact is significant after 2015, with a magnitude of 0.7% for heat waves, storm and heavy rain, and 1% for drought. Among chronic risks, sea level rise has an impact that is comparable to that of acute risks, whereas temperature rise in itself has no impact on leverage.

These results highlight that the impact of aggregate climate risk on leverage is primarily the result of the potential increase in the risks of extreme events at the 2050 horizon.

4.3. Climate risk and leverage: demand or supply effect?

The observed level of debt is a function of the firm's demand for debt: in the absence of frictions, firms can borrow up to their optimum leverage, which depends on their characteristics, according to the traditional assumption in the empirical capital structure literature. On the other hand, the reduction in leverage we observe in the post-2015 period may also be the result of supply factors. As lenders become more aware of climate risk, they could choose to lend less to firms facing high climate risk. To disentangle demand and supply factors, we conduct two empirical tests. In the first test, we examine the case of France, where a specific law required all bankers and institutional investors to disclose their climate risks and investment policies related to climate and environmental issues for all asset classes. In the second test, we examine the impact of climate risk on the leverage of firms according to their access to the public debt market to disentangle which of the bondholders or bankers are most aware of climate risks.

4.3.1. Compulsory disclosure of climate risks and capital structure: the case of France

Article 173 of France's Law on Energy Transition for Green Growth, adopted in August 2015, establishes new climate risk reporting requirements for French credit institutions and investors. This new regulation provides a unique opportunity to examine whether lenders subject to increased transparency requirements regarding their climate risks will decide to reduce the supply of debt to high-climate-risk companies. Due to investors' and bankers' home bias, the impact of the regulation will be most strongly felt by French companies. We rerun our regressions, including a variable interacting our climate risk rating and companies headquartered in France, in the post-2015 period. This approach allows for a difference-in-difference test between French companies subject to the new regulation after 2015 and non-French companies that are not affected. The results in Table 4, column 1, indicate that, in addition to the post 2015 effect already documented for the whole sample (a 10-point increase in the climate risk measure is associated with a 1% decrease in the long-term book debt ratio), after the adoption of the law, French companies are experiencing a further reduction in their debt ratio by 0.8% per 10 risk points. These findings suggest that when lenders have a better perception of climate risk, they reduce their lending to companies with the highest risk. This result is consistent with the fact that lenders may have a longer horizon than managers, especially for long-term debt.

4.3.2. Climate risk and access to the public debt market

In the second test, we focus on the access to bond markets to disentangle which of the bondholders or bankers are most aware of climate risks. Of the firms in our sample, 34% are not credit rated. We assume these firms have no access to the public debt market. We rerun our regressions including two variables: the first one interacts the variable “no credit rating” and the climate risk measure, and the second one further interacts the post-2015 dummy. We find that compared to firms with credit ratings and in the post-2015 period, firms that do not have access to public debt market experience a further reduction in their debt ratio by 0.5% per 10 climate risk points, whether or not we include the issuer grade for the rated firms (Table 4, columns 2 and 3). The results are robust to excluding firms with zero long-term debt (Table 4, columns 4 and 5). These findings suggest that bankers may be more prone than bondholders to reduce their lending in response to an increase in climate risk.

4.4. Credit ratings and climate risk

We have seen in previous tests that climate risk rating provides additional information compared to the credit rating to explain the firm's leverage after 2015. In this paragraph, we intend to explore the relationship between credit risk and climate risk in more detail. Credit ratings are fundamentally forward looking; they are beliefs about the downside risks surrounding promised future outcomes and the probability of financial distress. CRAs thus evaluate the fundamental drivers of creditworthiness over the long term. Climate change may affect creditworthiness through potential economic impact, physical damage to assets and indirect impacts from supply chain disruption. Credit ratings should at least partially reflect climate risks, even if they do not take them into account in their entirety. Rating agencies are multiplying the announcements related to E&C risk factors, with a primary focus on sovereign and municipal bonds. For example, Moody's has changed its sovereign bond methodology to capture the effects of physical climate change in a broad set of rating factors that influence a sovereign's ability and willingness to repay its debt (Moody's, 2016).

We acknowledge that credit ratings are not perfectly correlated with publicly observable and quantifiable information about firms' characteristics and that they bring a holistic creditworthiness assessment beyond financial and accounting ratios. Nevertheless, variables such as interest coverage, profitability, size, and risk measures are well-known determinants of rating levels and their corresponding expected default losses (see, for example, Standard and Poor's corporate rating criteria, 2013). We first examine rated firms. In this subsample, we regress the credit rating variable on the following explanatory variables: profitability, interest coverage, size, age, Tobin's Q, working capital divided by total assets, operating expenses divided by total assets, R&D expenses divided by total assets, and fraction of tangible assets. We control for year fixed effects (to take into account that rating standards have tightened over time (see Jorion et al., 2009, and Baghai et al., 2014), industry fixed effects (as business risk varies across sectors) and country fixed effects (the sovereign rating represents in almost all cases a ceiling for the private sector). As the results in Table 5 indicate (columns 1 and 2), the coefficient of our climate risk variable is not significantly different from zero, either before or after 2015, suggesting that credit ratings do not reflect physical climate risk specific to the firm (beyond headquarter country climate risk that is captured by country dummies).

However, it may also be that a high level of climate risk may discourage rating agencies from rating these firms. Thus, only the companies with the lowest climate risk would be rated, which could explain the absence of any impact of climate risk on credit risk. We run a regression explaining the fact of being rated (Table 5, columns 3 and 4). Again, the coefficient of our climate risk variable is not significantly different from zero, either before or after 2015. To sum up, climate risk as measured by CRIS ratings does not seem to be reflected in the credit ratings issued by the rating agencies, at least over the period we examine.

4.5. Robustness checks

A first question arises about the possibility of our climate risk measure being endogenous. Endogeneity is highly unlikely. First, this is a forward-looking measure that reflects the probability of future climate events that are highly exogeneous. Second, we acknowledge that this risk measure depends on the location of the firm's activities and the choice of business segments that are more or less vulnerable to climate risk. However, if the firm is aware of the climate risk, it would have had to make decisions over our sample period to locate its activities in less risky countries and in business segments that are less vulnerable to climate risk. Thus, it is unlikely that the firm's exposure to climate risk has increased voluntarily, and it is more likely that it has decreased. However, our results show that the effect of climate risk on leverage is significant only after 2015. Thus, it is unlikely that endogeneity will affect our results.

We conduct several robustness checks. First, we rerun all of our regressions, excluding zero-debt firms, and the pattern of results is unaltered. To take into account the possibility of time effects that are specific to certain industries, we re-estimate our basic regressions (Table 3), including year-industry fixed effects, and the results remain unchanged. Similarly, the institutional characteristics of countries may evolve over time in different ways, but the pattern of results is unaltered by the inclusion of country-year fixed effects. We also rerun our regressions, including several dummy variables for each level of credit rating rather than our continuous variable, and our results remain similar. Tables 3 and 4 report results for only book leverage, but all of our results remain similar when we use market leverage as a dependent variable. As an alternative to our 2050 horizon climate risk rating, we also use the 2100 horizon rating and low/high intensity risks, and the results are qualitatively unchanged, even if the coefficients of the variables change slightly depending on the chosen combination.

5. Conclusion

In this paper, we analyze the impact of climate risk rating on firms' leverage. We use a new forward-looking measure for physical climate risk at the firm level. Our work builds on the capital structure and climate risk literature. We find that firms exposed to a greater climate risk are less leveraged in the post-2015 period, i.e., after the Paris Agreement (COP21), a historic global climate deal to limit warming, which was signed by 195 countries in December 2015. We also show that the reduction in debt related to climate risk is shared between a demand effect and a supply effect. On the one hand, we find that, in addition to firm characteristics known to determine leverage, including credit ratings and several fixed effects, an increased climate risk lowers the optimal leverage. On the other hand, we find that lenders subject to increased transparency requirements on their climate risks reduce the supply of debt to high-climate-risk companies. Further, we find that firms that are not credit rated and do not have access to the public debt market experience a stronger reduction in their debt ratio when their climate risk increases than firms that have access to the bond market. Overall, our results suggest that over the recent period, climate risk has become an important factor in understanding the financial structure of firms.

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Table 1

Descriptive statistics.

This table reports summary statistics. Panel A presents the descriptive statistics for the CRIS climate variables. Each firm of the panel is covered by 8 CRIS climate grades (an overall rating and 7 subrisk ratings), computed on the basis of year 2016 figures. In Panel B, descriptive statistics of various firm-year characteristics are reported for the full sample and are disaggregated between low climate risk (<median) and high climate risk (>median) observations in the last two columns. All Compustat variables are winsorised at the 1st and 99th percentiles. The statistics for IssuerGrade are presented for the firms that are credit rated. See Appendix A for variable definitions and Appendix B for details regarding the variable IssuerGrade. The sample comprises all firms in the MSCI World index from 2010 to 2017, excluding financial firms (SIC 6000-6999).

Panel A

	N	Mean	SD	Median	P25	P75
Climate risk	1,212	35.161	10.833	36.994	26.919	42.225
Heavy rainfall	1,212	37.305	15.796	36.382	24.796	49.265
Heat waves	1,212	31.828	10.562	30.511	24.858	38.969
Droughts	1,212	29.795	10.338	31.130	21.354	37.947
Storms	1,212	44.197	15.096	46.349	30.081	53.050
Sea level rise	1,212	41.663	13.984	46.943	28.094	51.846
Temperature rise	1,212	23.873	8.940	23.735	17.619	29.852
Rainfall patterns	1,212	16.168	6.989	16.569	11.609	20.569

Panel B

	N	Mean	SD	Median	P25	P75	Mean – Low Risk	Mean – High risk
BookLev	9,138	0.213	0.156	0.196	0.097	0.306	0.236	0.190
MarketLev	9,138	0.143	0.118	0.120	0.053	0.207	0.151	0.134
EBIT	9,138	0.093	0.071	0.081	0.050	0.125	0.101	0.085
Log Age	9,138	2.632	1.520	3.091	1.946	3.951	2.398	2.867
TobinQ	9,138	1.971	1.378	1.525	1.165	2.198	2.091	1.852
OpEx	9,138	0.706	0.538	0.576	0.340	0.900	0.773	0.639
R&DExp	9,138	0.020	0.036	0.002	0.000	0.026	0.013	0.028
PPE	9,138	0.294	0.235	0.227	0.105	0.423	0.268	0.321
Log TotAssets	9,138	9.321	1.231	9.246	8.499	10.173	9.237	9.405
IssuerGrade	6,014	11.606	3.696	12.000	10.000	14.000	11.324	11.898
NoIssuerGrade	9,138	0.342	0.474	0.000	0.000	1.000	0.330	0.354
Log IntCoverage	8,884	0.006	0.022	0.000	0.000	0.002	0.007	0.005
WorkCap	9,138	0.135	0.172	0.102	0.007	0.230	0.109	0.162

Table 2

Climate risk and long-term debt.

This table presents estimates of the effects of overall climate risk on the level of long-term debt. Panel A reports estimates using BookLev as dependent variable. Panel B reports estimates using MarketLev as dependent variable. Columns (1) to (6) report OLS estimates. Column (7) reports 2SLS estimates, where average values of IssuerGrade and NoIssuerGrade at country-industry-year level are instruments for IssuerGrade and NoIssuerGrade. Regressions (1), (2), (4) and (5) include industry and year fixed effects. Regressions (3), (6), (4) and (7) include country, industry and year fixed effects. The sample comprises all firms in the MSCI World index from 2010 to 2017, excluding financial firms (SIC 6000-6999). Standard errors (in parentheses) are clustered at the firm level. ***, **, and * denote significance at the 1%, 5% and 10% levels, respectively.

Panel A

VARIABLES	(1) BookLev	(2) BookLev	(3) BookLev	(4) BookLev	(5) BookLev	(6) BookLev	(7) BookLev
EBIT	-0.132**	-0.131**	-0.187***	-0.126**	-0.125**	-0.164***	-0.297***
	(0.0607)	(0.0607)	(0.0599)	(0.0537)	(0.0536)	(0.0542)	(0.0388)
Log Age	0.00397*	0.00396*	0.00103	-0.00134	-0.00135	-0.00142	0.00229
	(0.00228)	(0.00228)	(0.00329)	(0.00218)	(0.00218)	(0.00311)	(0.00433)
TobinQ	0.00498	0.00498	-0.00128	0.00779**	0.00778**	0.00295	0.00492*
	(0.00363)	(0.00363)	(0.00361)	(0.00312)	(0.00312)	(0.00325)	(0.00257)
OpEx	-0.0476***	-0.0477***	-0.0485***	-0.0500***	-0.0501***	-0.0503***	-0.0306***
	(0.00991)	(0.00991)	(0.00934)	(0.00893)	(0.00893)	(0.00866)	(0.00858)
R&DExp	-0.616***	-0.614***	-0.618***	-0.583***	-0.581***	-0.582***	-0.366***
	(0.122)	(0.122)	(0.114)	(0.110)	(0.110)	(0.106)	(0.113)
Log TotAssets	0.00939***	0.00927***	0.00392	-0.00103	-0.00115	-0.00321	0.0123***
	(0.00325)	(0.00325)	(0.00350)	(0.00327)	(0.00327)	(0.00351)	(0.00450)
PPE	0.0864***	0.0867***	0.0950***	0.0881***	0.0884***	0.0948***	0.107***
	(0.0284)	(0.0284)	(0.0269)	(0.0266)	(0.0266)	(0.0261)	(0.0283)
IssuerGrade				-0.00675***	-0.00676***	-0.00560***	-0.00192**
				(0.00109)	(0.00109)	(0.00104)	(0.000881)
NoIssuerGrade				-0.173***	-0.173***	-0.142***	-0.0410***
				(0.0159)	(0.0159)	(0.0157)	(0.0157)
Climate risk	-0.00365***	-0.00339***	-0.000112	-0.00261***	-0.00235***	-0.000238	-6.11e-05
	(0.000512)	(0.000516)	(0.000612)	(0.000476)	(0.000480)	(0.000576)	(0.000594)
Climate risk*Post2015		-0.00103***	-0.00103***		-0.00103***	-0.00104***	-0.000997***
		(0.000231)	(0.000233)		(0.000239)	(0.000236)	(0.000219)
Constant	0.154***	0.146***	0.0694	0.325***	0.316***	0.237***	-0.00348
	(0.0500)	(0.0500)	(0.0537)	(0.0490)	(0.0490)	(0.0538)	(0.0588)
Observations	9,138	9,138	9,138	9,138	9,138	9,138	9,138
R-squared	0.288	0.289	0.354	0.365	0.366	0.400	
Country Fixed Effects	No	No	Yes	No	No	Yes	Yes
Industry Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of Firms							1,212

Panel B

VARIABLES	(1) MarketLev	(2) MarketLev	(3) MarketLev	(4) MarketLev	(5) MarketLev	(6) MarketLev	(7) MarketLev
EBIT	-0.284***	-0.284***	-0.307***	-0.272***	-0.271***	-0.286***	-0.329***
	(0.0293)	(0.0293)	(0.0304)	(0.0275)	(0.0275)	(0.0287)	(0.0293)
Log Age	6.72e-05	6.47e-05	-0.00195	-0.00229	-0.00230	-0.00293	-0.00717**
	(0.00152)	(0.00152)	(0.00232)	(0.00148)	(0.00148)	(0.00221)	(0.00342)
TobinQ	-0.0124***	-0.0124***	-0.0153***	-0.0108***	-0.0108***	-0.0128***	-0.0127***
	(0.00176)	(0.00176)	(0.00195)	(0.00162)	(0.00162)	(0.00183)	(0.00174)
OpEx	-0.0320***	-0.0321***	-0.0329***	-0.0329***	-0.0329***	-0.0336***	-0.0256***
	(0.00655)	(0.00655)	(0.00638)	(0.00600)	(0.00600)	(0.00595)	(0.00622)
R&DExp	-0.418***	-0.417***	-0.430***	-0.403***	-0.402***	-0.411***	-0.238***
	(0.0679)	(0.0679)	(0.0670)	(0.0618)	(0.0618)	(0.0628)	(0.0482)
Log TotAssets	0.0118***	0.0117***	0.00963***	0.00760***	0.00756***	0.00686***	0.0157***
	(0.00216)	(0.00216)	(0.00235)	(0.00219)	(0.00219)	(0.00236)	(0.00338)
PPE	0.0682***	0.0683***	0.0720***	0.0700***	0.0701***	0.0726***	0.0700***
	(0.0207)	(0.0207)	(0.0203)	(0.0197)	(0.0197)	(0.0197)	(0.0232)
IssuerGrade				-0.00504***	-0.00504***	-0.00460***	-0.00122*
				(0.000763)	(0.000763)	(0.000742)	(0.000630)
NoIssuerGrade				-0.103***	-0.103***	-0.0925***	-0.0270***
				(0.0107)	(0.0107)	(0.0108)	(0.00995)
Climate risk	-0.00145***	-0.00135***	-8.56e-05	-0.000911**	-0.000813**	-0.000160	-9.07e-05
	(0.000369)	(0.000376)	(0.000438)	(0.000359)	(0.000364)	(0.000423)	(0.000432)
Climate risk*Post2015		-0.000373**	-0.000370**		-0.000379**	-0.000377**	-0.000306**
		(0.000156)	(0.000156)		(0.000164)	(0.000162)	(0.000146)
Constant	0.0836**	0.0805**	0.120***	0.175***	0.172***	0.216***	0.0981**
	(0.0346)	(0.0346)	(0.0374)	(0.0341)	(0.0341)	(0.0374)	(0.0450)
Observations	9,138	9,138	9,138	9,138	9,138	9,138	9,138
R-squared	0.440	0.440	0.468	0.480	0.481	0.496	
Country Fixed Effects	No	No	Yes	No	No	Yes	Yes
Industry Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of Firms							1,212

Table 3

Climate sub-risks and long-term debt.

This table presents estimates of the effects of climate sub-risks on the level of long-term debt. Panel A reports OLS estimates using acute climate risks as independent variables. Panel B reports OLS estimates using chronic climate risks as independent variables. All regressions use BookLev as dependent variable. Regressions (1), (3), (5) and (7) include industry and year fixed effects. Regressions (2), (4), (6) and (8) include country, industry and year fixed effects. The sample comprises all firms in the MSCI World index from 2010 to 2017, excluding financial firms (SIC 6000-6999). Standard errors (in parentheses) are clustered at the firm level. ***, **, and * denote significance at the 1%, 5% and 10% levels, respectively.

Panel A

VARIABLES	(1) BookLev	(2) BookLev	(3) BookLev	(4) BookLev	(5) BookLev	(6) BookLev	(7) BookLev	(8) BookLev
EBIT	-0.112**	-0.164***	-0.121**	-0.165***	-0.134**	-0.166***	-0.119**	-0.160***
	(0.0534)	(0.0542)	(0.0537)	(0.0541)	(0.0538)	(0.0541)	(0.0538)	(0.0543)
Log Age	-0.00336	-0.00138	-0.00211	-0.00150	0.000201	-0.00139	-0.00257	-0.00153
	(0.00214)	(0.00311)	(0.00216)	(0.00310)	(0.00233)	(0.00311)	(0.00213)	(0.00311)
TobinQ	0.00836***	0.00295	0.00922***	0.00309	0.00846***	0.00297	0.00590*	0.00274
	(0.00310)	(0.00325)	(0.00313)	(0.00326)	(0.00312)	(0.00326)	(0.00313)	(0.00325)
OpEx	-0.0502***	-0.0504***	-0.0471***	-0.0496***	-0.0501***	-0.0505***	-0.0511***	-0.0505***
	(0.00893)	(0.00866)	(0.00889)	(0.00860)	(0.00894)	(0.00865)	(0.00872)	(0.00864)
R&DExp	-0.590***	-0.586***	-0.557***	-0.574***	-0.597***	-0.587***	-0.577***	-0.577***
	(0.110)	(0.106)	(0.112)	(0.108)	(0.110)	(0.106)	(0.109)	(0.106)
Log TotAssets	3.45e-05	-0.00324	0.000419	-0.00287	-0.00204	-0.00333	-0.00123	-0.00322
	(0.00328)	(0.00350)	(0.00331)	(0.00353)	(0.00329)	(0.00351)	(0.00325)	(0.00351)
PPE	0.0799***	0.0940***	0.0799***	0.0944***	0.0827***	0.0934***	0.0944***	0.0951***
	(0.0268)	(0.0261)	(0.0264)	(0.0260)	(0.0267)	(0.0261)	(0.0263)	(0.0260)
IssuerGrade	-0.00676***	-0.00557***	-0.00690***	-0.00559***	-0.00695***	-0.00559***	-0.00644***	-0.00558***
	(0.00110)	(0.00103)	(0.00110)	(0.00103)	(0.00111)	(0.00104)	(0.00107)	(0.00103)
NoIssuerGrade	-0.176***	-0.142***	-0.176***	-0.142***	-0.177***	-0.142***	-0.165***	-0.142***
	(0.0160)	(0.0157)	(0.0162)	(0.0157)	(0.0160)	(0.0158)	(0.0156)	(0.0157)
Droughts	-0.00211***	-0.000266						
	(0.000500)	(0.000570)						
Droughts*Post2015		-0.00109***						
		(0.000250)						
Heat waves			-0.00215***	-0.000317				
			(0.000441)	(0.000513)				
Heat waves*Post2015				-0.000743***				
				(0.000242)				
Storms					-0.00151***	-6.82e-05		
					(0.000313)	(0.000417)		
Storms*Post2015						-0.000660***		
						(0.000163)		
Heavy rainfall							-0.00193***	-0.000174
							(0.000287)	(0.000401)
Heavy rainfall*Post2015								-0.000786***
								(0.000156)
Constant	0.295***	0.239***	0.271***	0.231***	0.305***	0.232***	0.311***	0.235***
	(0.0479)	(0.0533)	(0.0460)	(0.0499)	(0.0489)	(0.0545)	(0.0473)	(0.0516)
Observations	9,138	9,138	9,138	9,138	9,138	9,138	9,138	9,138
R-squared	0.360	0.400	0.360	0.399	0.361	0.399	0.372	0.400
Country Fixed Effects	No	Yes	No	Yes	No	Yes	No	Yes
Industry Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Panel B

VARIABLES	(1) BookLev	(2) BookLev	(3) BookLev	(4) BookLev	(5) BookLev	(6) BookLev
EBIT	-0.108**	-0.166***	-0.0981*	-0.160***	-0.113**	-0.166***
	(0.0536)	(0.0542)	(0.0536)	(0.0545)	(0.0535)	(0.0540)
Log Age	-0.00447**	-0.00131	-0.00458**	-0.00130	-0.00358	-0.00150
	(0.00216)	(0.00309)	(0.00216)	(0.00310)	(0.00218)	(0.00311)
TobinQ	0.00944***	0.00305	0.00998***	0.00308	0.00929***	0.00296
	(0.00314)	(0.00326)	(0.00313)	(0.00326)	(0.00313)	(0.00326)
OpEx	-0.0505***	-0.0497***	-0.0496***	-0.0496***	-0.0515***	-0.0503***
	(0.00894)	(0.00857)	(0.00893)	(0.00858)	(0.00907)	(0.00865)
R&DExp	-0.599***	-0.584***	-0.593***	-0.582***	-0.598***	-0.588***
	(0.112)	(0.107)	(0.113)	(0.107)	(0.111)	(0.106)
Log TotAssets	-0.000991	-0.00284	0.000587	-0.00225	-0.00103	-0.00324
	(0.00331)	(0.00354)	(0.00336)	(0.00354)	(0.00330)	(0.00350)
PPE	0.0705***	0.0945***	0.0758***	0.0983***	0.0764***	0.0932***
	(0.0266)	(0.0261)	(0.0266)	(0.0260)	(0.0269)	(0.0261)
IssuerGrade	-0.00701***	-0.00561***	-0.00703***	-0.00561***	-0.00700***	-0.00559***
	(0.00111)	(0.00104)	(0.00112)	(0.00103)	(0.00111)	(0.00104)
NoIssuerGrade	-0.182***	-0.142***	-0.184***	-0.143***	-0.182***	-0.142***
	(0.0161)	(0.0157)	(0.0162)	(0.0157)	(0.0161)	(0.0158)
Temperature rise	0.000599	-0.000461				
	(0.000554)	(0.000569)				
Temperature rise*Post2015		-1.44e-05				
		(0.000303)				
Rainfall patterns			-0.00158**	-0.00135**		
			(0.000625)	(0.000675)		
Rainfall patterns*Post2015				-0.000598		
				(0.000388)		
Sea level rise					-0.00101**	0.000165
					(0.000395)	(0.000413)
Sea level rise*Post2015						-0.000636***
						(0.000191)
Constant	0.225***	0.235***	0.256***	0.236***	0.286***	0.221***
	(0.0468)	(0.0503)	(0.0461)	(0.0493)	(0.0495)	(0.0531)
Observations	9,138	9,138	9,138	9,138	9,138	9,138
R-squared	0.351	0.399	0.353	0.401	0.354	0.399
Country Fixed Effects	No	Yes	No	Yes	No	Yes
Industry Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes

Table 4

Climate risk and leverage: demand or supply effect?

This table presents additional OLS estimates of the effects of overall climate risk on the level of long-term debt. All regressions use BookLev as dependent variable and include country, industry and year fixed effects. In column 1, we include a variable interacting the overall climate risk and a dummy equal to 1 if the firm is headquartered in France, where lenders are subject to increased transparency requirements regarding their climate risks in the post-2015 period. In columns 2 to 5, we include a variable interacting the overall climate risk and a dummy equal to 1 if the firm is not rated (NoIssuerGrade = 1). Columns 2 and 3 report OLS estimates for the whole sample, and columns 4 and 5 report OLS estimates when excluding observations with BookLev equal to zero. The sample comprises all firms in the MSCI World index from 2010 to 2017, excluding financial firms (SIC 6000-6999). Standard errors (in parentheses) are clustered at the firm level. ***, **, and * denote significance at the 1%, 5% and 10% levels, respectively.

VARIABLES	(1) BookLev	(2) BookLev	(3) BookLev	(4) BookLev	(5) BookLev
EBIT	-0.164***	-0.197***	-0.163***	-0.230***	-0.186***
	(0.0542)	(0.0556)	(0.0540)	(0.0607)	(0.0593)
Log Age	-0.00145	-0.00232	-0.00133	-0.00309	-0.00200
	(0.00311)	(0.00312)	(0.00311)	(0.00318)	(0.00315)
TobinQ	0.00291	0.00208	0.00300	0.0128***	0.0140***
	(0.00325)	(0.00333)	(0.00326)	(0.00402)	(0.00391)
OpEx	-0.0503***	-0.0513***	-0.0502***	-0.0589***	-0.0581***
	(0.00866)	(0.00886)	(0.00866)	(0.00892)	(0.00869)
R&DExp	-0.580***	-0.582***	-0.584***	-0.620***	-0.635***
	(0.107)	(0.108)	(0.107)	(0.124)	(0.122)
Log TotAssets	-0.00326	-0.00612*	-0.00324	-0.0102***	-0.00693*
	(0.00351)	(0.00361)	(0.00351)	(0.00377)	(0.00367)
PPE	0.0947***	0.0928***	0.0951***	0.0760***	0.0785***
	(0.0261)	(0.0266)	(0.0261)	(0.0268)	(0.0263)
IssuerGrade	-0.00558***		-0.00565***		-0.00574***
	(0.00104)		(0.00103)		(0.00101)
NoIssuerGrade	-0.142***	-0.0777***	-0.132***	-0.0470*	-0.103***
	(0.0157)	(0.0263)	(0.0291)	(0.0264)	(0.0290)
Climate risk	-0.000233	-0.000257	-0.000171	-0.000189	-0.000126
	(0.000576)	(0.000666)	(0.000656)	(0.000664)	(0.000653)
Climate risk*Post2015	-0.00102***	-0.000802***	-0.000841***	-0.000726***	-0.000763***
	(0.000236)	(0.000244)	(0.000243)	(0.000258)	(0.000257)
Climate risk*France*Post2015	-0.000774***				
	(0.000267)				
Climate risk*NoIssuerGrade		0.000103	-0.000187	-0.000407	-0.000686
		(0.000649)	(0.000643)	(0.000665)	(0.000659)
Climate risk*NoIssuerGrade*Post2015		-0.000482***	-0.000477***	-0.000477***	-0.000470***
		(0.000131)	(0.000132)	(0.000144)	(0.000146)
Constant	0.237***	0.204***	0.230***	0.147**	0.169***
	(0.0537)	(0.0549)	(0.0557)	(0.0583)	(0.0587)
Observations	9,138	9,138	9,138	8,546	8,546
R-squared	0.400	0.390	0.400	0.371	0.383
Country Fixed Effects	Yes	Yes	Yes	Yes	Yes
Industry Fixed Effects	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes

Table 5

Credit rating and climate risk.

This table presents estimates of the effects of overall climate risk on credit rating. Columns (1) and (2) report OLS estimates using IssuerGrade (credit rating) as dependent variable, for firm-year observations with a credit rating. Columns (3) and (4) report OLS estimates using IssuerGrade (a dummy equal to 1 for firm-year observations without credit rating) as dependent variable. All regressions include country, industry and year fixed effects and exclude observations with missing Log IntCoverage. The sample comprises all firms in the MSCI World index from 2010 to 2017, excluding financial firms (SIC 6000-6999). Standard errors (in parentheses) are clustered at the firm level. ***, **, and * denote significance at the 1%, 5% and 10% levels, respectively.

VARIABLES	(1) IssuerGrade	(2) IssuerGrade	(3) NoIssuerGrade	(4) NoIssuerGrade
EBIT	12.42***	12.44***	-0.425**	-0.426***
	(1.925)	(1.922)	(0.165)	(0.165)
Log Age	0.345***	0.345***	-0.0408***	-0.0408***
	(0.110)	(0.110)	(0.0112)	(0.0112)
TobinQ	0.229*	0.228*	0.0323***	0.0323***
	(0.126)	(0.126)	(0.00988)	(0.00988)
OpEx	0.0907	0.0906	-0.0424*	-0.0424*
	(0.251)	(0.251)	(0.0256)	(0.0256)
R&DExp	-8.824**	-8.835**	0.316	0.316
	(4.084)	(4.087)	(0.349)	(0.349)
Log TotAssets	0.779***	0.778***	-0.116***	-0.116***
	(0.129)	(0.129)	(0.0108)	(0.0108)
PPE	0.878	0.883	0.0211	0.0211
	(0.647)	(0.647)	(0.0755)	(0.0755)
Log IntCoverage	-2.588	-2.554	1.674***	1.673***
	(8.251)	(8.263)	(0.430)	(0.430)
WorkingCap	1.819**	1.832**	0.211**	0.211**
	(0.842)	(0.841)	(0.0843)	(0.0843)
Climate risk	0.00201	0.00429	-0.00174	-0.00177
	(0.0170)	(0.0176)	(0.00173)	(0.00176)
Climate risk*Post2015		-0.00792		0.000109
		(0.00991)		(0.000691)
Constant	3.954**	3.880**	1.641***	1.642***
	(1.781)	(1.771)	(0.162)	(0.162)
Observations	5,955	5,955	8,884	8,884
R-squared	0.190	0.190	0.366	0.366
Country Fixed Effects	Yes	Yes	Yes	Yes
Industry Fixed Effects	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes

Appendix A. Variable Definitions

Variable	Description
BookLev	Ratio of long-term debt to book assets. DLTT/AT in Compustat
Climate risk	CRIS global risk grade for median scenario, 2050 time-horizon
Droughts	CRIS drought risk grade for median scenario, 2050 time-horizon
EBIT	Ratio of EBIT to book assets. EBIT/AT in Compustat
France	Equals one for companies headquartered in France and zero otherwise
Heavy rainfall	CRIS heavy rainfall risk grade for median scenario, 2050 time-horizon
Heat waves	CRIS heat wave risk grade for median scenario, 2050 time-horizon
IssuerGrade	This variable is based on S&P Long-term Issuer Rating when available. If not available, we rely on Moody's Long-term Issuer Rating; and eventually on Fitch Long-term Issuer Default Rating if both measures are not available. Similarly to Baghai et al. (2014), we linearize these ratings from 1 to 20. Missing ratings are coded 0. See Appendix B for more details
Log Age	Natural logarithm of the difference between the year of observation and the initial public offering year (using IPODATE in Compustat). If the Names file[1] indicates a higher age, we substitute the Names file number to our previous measure
Log IntCoverage	Natural logarithm of the ratio of EBIT to interest expenses. EBIT/XINT in Compustat
Log TotAssets	Natural logarithm of book assets (AT in Compustat). Book asset amounts are converted to US dollars using the year-end exchange rates from the OECD data portal[2]
MarketLev	Long-term debt divided by the sum of the year-end market capitalization and the difference between book asset value and common/ordinary equity. DLTT/(AT-CEQ+PRCC_F*CSHO)/AT in Compustat North America, DLTT/(AT-CEQ+PRCCD*CSHOC)/AT in Compustat Global
NoIssuerGrade	Equals one if IssuerGrade is null and zero otherwise
OpEx	Ratio of operational expenses to book assets. XOPR/AT in Compustat
Post2015	Equals one for observations after 2015 and zero otherwise
PPE	Ratio of net tangible assets to book assets. PPENT/AT in Compustat
R&DExp	Ratio of R&D expenses to book assets. XRD/AT in Compustat
Sea level rise	CRIS sea level rise risk grade for median scenario, 2050 time-horizon
Storms	CRIS storm risk grade for median scenario, 2050 time-horizon
TobinQ	Ratio of the sum of the year-end market capitalization and the difference between book asset value and common/ordinary equity, to book asset value. (AT-CEQ+PRCC_F*CSHO)/AT in Compustat North America, (AT-CEQ+PRCCD*CSHOC)/AT in Compustat Global
WorkingCap	Ratio of working capital to book assets. WCAP/AT in Compustat

[1] https://wrds-web.wharton.upenn.edu/wrds/tools/variable.cfm?library_id=129&file_id=65815
[2] https://data.oecd.org/conversion/exchange-rates.htm

Appendix B. Credit rating linearization

S&P Rating	Moody's Rating	Fitch Rating	Linear value
AAA	Aaa	AAA	20
AA+	Aa1	AA+	19
AA	Aa2	AA	18
AA-	Aa3	AA-	17
A+	A1	A+	16
A	A2	A	15
A-	A3	A-	14
BBB+	Baa1	BBB+	13
BBB	Baa2	BBB	12
BBB-	Baa3	BBB-	11
BB+	Ba1	BB+	10
BB	Ba2	BB	9
BB-	Ba3	BB-	8
B+	B1	B+	7
B	B2	B	6
B-	B3	B-	5
CCC+	Caa1	CCC+	4
CCC	Caa2	CCC	4
CCC-	Caa3	CCC-	4
CC	Ca	CC	3
C	C	C	2
RD	D	DDD	1
SD		DD	1
D		D	1