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The impact of climate vulnerability on firms' cost of capital and access to finance

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ABSTRACT

This article presents the first systematic investigation of the effects of climate-related vulnerability on firms' cost of capital and access to finance and sheds light on a hitherto under-appreciated cost of climate change for climate vulnerable developing economies. We first show theoretically how climate vulnerability could affect firms' cost of capital and access to finance. Apart from a possible impact on cost of debt and equity, which drive cost of capital, firms in countries with high exposure to climate risk might be more financially constrained. The latter results in low levels of debt relative to total assets or equity due to restricted access to finance. We then examine this issue empirically, using panel data of 15,265 firms in 71 countries over the period 1999–2017. We invoke panel data regressions and structural equation models, with firm-level data from the Thomson Reuters Eikon database and different measures of climate vulnerability based on the ND-GAIN climate vulnerability index. We construct a new climate vulnerability index and use panel instrumental variable regressions to address endogeneity problems. Our empirical findings suggest that climate vulnerability increases cost of debt directly and indirectly through its impact on restricting access to finance. However, we find limited evidence that climate vulnerability affects cost of equity. Our estimations suggest that the direct effect of climate vulnerability on the average increase in cost of debt from 1991 to 2017 has been 0.63%. In addition, the indirect effect through climate vulnerability's impact on financial leverage has contributed an additional 0.05%.

1. Introduction

Climate change is having real impact on economies already. Indeed, the frequency of natural disasters such as droughts, extreme temperatures, floods, landslides and storms, is on the rise (IPCC, 2018). This dramatic increase in climate change-related catastrophes translates into enormous economic costs. The direct impact of catastrophic natural disasters on economies is empirically well established (e.g., Cavallo, Galiani, Noy, & Pantano, 2013; Felbermayr & Gröschl, 2014; Ferreira & Karali, 2015; Mendelsohn, Kerry, Chonabayashi, & Bakkensen, 2015; Alano & Lee, 2016; Botzen, Deschenes, & Sanders, 2019). Moreover, both gradual global warming and natural disasters are associated with significant negative effects on long-run economic growth (e.g., Burke, Hsiang, & Miguel, 2015; Klomp & Valckx, 2014; Kompas, Pham, & Che, 2018; Kahn et al., 2019). Although impacts differ across countries, there is a consensus that the biggest impacts of climate change are being felt in developing countries.

One interesting dimension of these economic costs relates to recent empirical evidence by Kling, Lo, Murinde, and Volz (2018) that climate vulnerability increases the cost of sovereign borrowing: vulnerability to climate risks, as measured by the Notre-Dame Global Adaptation Initiative (ND-GAIN) sub-indices for climate sensitivity and capacity, has increased sovereign cost of debt by 1.17 percentage points on average for climate vulnerable developing countries over the last decade. The cost at which governments can access finance affects public budgets and governments' ability to invest in climate mitigation and adaptation; it also constrains possible investments in areas such as infrastructure, education and public health.

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This study explores a related and equally interesting question: how does climate vulnerability affect the private sectors' cost of capital and access to finance? In a recent attempt to address related issues, Huang, Kerstein, and Wang (2018) investigate the effect of climate-related risk on financing choices by publicly listed firms covering 54 countries from 1993 to 2012. They find that firms located in climate vulnerable countries anticipate the likelihood of losses from major storms, flooding, heat waves, and other adverse weather conditions by holding more cash, less short-term debt but more long-term debt, and are less likely to distribute cash dividends. Moreover, firms in certain industries are less vulnerable to extreme weather and so face less climate-related risks. However, the more directly relevant question is whether climate vulnerability increases firms' cost of capital and affects their access to finance. The latter is not covered by Huang et al. (2018) as they regard a firms' financing decision as a choice and not a consequence of being financially excluded.

This article examines the alleged impact of climate vulnerability on cost of capital first theoretically, identifying the main channels through which an effect can materialise. In summary, cost of capital refers to a weighted average of cost of debt and cost of equity. The weights represent the proportion of debt and equity finance. Theoretically, we outline how climate vulnerability can change cost of debt and equity. Finally, climate risks can contribute to financial exclusion as additional risks might make loans unviable for banks. Usually banks can charge higher interest rates to cover expected losses; however, frequent climate events might affect their abilities to predict outcomes and might make firms more vulnerable to higher interest rates, leading to credit rationing. Hence, the pricing mechanism can fail as shown theoretically by Kling (2018).

Empirically, this article tests these theoretical predictions using a large-scale panel dataset covering 15,265 firms in 71 countries over the period 1999–2017. First, we show that the ND-GAIN climate vulnerability index, the most widely used measure of climate vulnerability, is endogenous due to its close relationship with economic variables. Hence, to assess the impact of climate vulnerability on cost of capital, an instrument is needed. From raw data used by ND-GAIN to construct their indices, we redesign an index less correlated with macroeconomic variables. Second, we derive initial results for cost of debt and equity using panel instrumental variable regressions. Climate vulnerability does increase cost of debt – but not cost of equity. Third, to account for the alleged impact of climate vulnerability on access to finance and high correlations between GDP per capita and governance measures, we specify structural equation models. These reveal a direct effect of climate vulnerability in line with our instrumental variable approach – but also show an indirect effect as firms located in countries with high climate related risks exhibit restricted access to finance.

The analysis sheds light on a hitherto under-appreciated cost of climate change for climate vulnerable developing economies: higher corporate financing cost and financial exclusion. Both factors hold back economic development and by restraining fiscal revenue limit the scope of governments to invest in public (climate resilient) infrastructure and climate adaptation. Underinvestment in turn curbs growth prospects and puts firms in climate vulnerable developing economies at a disadvantage when competing in both domestic and export markets. In other words, the climate vulnerability risk premium causes a vicious circle, where a higher cost of capital reduces both sovereign and private sector investment, suppresses firm growth and tax revenue, and limits the scope for public adaptation finance.

The article is structured as follows. Section 2 reviews prior research. Section 3 then discusses theoretically the effect of climate vulnerability on firms' cost of capital as well as financial exclusion of firms. Section 4 provides an overview of the sample, the construction of variables, and a discussion of the ND-GAIN climate vulnerability index. Section 5 shows our empirical findings including descriptive statistics, endogeneity tests, panel instrumental variable regressions, and structural equation models. Finally, Section 6 concludes.

2. Prior research

The economic impact of climate change on both countries and corporations is complex and sometimes ambivalent. Several studies have investigated the relationship between global climate change and economic performance at the country-level (e.g., Dell, Jones, & Olken, 2014; Nordhaus, 2006). In addition, studies have also examined the influence of climate change on firm-level performance. Climate change may impact businesses from any industry and size. Firms may face several climate-related risks such as emission-reduction regulation and negative reactions from environmentally concerned investors or lenders. For instance, Beatty and Shimshack (2010) explore the relationship between greenhouse gas emissions and stock market returns. They find that some investors tend to react adversely to new information about greenhouse gas emissions, leading to a substantial decrease in stock market valuation between 0.6 and 1.6 percent. Another study by Konar and Cohen (2001) reports that bad environmental performance is negatively associated with the value of intangible assets of firms.

Even if government regulations intended to curtail greenhouse gas emissions are not currently introduced in every country, it may be a significant indicator for environmentally sensitive investors and lenders which increasingly demand more disclosure from firms. Matsumura, Prakash, and Vera-Munoz (2013) collect carbon emissions data from S&P 500 firms over the period 2006–2008 and find a negative relationship between carbon emissions and firm value. Their results suggest that firm value might fall by USD 212,000 for every additional thousand metric tons of carbon emissions.

Investors are increasingly considering environmental, social and governance (ESG) performance of businesses before they take investment decisions. Using data for 13,114 firms for the period 1992–2007, Chava (2014) identifies the effect of firms' environmental profile on their cost of equity and debt capital. According to this research, investors require higher expected returns from companies that are less concerned about climate change. Furthermore, Chava (2014) also finds that lenders charge a significantly lower interest rate on bank loans to environmentally responsible firms. More recently, Huang et al. (2018) analyse a dataset comprising 353,906 observations from 54 countries and find that climate risk at country level, measured by Germanwatch's Global Climate Risk Index which is based on economic losses and fatalities from extreme weather events, might be negatively related to firm earnings and positively related to earnings volatility. Previous research has also indicated that various environmental indicators have a positive impact on firms' cost of capital. Sharfman and Fernando (2008) examine data from 267 U.S. firms and assert that there is a negative relationship between environmental risk management and cost of capital, suggesting that better environmental risk management contributes to reducing firms' cost of equity.

El Ghoul, Guedhami, Kwok, and Mishra (2011) analyse data from 12,915 firms between 1992 and 2007 and find that corporate social responsibility (CSR) practices have an influence on equity financing. Dealing with employee relations and environmental issues decreases firms' cost of equity. Similarly, Dhaliwal, Li, Tsang, and Yang (2011) find a negative association between voluntary disclosure of CSR activities and firms' cost of equity capital.

Therefore, this may draw more attention of institutional investors and analyst coverage.

Climate risks are increasingly recognized as a serious and worldwide concern for both governments and businesses. This is also reflected by a growing number of financial supervisors who are calling on financial firms and corporations to disclose climate-related financial risks (Monasterolo, Battiston, Janetos, & Zheng, 2018). However, much uncertainty still exists about the relation between climate risks and cost of capital. Although some research has been carried out on the effect of global climate risk on firm performance using cross-country data (Huang et al., 2018), there is very little scientific understanding of the impact of climate risk as a determinant of firms' cost of capital and access to finance. This study aims to address this research gap.

3. Theoretical considerations

A firm's cost of capital refers to its weighted average cost of capital (WACC), denoted r_{WACC}, which depends on the proportion of debt finance (D) to debt and equity (D + E), the cost of debt (r_D), the cost of equity (r_E) and the marginal tax rate (τ). The latter matters as interest expenses are tax deductible in some countries, reducing the after-tax cost of capital. Denoting the proportion of debt finance L = D/(D + E), i.e. financial leverage, (1) states the WACC:

$$r_{WACC} = L \cdot r_D \cdot (1 - \tau) + (1 - L)r_E \qquad (1)$$

Due to differences in pay-out profiles, equity holders bear more risk than debt holders, requiring higher expected returns. This implies $r_E > r_D$. It is obvious from (1) that climate vulnerability (VUL) can increase the WACC r_{WACC} in three ways: (1) $\partial L/\partial VUL < 0$ (shift to equity as it is more difficult to secure debt finance, e.g. due to volatile cash flows); (2) $\partial r_D/\partial VUL > 0$ (increased cost of debt); and (3) $\partial r_E/\partial VUL > 0$ (increased cost of equity).

Considering the cost of debt, we can state the following components, where r_f refers to the risk-free rate, d is a default component (credit spread), and l is a liquidity component. The spread s contains the default and liquidity component:

$$r_D = r_f + \Delta INF + \Delta EX + d + l = \sum_{k=1}^{K} c_k D_k + r_f + s \qquad (2)$$

The risk-free rate usually refers to the yield of ten-year US government bonds. If debt is taken outside the US, country risk needs to be added (using country dummies D_k with k = 1, 2, ..., K), and the expected difference in inflation should be considered ΔINF. If debt is denominated in a foreign currency, differences in expected inflation should be reflected in exchange rates (purchasing power parity). Thus, an exchange rate effect can be added to (2).

The problem is that, empirically, most of these components cannot be determined due to lack of data. First, credit default swaps (CDS) are not available for most companies; hence, we cannot decompose the spread into a default and liquidity component. This is not a major limitation as working with annual data should suggest a low average liquidity component. Furthermore, the impact of climate vulnerability on default risk is more plausible. Second, financial data does not provide details on USD denominated debt and debt in other currencies. Hence, using country dummies we proxy country risk and other factors such as inflation differentials and exchange rate changes. Alternatively, both factors could be included in an empirical specification. From Eq. (2), climate vulnerability can affect cost of debt in three ways: (1) changing country risk; (2) influencing the risk-free rate, which seems to be less likely; (3) increasing the spread mainly due to higher default risk.

Finally, cost of equity is explained using the capital asset pricing model (CAPM), which links firms' cost of equity to the risk-free rate, the expected market risk premium and systematic risk through the beta coefficient. Note that r_m refers to the market return, and E is the expectations operator:

$$r_E = r_f + \beta(Er_m - r_f) \qquad (3)$$

Climate vulnerability can increase cost of equity by (1) shifting the risk-free rate as in the case of cost of debt, (2) changing the market risk premium, and (3) increasing a firm's beta coefficient. The latter point seems to be plausible at first; however, one needs to note that the market return is the sample average return. Thus, the average beta cannot increase due to climate change. Furthermore, there are empirical limitations. First, beta coefficients trend to vary over time. Second, the CAPM has low predictive power in less developed markets. Hence, it might be better to estimate country-level betas using countries' leading stock market index compared to the MSCI world market index.

The arguments thus far implicitly assume that firms have access to finance, i.e. firms have a choice between debt and equity finance reaching their desired leverage L* and raising their desired level of capital to invest and grow the firm. However, financial inclusion is not guaranteed and potentially itself a function of climate vulnerability. Hence, climate vulnerability might increase cost of debt under the condition that firms have access to finance, and climate vulnerability might contribute to a higher probability to be financially excluded. Financial exclusion can be due to information asymmetry, e.g. banks might struggle to derive expected default risk in countries exposed to high climate risk, but also price sensitivity (Kling, 2018). Basically, if higher interest rates increase default risk (i.e. make liquidity default more likely), it might be impossible to find an optimal interest rate that compensates for the expected default risk. This leads to credit rationing, even in the absence of information asymmetry.

4. Data and variables

4.1. Sampling

Our aim is to assess cost of debt and equity of firms located in countries with varying climate vulnerability. We use firm-level data from the Thomson Reuters Eikon database and try to include as many countries as possible. However, the database does not provide sufficient data for many small countries with high climate risk (e.g. Tuvalu). In particular, we try to cover countries that are members of the Climate Vulnerable Forum, which consists of 48 countries. Larger countries in this group such as Bangladesh, Ghana, Vietnam and Kenya can be included in the sample. For inclusion, we require at least ten companies with financial data in the Thomson Reuters Eikon database. In total, our sample contains 95,037 firm-year observations with 18,431 firm-year observations in countries with high climate vulnerability (see Section 4.2). Our panel dataset contains 15,265 firms from 71 countries after listwise deletion.[1] With 3,683 firms in high-risk countries, our analysis should be able to assess their cost of capital and access to finance.

The sample excludes financial firms as their investment and financing decisions differ from non-financial firms. For instance, deposit taking banks can finance their loan book through customers' savings. In addition, regulation for financial firms is strict and includes minimum equity requirements, which affects standard financial ratios.

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[1] We require that the database has information that permits calculating cost of debt, interest coverage, working capital, financial leverage, firm size, dividends, tangible assets, and return on assets.

4.2. Measuring climate vulnerability

Climate vulnerability data are obtained from the Notre Dame Global Adaptation Index (ND-GAIN). This index brings together 74 variables to form 45 core indicators for 181 countries to measure their environmental vulnerability and their readiness to adapt. The technical report outlines the methodology and data sources; hence, we refer to Chen et al. (2015) for a detailed discussion. Our focus is on climate vulnerability, which combines exposure, sensitivity and adaptive capacity. The latter is partly affected by countries' economic, political and social settings. Geography, however, determines a countries' exposure, which is not a matter of choice.

Inherently, climate vulnerability is not independent from macroeconomic conditions, which can cause empirical concerns such as endogeneity (see Section 5.2). This alleged problem is likely to be more pronounced when using the ND-GAIN climate readiness index, which focuses on economic, governance and social measures. These tend to be highly correlated; an issue we address in our structural equation model (see Section 5.5).

Exploring the ND-GAIN climate vulnerability index (VUL) for our sample and period from 1999 to 2017, we must ensure that countries exhibit a sufficient degree of variability. Otherwise, our analysis cannot distinguish between country-level fixed effects (dummies in regressions) and stable climate vulnerability. Fortunately, VUL exhibits some variability over time. For instance, Gambia exhibited an increase of 9.9% from 1995 to 2016, while Mongolia has improved by 15.9% as it benefits from rising temperatures. Section 5.2 explores the ND-GAIN VUL and empirical issues in more detail.

4.3. Construction of variables

The first dependent variable is cost of debt (COD), which we estimate using interest expense in year t divided by total debt reported in period t.[2] To obtain a firm-level proxy for cost of equity (COED), our second dependent variable, we rely on dividend payments relative to the value of equity. In addition, we derive country-level measures of cost of equity (COE) by estimating country betas (BETA) and market risk premiums (MRP). Data for the MRP is obtained from Damodaran (2013). Country betas are estimated using each countries' leading stock market index from which we obtain the stock market return. Countries' stock return is then regressed on the return of the US stock market, which provides an estimate of countries' beta coefficient.

Financial leverage is a standard control variable and measure of financial risk. Leverage (LEV) is calculated as the ratio of a firm's total debt to total assets. Firms with high leverage are highly indebted and hence riskier, resulting in higher cost of debt. However, if firms are financially constrained, i.e. they do not get access to debt finance, this relationship might not hold. For instance, a firm that cannot get a bank loan has low leverage – but it might be still risky. Net operating working capital measures a firm's access to trade credit, which lowers working capital. We measure working capital (WC) as operating current assets minus operating current liabilities. Interest coverage refers to earnings before interest and taxes divided by interest expenses (COVER). A high interest coverage reduces the risk of liquidity default as a firm can use its earnings to pay interest on debt. Firm size (SIZE) is defined as the log of total assets. Additional firm-level controls are dividend payments (DIV), tangible assets (TANG) and return on assets

(ROA). All variables on the firm-level are expressed relative to total assets.

Industry controls account for the volatility of cash flows to total assets (VOL) in an industry defined based on two-digit GICS codes. Firms operating in industries most affected by climate risk such as oil, gas, coal, energy & agriculture are flagged with an indicator variable labelled IND RISK. Our definition of industries more exposed to climate risks is partly overlaps with Huang et al. (2018). They use the term 'vulnerable industries', which include energy, oil and food production. They also incorporate business services, communication, health care and transportation. The categories of business services and communication are too broad, and health care and transportation are partly provided by public entities. Consequently, we use a narrower definition of vulnerable industries.

Country controls are based on the World Development Indicators database. We consider the log of GDP per capita in constant 2010 USD, annual GDP per capita growth rate (GROWTH), and population density (POP). To account for the quality of institutions and governance, we include the rule of law (LAW) based on the World Governance Indicators.

Finally, we include annual average rainfall (M RAIN) and temperature (M TEMP) as well as their standard deviations (SD RAIN, SD TEMP) provided by the World Bank. These country-level measures serve as exogenous variables, unaffected by countries' economic condition – but influenced by climate change. To mitigate the impact of outliers, we apply a winsorization to all variables at the 5 and 95-percentile. The Appendix summarises the definitions of variables and data sources.

5. Results

5.1. Descriptive findings

We estimate the cost of debt using interest expenses and total debt reported in firms' balance sheets. Countries that are in the top 25% regarding climate vulnerability are categorized as high-risk countries, whereas countries below that threshold are regarded as medium or low risk countries. If we want to compare cost of debt for both sub-groups of countries over time, year effects should be considered. The Asian crisis in 1997 and the Global Financial Crisis did have an impact on cost of debt, and they affected developing and developed countries differently due to loose monetary and fiscal policies in some countries. To account for these year effects, we ran a regression to explain cost of debt with year dummies. The year dummies alone only explain 0.45% of the observed variability in cost of debt. Yet, the F-test with a test statistic of 32.15 and p-value of 0.000 indicates explanatory power. Fig. 1 plots year adjusted average cost of debt in low and high-risk countries. After accounting for year effects, unexplained cost of debt has remained on a higher level in high-risk countries throughout the investigation period.

Table 1 reports cost of debt (COD), financial leverage (LEV), working capital relative to total assets (WC) and interest coverage (COVER) for low and high-risk countries in terms of their climate vulnerability. In line with Figure 1, cost of debt is considerably higher in countries more exposed to climate risk with a median of 6.1% compared to 3.2%. Companies located in these countries have higher financial leverage and working capital, although the difference in financial leverage is modest with a median of 12.7% compared to 12.2%. Median interest coverage is 4.38 in high-risk countries, which is considered healthy by rating agencies. However, companies in low-risk countries exhibit a median in excess of 8. Descriptive evidence suggests that companies in countries with more exposure to climate risks exhibit higher indebtedness

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[2] We also considered alternative measures based on taking the average level of debt in year t and t − 1, which does not lead to qualitatively different results.
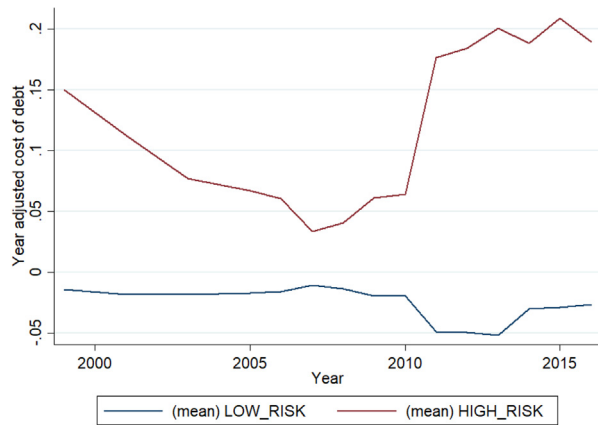
Fig. 1. Year adjusted average cost of debt in low and high-risk countries Notes: We explain cost of debt using year dummies and predict residuals. The average unexplained cost of debt is plotted for the two sub-groups of countries.

and higher financing costs. In addition, interest coverage suggests that financial risk is higher, which might justify higher cost of debt.

Table 2 shows descriptive statistics including the number of observations (N), the mean, median (p50), standard deviation (sd), the minimum, the maximum, the 25-percentile and the 75-percentile for the whole sample. The dependent variables refer to cost of debt (COD) measured based on interest expenses and short and long-term debt, the components of cost of debt (FIRM COMP, COUNTRY COMP, LONGRUN COMP) and cost of equity (COE). To obtain measures of cost of equity two approaches are followed. First, dividends relative to the value of equity are used to obtain firm-level measures (COED). Second, country-level measures refer to the country beta (BETA), i.e. the empirical beta coefficient of the countries' leading stock market index in relation to the US stock market index, and the market risk premium (MRP). The dividend-based measure is of limited use for certain industries, such as high-tech. Hence, the study focuses on the second approach.

Climate vulnerability is denoted VUL and based on the ND-GAIN. The following firm-level controls are expressed relative to

Table 1
Cost of debt and financial variables in low and high-risk countries.

Variables	N	Mean	Sd	Min	p25	Median	p75	Max
Low-risk countries								
COD	76,606	0.165	0.356	0.015	0.032	0.057	0.107	1.894
LEV	76,606	0.153	0.131	0.000	0.041	0.122	0.235	0.474
WC	76,606	0.167	0.192	−0.408	0.030	0.154	0.291	0.701
COVER	76,606	42.755	106.838	0.442	2.874	8.317	26.626	612.85
High-risk countries								
COD	18,431	0.309	0.492	0.015	0.061	0.111	0.26	1.894
LEV	18,431	0.166	0.146	0.000	0.037	0.128	0.268	0.474
WC	18,431	0.195	0.201	−0.408	0.053	0.179	0.325	0.701
COVER	18,431	33.721	101.13	0.442	1.471	4.381	14.625	612.85

Notes: After listwise deletion, two sub-samples of countries are defined based on whether they belong to the top 25% in terms of climate vulnerability or otherwise. The former sub-group is labelled high-risk countries. Descriptive statistics for both sub-groups include the number of observations (N), means, standard deviations (Sd), minimums (Min), 25th percentile (p25), medians, 75th percentile (p75), and maximums (Max).

Table 2
Descriptive statistics.

Variable	N	Mean	Sd	Min	p25	Median	p75	Max
COD	101,532	0.19	0.39	0.01	0.03	0.06	0.13	1.89
COE	96,733	0.04	0.02	0.00	0.03	0.04	0.05	0.10
COED	101,528	0.10	10.50	−94.38	0.00	0.02	0.05	3096.43
BETA	99,707	0.60	0.28	−0.57	0.42	0.55	0.84	1.66
MRP	98,507	0.07	0.03	0.05	0.06	0.06	0.09	0.23
VUL	101,532	0.37	0.06	0.26	0.34	0.37	0.37	0.57
N VUL	101,532	0.45	0.07	0.28	0.41	0.46	0.51	0.55
M RAIN	95,037	103.32	52.70	1.53	57.03	97.87	142.18	311.04
SD RAIN	95,037	53.10	31.94	2.67	22.98	56.00	73.05	314.91
M TEMP	95,037	13.78	7.50	−6.48	9.04	11.42	20.90	28.96
SD TEMP	95,037	6.81	2.93	0.22	4.55	8.05	9.14	15.89
LEV	101,532	0.16	0.13	0.00	0.04	0.12	0.24	0.47
WC	101,532	0.17	0.19	−0.41	0.03	0.16	0.30	0.70
COVER	101,532	42.31	108.00	0.44	2.57	7.61	25.07	612.85
SIZE	101,532	19.74	1.94	13.73	18.36	19.71	21.21	22.93
DIV	101,532	0.01	0.02	0.00	0.00	0.01	0.02	0.06
TANG	101,532	0.31	0.22	0.00	0.12	0.27	0.45	0.81
ROA	101,532	0.07	0.05	0.00	0.03	0.06	0.10	0.20
IND RISK	101,532	0.17	0.37	0.00	0.00	0.00	0.00	1.00
VOL	101,532	560.04	1143.69	0.31	9.15	49.2	375.81	4508.17
GDP	101,532	10.03	1.25	6.45	9.39	10.7	10.77	11.63
GROWTH	101,532	1.83	2.52	−14.38	0.8	1.58	2.97	23.94
POP	101,532	328.07	866.26	1.72	51.6	253.47	350.54	7915.73
LAW	101,532	1.08	0.72	−1.85	0.52	1.34	1.6	2.1

Notes: Descriptive statistics include the number of observations (N), means, standard deviations (Sd), minimums (Min), 25th percentile (p25), medians, 75th percentile (p75), and maximums (Max).

total assets. They include financial leverage (LEV), net operating working capital (WC), interest coverage (COVER), cash holding (CASH), dividend payments (DIV), research and development (RD), tangible assets (TANG) and return on assets (ROA). Finally, to account for firm size we use the log of total assets (SIZE).

Country-level controls refer to the log of GDP per capita in constant 2010 USD (GDP), annual GDP per capita growth rate (GROWTH), population density (POP), and the rule of law (LAW). Industry measures account for cash flow risk in the industry (VOL) and flag high-risk industries (IND RISK) such as oil, gas, energy and agriculture.

5.2. Endogeneity

Trying to explain cost of debt using climate vulnerability and a set of explanatory variables including macroeconomic controls might suffer from endogeneity depending on how climate vulnerability is measured. A stated in Section 4.2, we use climate vulnerability (VUL) compiled by the Notre-Dame Global Adaptation Initiative (ND-GAIN). ND-GAIN also reports a readiness index, which combines many economic indicators, increasing the likelihood of endogeneity problems. However, even the climate vulnerability index contains some measures, which are potentially correlated with macroeconomic variables. Table 3 outlines the underlying measures used in the construction of the climate vulnerability index in the six life-supporting sectors (e.g. water, food, etc.).

To disentangling climate and economic measures in the climate vulnerability index, we explore the underlying raw data used to construct the climate vulnerability index and remove measures that exhibit a strong relation with macroeconomic variables. Table 3 indicates whether the respective measure has a low, medium or high alleged correlation with economic variables. From raw data, we re-construct a vulnerability index, which excludes measures with assumed high correlation with economic variables. Hence, we take indicators 1, 2 and 3 for the food sector, indicators 1, 2, 3 and 4 for water, 1 and 2 for health, 1, 2, 4, 5 and 6 for ecosystems, 1 and 2 for human habitat, and 1, 2, 3 and 4 for infrastructure. This newly constructed index denoted N_VUL reflects countries' climate vulnerability but should be less correlated with countries' financial or economic conditions, which might cause endogeneity.

To test for endogeneity in our panel dataset, we follow Wooldridge (2010). Starting with a random-effects model on the firm level, we try to explain cost of debt (COD) using the original climate vulnerability index (VUL) and a set of control variables including financial leverage (LEV), working capital (WC), interest coverage (COVER), firm size (SIZE), dividend payments (DIV), tangible assets (TANG) and return on assets (ROA).

$$COD_{it} = \alpha_1 + \beta_1 VUL_{jt} + \beta_2 SIZE_{it} + \cdots + u_i + \varepsilon_{it} \quad (4)$$

In Eq. (4), u_i refers to the firm-level random effect, capturing any unobserved firm-level variables. A second equation explains the alleged endogenous variable, the climate vulnerability index (VUL), using all explanatory variables in (4) and the newly constructed vulnerability index denoted N_VUL.

$$VUL_{jt} = \alpha_2 + \delta_1 N\_VUL_{jt} + \beta\delta_2 SIZE_{it} + \cdots + w_{it} \quad (5)$$

From Eq. (5) (see [R1] in Table 4), we obtain the residuals, which we include in the first Eq. (4). The coefficient of the residual denoted VUL_hat exhibits a p-value of 0.000. Hence, we reject the null hypothesis that the coefficient is equal to zero, suggesting that the climate vulnerability index (VUL) is endogenous (see [R2] Table 4).

Accordingly, an instrumental variable approach is needed; however, we must ensure that the newly constructed climate vulnera-

Table 3
Measures for climate vulnerability and their relatedness to economic variables.

Sector	Indicators	Related to economic variables
Food	1 Projected change of cereal yields	Low
	2 Projected population change	Medium
	3 Food import dependency	Medium
	4 Rural population	High
	5 Agriculture capacity	High
	6 Child malnutrition	High
Water	1 Projected change of annual runoff	Low
	2 Projected change of annual groundwater recharge	Low
	3 Fresh water withdrawal rate	Low
	4 Water dependency ratio	Low
	5 Dam capacity	High
	6 Access to reliable drinking water	High
Health	1 Projected change of deaths from climate induced diseases	Medium
	2 Projected change in vector-borne diseases	Medium
	3 Dependency on external resource for health services	High
	4 Slum population	High
	5 Medical staff	High
	6 Access to improved sanitation facilities	High
Ecosystems	1 Projected change of biome distribution	Low
	2 Projected change of marine biodiversity	Low
	3 Natural capital dependency	High
	4 Ecological footprint	Medium
	5 Protected biome	Medium
	6 Engagement in international environmental conventions	Medium
Habitat	1 Projected change of warm periods	Low
	2 Projected change of flood hazard	Low
	3 Urban concentration	High
	4 Age dependency ratio	High
	5 Quality of trade and transport infrastructure	High
	6 Paved roads	High
Infrastructure	1 Projected change of hydropower generation capacity	Medium
	2 Projected change of sea level rise impacts	Medium
	3 Dependency on imported energy	Medium
	4 Population living under 5 m above sea level	Medium
	5 Electricity access	High
	6 Disaster preparedness	High

bility index (N_VUL) is a suitable instrument. Considering GDP per capita as a proxy for countries' economic and financial conditions, the original climate vulnerability index exhibits a very high negative correlation (−0.8676). This is in line with our finding that the climate vulnerability index (VUL) is endogenous as countries with low GDP per capita, i.e. challenging economic and financial conditions, tend to score highly in terms of climate vulnerability. The newly constructed climate vulnerability index (N_VUL) is positively correlated with the climate vulnerability index (VUL) with a correlation coefficient of (0.7207) and – most importantly – shows a much lower negative correlation of −0.3331 with GDP per capita. These findings hint that the newly constructed index might be a suitable instrument.

However, to ensure that the newly constructed index passes an endogeneity test, additional instruments are needed. Using country-level data provided by the World Bank on monthly temperature and rainfall from 1991 to 2016, we determine annual average temperature and rainfall (M_RAIN, M_TEMP) as well as

Table 4
Endogeneity tests.

	[R1]	[R2]	[R3]	[R4]
VUL		−0.568***		
VUL_hat		2.233***		
N_VUL	0.658***			−0.306***
N_VUL_hat				0.022
LEV		−1.315***		−1.299***
WC	0.012***	−0.100***	0.006***	−0.119***
COVER	−0.000***	−0.000***	0.000***	−0.000***
SIZE	−0.006***	−0.034***	0.001***	−0.029***
DIV	0.324***	0.774***	−0.245***	0.244
TANG	0.033***	−0.049***	0.005***	−0.087***
ROA	0.083***	0.192***	0.018***	0.018
M_RAIN			0.000***	
SD_RAIN			0.001***	
M_TEMP			0.009***	
SD_TEMP			0.024***	
Adj. R^2	0.581		0.794	
R^2_w		0.121		0.123
R^2_b		0.261		0.218
R^2_o		0.197		0.164
N	101,532	101,532	95,037	95,037

Note: [R2] and [R4] refer to firm-level random effects with clustered standard errors. [R1] and [R2] are OLS regression to predict climate vulnerability (VUL) and the newly constructed index (N_VUL), respectively. VUL_hat and N_VUL_hat refer to residuals from equations [R1] and [R2], respectively. For random effects models, overall (o), within (w) and between (b) R-squared are reported.

* $p < 0.05$.

** $p < 0.01$.

*** $p < 0.001$.

standard deviations of temperature and rainfall (SD_RAIN, SD_TEMP). The four exogenous variables, i.e. not affected by country-level economic variables, are used in equation (5) and explain 79.4% of the observed variability of N_VUL (see [R3] in Table 4). Inserting the predicted residual from this equation into the first equation leads to an insignificant coefficient of N_VUL_hat, suggesting that the newly constructed index is indeed exogenous and is a suitable instrument (see [R4] in Table 4).

Having found a valid instrument, we adopt an instrumental variables panel-data model, where our constructed climate vulnerability index serves as an instrument for the 'off the shelf' climate vulnerability index. Firm-level effects are modelled using random effects, and our models include country and year dummies to capture any unobserved year effects or country-specific effects.

5.3. The determinants of cost of debt

Selecting cost of debt as dependent variable, five multivariate models provide insights into the impact of climate vulnerability (VUL) on firms' cost of debt. Table 5 presents the five model specifications. In line with Section 5.2, all models refer to instrumental variable regressions, where the newly constructed climate vulnerability index (N_VUL) serves as an instrument for the ND-GAIN climate vulnerability index (VUL). To account for unobserved country-level and year effects, all specifications add country and year dummies. As we work with panel data, i.e. firms observed over time, all models also consider firm-level random effects. Hence, we can be confident that any remaining partial impact of climate vulnerability is not explained by unobserved firm, country or year effects or affected by an endogeneity bias due to the construction of the ND-GAIN climate vulnerability index.

Specification [A1] demonstrates that climate vulnerability as a single factor increases firms' cost of debt. Model [A2] incorporates firm controls, highlighting expected partial impacts such as negative effects of firm size (SIZE), working capital (WC), interest coverage (COVER) and tangible assets (TANG). Specification [A3] adds industry measures and demonstrates that firms in industries with more pronounced cash flow volatility (VOL) do exhibit higher cost of debt, while other partial impacts remain unchanged. Operating in a high-risk industry such as such as oil, gas, energy and agriculture (IND RISK) does not seem to add explanatory power.

Adding country-level controls in model [A4] changes the sign of climate vulnerability but no other partial effects. Hence, even after accounting for endogeneity of the ND-GAIN climate vulnerability index some problems remain as the rule of law and GDP per capita are highly correlated with a correlation coefficient of 0.882. Finally, model [A5] adds financial leverage (LEV), which is associated with higher cost of debt, which seems to be counter intuitive. However, if firms face high cost of debt, they might be forced to look for alternative sources of finance, reducing their financial leverage. This effect might also explain that high dividend payments (DIV) are associated with high cost of debt, which can be used as a proxy for cost of equity. Firms with higher profitability (ROA) seem to face higher cost of debt. In countries with expensive access to debt, internal finance is the predominant source of funding, explaining the positive association between cost of debt and ROA.

To disentangle the impact of climate vulnerability on cost of debt and the alleged impact on access to finance, which might drive our findings regarding the negative impact of financial leverage on cost of debt, Section 5.5 specifies structural equation models (SMEs). In these models, we can also account for the fact that countries with low GDP per capita tend to also exhibit weak governance.

5.4. Cost of equity

Establishing the impact of climate vulnerability on cost of equity is more challenging as firm level proxies of cost of equity are more difficult to obtain. There are two approaches to estimating cost of equity. First, one could rely on a dividend growth model and use dividends relative to the value of equity as a proxy. Our measure denoted COED refers to this approach. However, many firms, mostly in the high technology sector, do not pay any dividends, limiting the usefulness of this measure. Second, the capital asset pricing model (CAPM) suggests that cost of equity of a firm i can be estimated using a stochastic market model as in (5), where r_{mt} represents the market index and r_{ft} is the risk-free rate.

Table 5
Determinants of cost of debt.

	[A1]	[A2]	[A3]	[A4]	[A5]
VUL	4.360***	3.270**	3.295**	0.643	−0.201
WC		−0.185***	−0.185***	−0.142***	−0.112***
COVER		−0.000***	−0.000***	−0.000***	−0.000***
SIZE		−0.035***	−0.034***	−0.039***	−0.019***
DIV		0.653***	0.653***	0.654***	0.119
TANG		−0.295***	−0.293***	−0.269***	−0.134***
ROA		0.365***	0.366***	0.359***	−0.033
IND_RISK			−0.009	−0.006	−0.004
VOL			0.000***	0.000***	0.000
GDP				0.422***	0.103**
GROWTH				−0.004***	−0.002*
POP				−0.000***	−0.000***
LAW				−0.058***	−0.023
LEV					−1.278***
R_w^2	0.058	0.095	0.095	0.106	0.216
R_b^2	0.092	0.152	0.153	0.161	0.295
R_o^2	0.000	0.012	0.012	0.025	0.125
N	101,532	101,532	101,532	101,532	101,532

Note: All models refer to instrumental variable regressions, where the newly constructed climate vulnerability index (N_VUL) serves as an instrument for the ND-GAIN climate vulnerability index (VUL). All specifications add country and year dummies. All models use firm-level random effects. Overall (o), within (w) and between (b) R-squared are reported.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

$$r_E = r_f + \beta(Er_m - r_f) \qquad (6)$$

Eq. (6) is difficult to estimate in less developed markets as these economies tend to be less integrated, resulting in lower betas. Moreover, betas tend to vary over time, and the quality of data (e.g. lack of trading) is an issue. Hence, we estimate country-betas, comparing the leading stock market index with the US market, i.e. we take the perspective of an US investor. The difference between countries' leading stock market index and the risk-free rate is the market risk premium (MRP).

Table 6 shows multivariate models that explain country-level measures such as the expected cost of equity (COE) using country betas and countries' market-risk premium in column [B1], whereas specification [B2] explains country betas and [B3] countries' market risk premia. All models refer to instrumental variable regressions, where the newly constructed climate vulnerability index (N_VUL) serves as an instrument for the ND-GAIN climate vulnerability index (VUL). Specifications [B1] to [B3] are country-level models, which include year dummies.

As shown in specification [B1], overall climate vulnerability does not have a significant partial impact on countries' cost of equity. Models [B2] and [B3] show that climate vulnerability reduces a country's beta, whereas it increases a country's market

Table 6
Determinants of cost of equity.

	[B1]	[B2]	[B3]	[B4]
VUL	0.022	−2.025***	0.125***	−6.312
BETA	0.074***			
MRP	0.303***			
LEV				0.533
WC				0.101
COVER				0.000
SIZE				0.019
TANG				0.296
ROA				−0.122
IND_RISK				0.189*
VOL				−0.000
GDP	0.002**			0.111
GROWTH	0.000			0.011
POP	−0.000			−0.000
LAW	−0.002***			0.286
Adj. R²	0.885	0.324	0.194	
R_w^2				0.001
R_b^2				0.007
R_o^2				0.000
N	762	797	934	101,528

Note: All models refer to instrumental variable regressions, where the newly constructed climate vulnerability index (N_VUL) serves as an instrument for the ND-GAIN climate vulnerability index (VUL). Specifications [B1] to [B3] refer to country-level models. Year dummies are added in these three models. Model [B4] uses firm-level random effects and adds country and year dummies. All specifications add country and year dummies. For random effects models, overall (o), within (w) and between (b) R-squared are reported.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

risk premium. Countries more exposed to climate risk tend to be less developed and hence less integrated with developed markets such as the US, reducing the correlation between markets, captured by the country beta. In contrast, the market risk premium – both effects seem to offset each other. Using our firm-level proxy of cost of equity, model [B4] applies firm-level random effects and adds country and year dummies. Model [B4] cannot establish any partial impact on firm-level proxies using dividend payments. In summary, there is limited evidence that climate vulnerability contributes to higher cost of equity.

5.5. Structural equation model

The instrumental variable approach used to derive the findings in Tables 5 and 6 did account for the endogeneity of the ND-GAIN climate vulnerability index. However, two additional issues remain: first, GDP per capita and the rule of law are highly correlated; second, access to finance might be constrained in countries more exposed to climate risk. The latter might explain our findings based on model [A5] in Table 5 that firms with higher leverage exhibit lower cost of debt, which is counter intuitive.

To disentangle the effect of climate vulnerability and its alleged association with cost of debt and access to finance, we specify a structural equation model. Fig. 2 illustrates a simplified structure of the model, which permits that climate vulnerability affects cost of debt directly and indirectly through its impact on access to

Fig. 2. Illustrated structural equation model *Notes:* We estimate four equations: (1) explaining cost of debt (COD) with a set of explanatory variables including leverage (LEV) and climate vulnerability (VUL); (2) explaining the rule of law (LAW) using GDP per capita; (3) explaining climate vulnerability (VUL) using the newly constructed index (N_VUL) and GDP; (4) explaining access to finance (LEV) using climate vulnerability and other variables.

finance, i.e. firms positioned in countries with high climate vulnerability might not get the level of debt needed. Hence, these financially constrained firms exhibit low leverage and high working capital as other sources of funding are used such as trade credit.

To derive a model with good fit, we start with a parsimonious specification and add neglected links or error covariances into the model as suggested by modification indices. The initial specification takes model [A5] to explain cost of debt (COD). It then adds additional equations to capture the link between countries' GDP per capita and the rule of law and – similar to our instrumental variable approach – the impact of GDP per capita and the newly constructed climate vulnerability index on the ND-GAIN climate vulnerability index. Finally, a fourth equation models financial leverage, as a measure of access to debt finance, using climate vulnerability, firm-level and macroeconomic variables as controls. This initial model exhibits inadequate goodness-of-fit measures as the Root Mean Square Error of Approximation (RMSEA) is 0.108, above the cut-off point of 0.1, and the Comparative Fit Index CFI is 0.944, slightly below 0.95 suggested by Acock (2013). Hence, in line with Wooldridge (2010) and Sörbom (1989), we determine modification indices and incorporate additional variables (one-by-one) and covariances between error terms until we obtain a model that satisfies these criteria. Finally, we add country and year-dummies to capture any unobserved variables.

Climate vulnerability (VUL) has a positive direct effect on cost of debt shown in column one [C1] of Table 7 in line with previous models [A1] to [A4]. In addition, column three [C3] shows that companies based in countries with high climate vulnerability exhibit lower financial leverage. That is, after controlling for firm-level variables (firm size, interest coverage, dividend payments, tangible assets, return on assets) and macroeconomic variables (GDP, growth, population growth, rule of law), these firms do not take or get the same expected level of debt. Hence, climate vulnerability has an indirect effect through restricting access to finance. Column two [C2] reiterates our finding that the ND-GAIN climate vulnerability index is correlated with GDP per capita and the newly constructed climate vulnerability index (N_VUL). Finally, column four [C4] shows the interrelation between GDP per capita and the rule of law. The effect of the rule of law is more complicated, as the direct effect on cost of debt is negative [C1] – but firms located in countries with better governance can achieve higher financial leverage, providing a positive indirect effect of the rule of law.

Are the direct and indirect effects of climate vulnerability on cost of debt of economic significance? On average, climate vulnerability has increased by 0.0057 from 1991 to 2017, which resulted in a direct effect of $0.0057 \times 1.102 = 0.0063$, i.e. on average cost of debt has increased by 0.63%. In addition, the indirect effect through climate vulnerability's impact on financial leverage has contributed to $0.0057 \times (-0.071) \times (-1.116) = 0.0005$. Hence, the combined impact on cost of debt has been 0.63% + 0.05% = 0.68%.

6. Conclusion

Our article combines the effect of climate vulnerability on firms' cost of capital as well as financial exclusion of firms. Our analysis highlights a previously under-appreciated economic cost of climate change for climate vulnerable developing economies. Our results suggest that companies in countries with a greater exposure to climate risks exhibit higher financing costs and are financially more constrained.

This has significant implications for economic development: higher corporate financing cost and financial exclusion restrain economic growth and development, reduce tax revenue, and limit the scope of governments to undertake investments in public
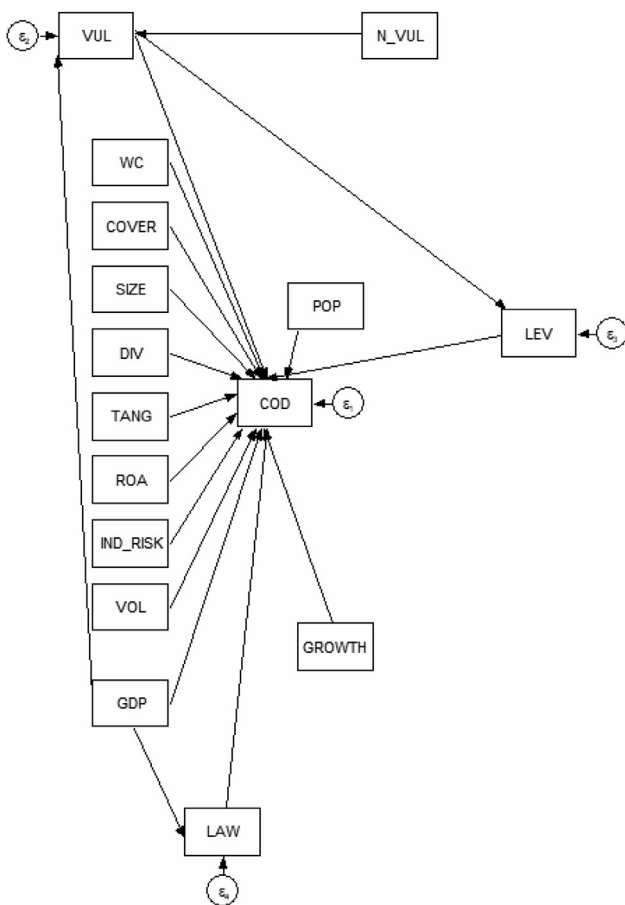
Table 7
Structural equation model.

Dependent variable	[C1] COD	[C2] VUL	[C3] LEV	[C4] LAW
VUL	1.102**	–	−0.071***	–
N_VUL		0.426***	–	–
LEV	−1.116***	–	–	–
WC	−0.103***	–	–	–
COVER	−0.000***	–	−0.000***	–
SIZE	−0.016***	–	0.016***	–
DIV	0.145	–	−0.054*	–
TANG	−0.136***	–	0.099***	–
ROA	−0.048	–	−0.235***	–
IND_RISK	−0.006	–	–	–
VOL	0.000	–	–	–
GDP	0.179***	−0.036***	−0.043***	0.506***
GROWTH	−0.002*	–	0.001***	–
POP	−0.000***	0.000***	−0.000***	–
LAW	−0.039**	–	0.065***	–
RMSEA	0.085			
CFI	0.966			
N	101,532			

* p < 0.05.
** p < 0.01.
*** p < 0.001.

infrastructure and climate adaptation. This, in turn, contributes to greater vulnerability, curbs economies' growth prospects and puts the corporate sector in climate vulnerable developing economies at a disadvantage when competing in both domestic and foreign markets. Thus, the climate vulnerability risk premium could cause a vicious circle, where a higher cost of capital reduces both public and private sector investment, suppresses firms' growth and public tax revenue, and limits the scope for public adaptation finance.

Given that climate risks are expected to increase in the future, climate vulnerability is likely to increase without adaptation investments that can mitigate these risks, which implies that the cost of capital for the public and private sector in climate vulnerable economies are bound to increase unless this vicious circle can be reversed. For this to happen, climate vulnerable developing economies – which have not caused global warming and are not able to address the root causes through national action – will need international support. International support through innovative risk transfer mechanisms would help to reduce the cost of capital in climate vulnerable countries, enabling private and public investments that will empower these countries to enter a virtuous circle where higher investments and growth allow for greater adaptation finance, greater resilience and lower climate vulnerability, which will reduce the cost of capital, facilitate further investment, and improve firm competitiveness.

Conflict of interest statement

The authors have no financial and personal relationships with other people or organizations that could inappropriately influence (bias) their work.

Declarations of interest

None.

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Appendix. Definitions of variables and data sources

Variable	Definition	Data source
COD	Cost of debt measured as interest expense in year t divided by total debt reported in period t	Thomson Reuters Eikon database
COE	Country-level cost of equity estimated using country betas and market risk premiums	Damodaran (2013)
COED	Firm-level cost of equity measured as dividend payments relative to equity	Thomson Reuters Eikon database
BETA	Country betas are estimated using each countries' leading stock market index regressed on the return of the US stock market	Thomson Reuters Eikon database
MRP	Market risk premium defined as average stock market return minus the risk-free rate proxied by 10-year US government bond yield	Damodaran (2013)

Appendix (*continued*)

Variable	Definition	Data source
VUL	ND-GAIN climate vulnerability index	ND-GAIN
N VUL	Newly constructed climate vulnerability index (see Section 5.2)	ND-GAIN (raw data)
M RAIN	Annual average rainfall based on monthly data	World Bank
SD RAIN	Annual standard deviation of rainfall based on monthly data	World Bank
M TEMP	Annual average temperature based on monthly data	World Bank
SD TEMP	Annual standard deviation of temperature based on monthly data	World Bank
LEV	Leverage defined as the ratio of a firm's total debt to total assets	Thomson Reuters Eikon database
WC	Working capital refers to operating current assets minus operating current liabilities	Thomson Reuters Eikon database
COVER	Interest coverage refers to earnings before interest and taxes divided by interest expenses	Thomson Reuters Eikon database
SIZE	Firm size is defined as the log of total assets	Thomson Reuters Eikon database
DIV	Dividend payments relative to total assets	Thomson Reuters Eikon database
TANG	Tangible assets relative to total assets	Thomson Reuters Eikon database
ROA	Return on assets	Thomson Reuters Eikon database
IND RISK	Industries most affected by climate risk such as oil, gas, coal, energy & agriculture	Thomson Reuters Eikon database
VOL	Volatility of cash flows to total assets in an industry defined based on two-digit GICS codes	Thomson Reuters Eikon database
GDP	Log of GDP per capita in constant 2010 USD	World Development Indicators
GROWTH	Annual GDP per capita growth rate	World Development Indicators
POP	Population density	World Development Indicators
LAW	The rule of law	World Governance Indicators

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