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

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Abstract

This paper investigates the effect of climate-related risk on firms' cost of capital and access to finance. Building on recent findings that climate vulnerability significantly increases sovereign cost of debt, we posit a 'pass-through effect' whereby higher sovereign cost of debt affects firms' cost of capital in two ways: it raises the costs of corporate debt; and it induces financial exclusion as credit-constrained firms are priced out of the market due to credit rationing. We invoke panel data regressions and structural equation models, using firm-level data from the Thomson Reuters Eikon database matched with ORBIS/Bureau van Dijk data on financial firms. We also use a novel measure, the distance to the steady-state, to estimate firms' production functions, their steady-state and the shadow price of access to finance (or financial inclusion). Our empirical findings confirm the posited effects of the climate vulnerability risk premium on sovereign debt on both corporate cost of capital and on firms' financial inclusion. Our analysis of 63,102 firms in 80 countries over the period 1993-2017 shows that on average the cost of debt in high-risk countries is 0.83 percentage points higher than in low-risk countries because of climate vulnerability.

Keywords: Financial inclusion, cost of capital, firms access to finance, climate risk

Preprint submitted to Working Paper *August 10, 2019*

1. Introduction

Climate risk is real. Indeed, the frequency of natural disasters such as droughts, extreme temperatures, floods, landslides and storms, is on the rise (ECIU, 2017). This dramatic increase in weather-related catastrophes translates into enormous economic costs. The direct link between catastrophic natural disasters and economic growth is empirically established (Cavallo et al., 2013). Moreover, both climate change and natural disasters are associated with significant negative effects on economic growth, as shown, for instance, by Mei et al. (2015); Mendelsohn et al. (2015); Felbermayr and Groschl (2014); Alano and Lee (2016); and Ferreira and Karali (2015), among others.

One interesting dimension of these economic costs relates to the recent empirical evidence by Kling et al. (2018) that climate risk increases the cost of sovereign borrowing. It is found that that climate risk, as measured by the Notre-Dame Global Adaptation Initiative (ND-GAIN) sub-indices for climate sensitivity and capacity, has increased sovereign debt costs by 1.17 percentage points on average for climate vulnerable developing countries over the last decade. This fiscal impact of climate risk is important because climate vulnerable countries can only access debt at a higher risk premium that is triggered by climate risk. The cost at which governments can access finance affects the public budget and the government's ability to invest in climate mitigation and adaptation; it also constrains possible investments in areas such as infrastructure, education and public health.

An equally interesting question is how the increased cost of sovereign debt affects the performance of firms in climate vulnerable countries, i.e., what are the ramifications of climate vulnerability for investments undertaken by the private sector? In a recent attempt to address this question, Huang et al. (2018) investigate the effect of climate-related risk on financing choices by publicly listed firms across the world. It is found that firms located in climate vulnerable countries anticipate the likelihood of loss 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. It is also found that firms in certain industries are less vulnerable to extreme weather and so face less climate-related risk. However, the more directly relevant question is the 'pass through effect' from the increase in sovereign cost of debt to an increase in firms' cost of debt capital, associated with climate risk. To the best of our knowledge, this question has not been addressed in the existing literature.

In this paper, we address the above question by examining the implications of the climate vulnerability risk premium on sovereign debt for the private corporate sector. Higher sovereign cost of debt can be expected to affect firms' cost of capital in two ways: first, it raises the costs of corporate debt, and second, it causes financial exclusion as firms are being priced out of the market due to credit rationing. These effects reduce firm value (e.g., market to book value) as discounted cash flows have lower value and lead to less investment. Lower investment, in turn, limits firms' competitiveness and growth. We first discuss these relationships theoretically. Subsequently, we investigate this nexus empirically.

In summary, our paper combines the effect of climate vulnerability on the cost of corporate debt as well as financial exclusion of firms. Our empirical findings confirm the predicted effects of the climate vulnerability risk premium on sovereign debt on the financing conditions of the private corporate sector. We find effects both on the cost of capital and on financial exclusion. Both effects limit growth, which in turn reduces productivity from economies of scale and investment into better production technologies. We therefore conclude that climate vulnerability is holding back the competitiveness and the development prospects of the corporate sector in climate vulnerable developing economies.

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 hold back economic development and by restraining fiscal revenue limit the scope of governments to invest in public (climate resilient) infrastructure and climate adaptation, which in turn curb growth prospects and put 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 paper is structured as follows. Section 2 provides a brief literature review. Section 3 then discusses theoretically the effect of climate vulnerability on the cost of corporate debt as well as financial exclusion of firms. Section 4 provides an overview of the data and variables that we use for our empirical analysis, followed by a review of descriptive findings in Section 5. Section 6 presents and discusses the results of our multivariate analysis. Section 7 concludes.

2. Prior research

The economic impact of climate risk 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 (Dell et al., 2014; Nordhaus, 2006). A number of 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 risk related issues such as emission-reduction regulation and negative reactions from environmentally concerned investors/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 intangible asset value 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 et al. (2013) collected 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 $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. 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) analyze a dataset comprising 353,906 observations from 55 countries and find that climate risk at country level 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 et al. (2011) analyze data from 12,915 firms between 1992 and 2007 and find that corporate social responsibility (CSR) practices have an influence on equity financing. In particular, dealing with employee relations and environmental issues decreases firms' cost of equity. Similarly, Dhaliwal et al. (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 risk is increasingly recognized as a serious and worldwide concern for both governments and businesses. However, much uncertainty still exists about the relation between climate risk 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. 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, reducing the after-tax cost of capital. Denoting the proportion of debt finance $L = \frac{D}{D+E}$, i.e. financial leverage, (1) states the WACC:

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

Due to differences in payout 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 (CV) can increase the WACC r_{WACC} in three ways: (1) $\frac{\partial L}{\partial CV} < 0$ (shift to equity: it is more difficult to secure debt finance, e.g. due to volatile cash flows); (2) $\frac{\partial r_D}{\partial CV} > 0$ (increased cost of debt); and (3) $\frac{\partial r_E}{\partial CV} > 0$ (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:

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

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 $k = 1, 2, \ldots, K$), 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 (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:

$$r_E = r_f + \beta\left(Er_m - r_f\right) \tag{3}$$

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 $\sum_{i=1}^{N} \beta_i = 1$, where $i = 1, 2, \ldots, N$ refers to firms. This is true as 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 make 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. The latter also causes costs due to delayed investment. This can be quantified by deriving the shadow price of external finance. In a theoretical model developed by Kling (2018), firms with access to a given production technology face financial constraints which reduce these firms' ability to invest. In particular, firms cannot raise enough capital externally to invest in their capital stock and hence must rely on internal finance (cash flows). The exclusion from external finance reduces their ability to grow their capital stock. Consequently, firms that are excluded from capital markets cannot reach their full potential determined by their production technology, i.e., they grow more slowly. This slow growth results in a quantifiable cost, the shadow price of access to finance.

4. Data and variables

For our econometric analysis we use firm-level data from the Thomson Reuters Eikon database and match these with ORBIS/Bureau van Dijk data on financial firms. We derive firms' cost of debt and their financial health including financial leverage, net operating working capital and interest coverage. Based on these firm-level indicators, we derive the impact on climate vulnerability on cost of debt using panel data regressions. Apart from the direct effect of climate vulnerability on the cost of debt, we consider financial exclusion using a novel measure, the distance to steady-state developed by Kling (2018). Using standard methods, we estimate firms' production functions, their steady-state and the shadow price of access to finance. The latter serves as a measure of financial exclusion.

In this research, we investigate the role of climate vulnerability (VUL) in affecting a firm's cost of debt. 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 environmental vulnerability and readiness which means how ready they are to adapt. It also offers various information to us about which countries are best prepared to handle global changes and climate risk.

We also use firms' financial data on balance sheets, income statements, and cash flow statements from Thomson Reuters Eikon Database. Our dependent variables include measures of cost of debt (COD) and its components as outlined in Section 5.2. We estimate a firm's cost of debt using interest expense in year t divided by total debt reported in period t. To obtain firm-level proxies for cost of equity (COED), 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 is obtained from Damodaran et al. (2013), which also includes data on credit risk measured by yield spreads (SPREAD).

Financial leverage is another significant indicator of the degree to which a firm deals with its debt and preferred equity. It is calculated as the ratio of a firm's total debt to the total debt and the book value of equity (LEV). Net operating working capital also provides us with some insights about financial health. We measure working capital (WC) as the excess of operating current assets over operating current liabilities. Interest coverage shows us exactly to what extent a firm could pay its interest expenses on its debt. It is measured by dividing earnings before interest and taxes by the interest expenses for the same period (COVER). Additional firm-level controls are cash holding (CASH), dividend payments (DIV), research and development spending (RD), tangible assets (TANG) and return on assets (ROA). All variables on the firm-level are expressed relative to total assets. Firm size (SIZE) refers to the log of total assets.

Industry controls account for the volatility of cash flows to total assets 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 labeled IND RISK.

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. To mitigate the impact of outliers, we apply a winsorization to all variables at the 5 and 95-percentile.

5. Descriptive findings

5.1. Comparison of key variables

We estimate the cost of debt using interest expenses and total debt reported in firms' balance sheets. Countries that are in the top 25% with regard to climate vulnerability are categorized as high-risk countries, whereas countries below that threshold are regarded as medium or low risk countries. Based on this classification, Figure 1 plots the median cost of debt for both groups of countries, demonstrating that climate vulnerable countries exhibit higher cost of debt.

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 higher in countries more exposed to climate risk. Companies located in these countries have higher financial leverage and lower interest coverage. However, working capital, a measure for short-term liquidity management, seems to be similar across these two groups of countries. Accordingly, descriptive evidence suggests that companies in countries with more exposure to climate risk exhibit higher indebtedness and higher financing costs. In addition, interest coverage suggests that financial risk is higher, which might justify higher cost of debt.

[Insert Figure 1]

[Insert Table 1]

5.2. Decomposition of cost of debt

To identify the firm (*FIRM COMP*), country (*COUNTRY COMP*) and long-run components of cost of debt (*LONGRUN COMP*), we apply the decomposition developed by

Rhodes-Kropf et al. (2005). We regress the log of interest expenses, $\ln(\text{INTER})_{it}$, of firm i in year t on the log of debt $\ln(\text{DEBT})_{it}$. Coefficients, α_{0jt} and α_{1jt}, vary over time and country j.

$$\ln(\text{INTER})_{it} = \alpha_{0jt} + \alpha_{1jt} \ln(\text{DEBT})_{it} + \epsilon_{it} \tag{4}$$

(4) constitutes a benchmarking exercise, where interest expenses are related to firms' level of debt, country and time-specific effects. In particular, firm-specific errors refer to the observed interest expense minus the predicted value given a firm's level of debt, where coefficients vary over time and across countries. Country-specific effects are equal to the difference in predicted valuations with varying time-country coefficients and predictions based on time averages. Hence, coefficients in (4) are averaged over time so that $\bar{\alpha}_{1j} = \frac{1}{T}\sum_{t=1}^{T} \alpha_{1jt}$. The difference between predicted interest expenses based on time averages and actual levels of debt determines the long-run component, which reflects a firm's long-run cost of debt.

Table 2 reports the three components of cost of debt for low and high-risk countries in terms of climate vulnerability. Country specific differences do matter but firm and long-term time effects seem to be relatively more important. Most importantly, firms located in high-risk countries have on average (and based on medians) higher cost of debt overall and in all three components. This decomposition method does not identify underlying drivers for the three components. For instance, climate vulnerability, macroeconomic factors and other control variables can influence all three components. Further, multivariate analysis is needed to disentangle these observed differences. This will be conducted in Section 6.

[Insert Table 2]

5.3. *Descriptive statistics*

Table 3 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).[1] 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 estimated default risk (SPREAD) is based on countries' credit ratings and differences in bond yields compared to US government bonds.

Climate vulnerability is denoted VUL and based on the Notre-Dame Global Adaptation Initiative. The following firm-level controls are expressed relative to 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),

[1]The dividend based measure is of limited use for certain industries, e.g. high-tech. Hence, the study focuses on the second approach.

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.

[Insert Table 3]

6. Multivariate analysis

6.1. The determinants of cost of debt

Selecting cost of debt as dependent variable, five OLS regressions, which account for year dummies, provide insights into the impact of climate vulnerability (VUL) on firms' cost of debt. Table 4 presents five model specifications. Standard errors are based on the Huber-White sandwich estimator and hence robust in the presence of heteroscedasticity. Specification [*A*1] demonstrates that climate vulnerability as a single factor increases firms' cost of debt. Model [*A*2] 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). Low financial leverage (LOW) 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. These effects remain unchanged even after using random-effects models.

Specification [$A3$] adds industry measures and demonstrates that firms in industries more exposed to climate change exhibit higher cost of debt, while other partial impacts remain unchanged. Adding country-level controls in model [$A4$] changes the sign of climate vulnerability but not other partial effects. Multicollinearity between GDP per capita and climate vulnerability (correlation coefficient −0.89) and the rule of law and climate vulnerability (correlation coefficient −0.72) is to blame for this effect. Replacing the continuous measure of climate vulnerability (VUL) with a dummy for medium to high risk countries (MEDIUM) in model [$A5$] reemphasizes that climate risk does increase of cost debt.

[Insert Table 4]

To disentangle the effect of climate vulnerability and its alleged association with countries' GDP per capita and the rule of law, we specify a structural equation model (SEM). Figure 2 illustrates the simplified structure of the model, which permits that climate vulnerability affects cost of debt directly and indirectly through its interaction with country-level variables. Note that CON in Figure 2 refers to other control variables. Table 5 depicts the initial specification [$S1$]. This model exhibits inadequate goodness-of-fit measures as the Root Mean Square Error of Approximation (RMSEA) is not below 0.05 and the Comparative Fit Index (CFI) is not above 0.95 as 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 the covariance between error terms of GDP per capita and the rule of law. Subsequent models such as [$S2$] and finally [$S3$] meet the required criteria.

Climate vulnerability (VUL) has a negative direct effect on cost of debt but a positive indirect effect through countries' level of development based on log GDP per capita. Hence, countries with higher climate risk exhibit lower log GDP per capita, resulting in higher cost of debt. The interrelation between economic development, the rule of law and climate risk is more complicated. After accounting for all control variables, the direct impact of the rule of law on cost of debt is positive – but the coefficient is small, suggesting low economic significance. This finding seems to be counter-intuitive, requiring further explanation. Economic development and the rule of law are positively related; hence, the impact of the former seems to dominate, driving cost of debt.

[Insert Figure 2]

[Insert Table 5]

Table 6 combines the direct and indirect effects of each variable on cost of debt. This is shown for the overall cost of debt in column labeled ALL and the three components of cost of debt. The combined effect of climate vulnerability on cost of debt and all of its components is positive. After controlling for the interrelation between good governance, economic development and climate vulnerability, it is evident that countries more exposed to climate risk suffer an additional increase in cost of debt. The effect of GDP per capita is negative based on all three components of cost of debt. Yet, the impact of the rule of law is again more complicated. In line with Table 5, the overall impact of the rule of law on cost of debt is positive with a small magnitude of impact. However, on the country level and in the long run, improving the rule of law diminishes these components – but the firm-level effects dominate. In summary, the results demonstrate that economic development as measured by the log GDP per capita is a reliable predictor of cost of debt. Climate risk drives cost of capital through its impact on the log GDP per capita.

[Insert Table 6]

Our empirical results can provide an estimate of the average impact of climate vulnerability on cost of debt based on 63,102 of firms in 80 countries over the period 1993-2017. Considering the partial impact reported in Table 6 based on the structural-equation model, we estimate an effect of 0.061 on cost of debt due to a marginal increase in climate vulnerability. Taking the average values of climate vulnerability in low and high-risk countries suggests that cost of debt is $(0.478-0.342)\times 0.061 = 0.830\%$ higher in high-risk countries than in low-risk countries due to their climate vulnerability.

6.2. *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.

$$r_{it} = \alpha + \beta_i(r_{mt} - r_{ft}) + u_{it} \tag{5}$$

Equation (5) 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 r_{mt}, the market index, and r_{ft}, the risk-free rate, is the market risk premium (MRP). Using data based on Damodaran et al. (2013), we can establish the following model parameters, where j is the index of countries in our sample.

$$r_{jt} = \alpha + \beta_j(r_{mt} - r_{ft}) + \nu_{jt} \tag{6}$$

Table 7 explores country-level measures such as the expected cost of equity (COE) using country betas and countries' market-risk premium in column [$B1$], country betas [$B2$] and the market risk premium [$B3$]. As shown in specification [$B1$], overall climate vulnerability increases cost of equity using country-level measures. Models [$B2$] and [$B3$] show that climate vulnerability reduces a country's beta, whereas it increases a country's market 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 is higher due to higher default risk. Finally, 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.

[Insert Table 7]

6.3. Financial exclusion

Any study on cost of capital needs to rely on reported items in firms' income statements and balance sheets. Firms that are financially excluded do not have access to finance and might report low levels of debt or might appear debt-free. To capture lost growth opportunities, we need to establish a profit or production function, linking firms' financial outcome π (measured by earnings before interest and taxes, EBIT) to inputs such as financial assets A and labor L, which is measured by the number of employees. Using a standard Cobb-Douglas production function with total factor productivity T, we estimate the following specification in logs:

$$\pi_{it} = TA^{\alpha}L^{\beta}$$

$$\ln \pi_{it} = \ln T + \alpha \ln A + \beta \ln L + w_{it} \tag{7}$$

To permit a change in parameters for countries more exposed to climate risk, we incorporate the dummy MEDIUM and interaction terms as follows:

$$\ln \pi_{it} = \ln T + \alpha \ln A + \beta \ln L + w_{it} \tag{8}$$

Table 8 reports different specifications based on (7) in [$P1$], with year dummies [$P2$], industry dummies [$P3$], and country dummies [$P4$]. Model [$P5$] estimates (8) and establishes significant effects of medium to high-risk countries on the profit function. All specifications show that $\alpha + \beta < 1$, i.e. overall firms have declining returns to scale.

[Insert Table 8]

From (7) and (8), the marginal product of capital (MPC) can be calculated.

$$\text{MPC} = \frac{\partial T f(A, L)}{\partial A} = \alpha T L^{\beta} A^{\alpha - 1} \tag{9}$$

Optimal investment in capital A^* follows from setting (9) equal to cost of capital.

$$A^* = \left(\frac{T \alpha L^{\beta}}{\text{COC}} \right)^{\frac{1}{1-\alpha}} \tag{10}$$

Hence, comparing actual capital with optimal capital results in a measure of underinvestment, which we standardize so that the measure lies in the closed interval $[0, 100]$. On average, low risk countries have lower marginal products of capital suggesting higher investment. They tend to invest close to optimal levels. In contrast, firms located in medium and high-risk countries have higher marginal products of capital and show signs of underinvestment.

7. Conclusion

Our paper combines the effect of climate vulnerability on the cost of corporate debt as well as financial exclusion of firms. Our analysis highlights a previously under-appreciated cost of climate change for climate vulnerable developing economies. Our results suggest clearly that companies in countries with more exposure to climate risk exhibit higher indebtedness and higher financing costs. In summary, our analysis of 63,102 firms in 80 countries over the period 1993-2017 shows that on average the cost of debt in high-risk countries is 0.83 percentage points higher than in low-risk countries because of climate vulnerability.

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 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 sovereign and private sector investment, suppresses firm growth and 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 and improve firm competitiveness.

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Figure 1: Median cost of debt in low and high risk countries

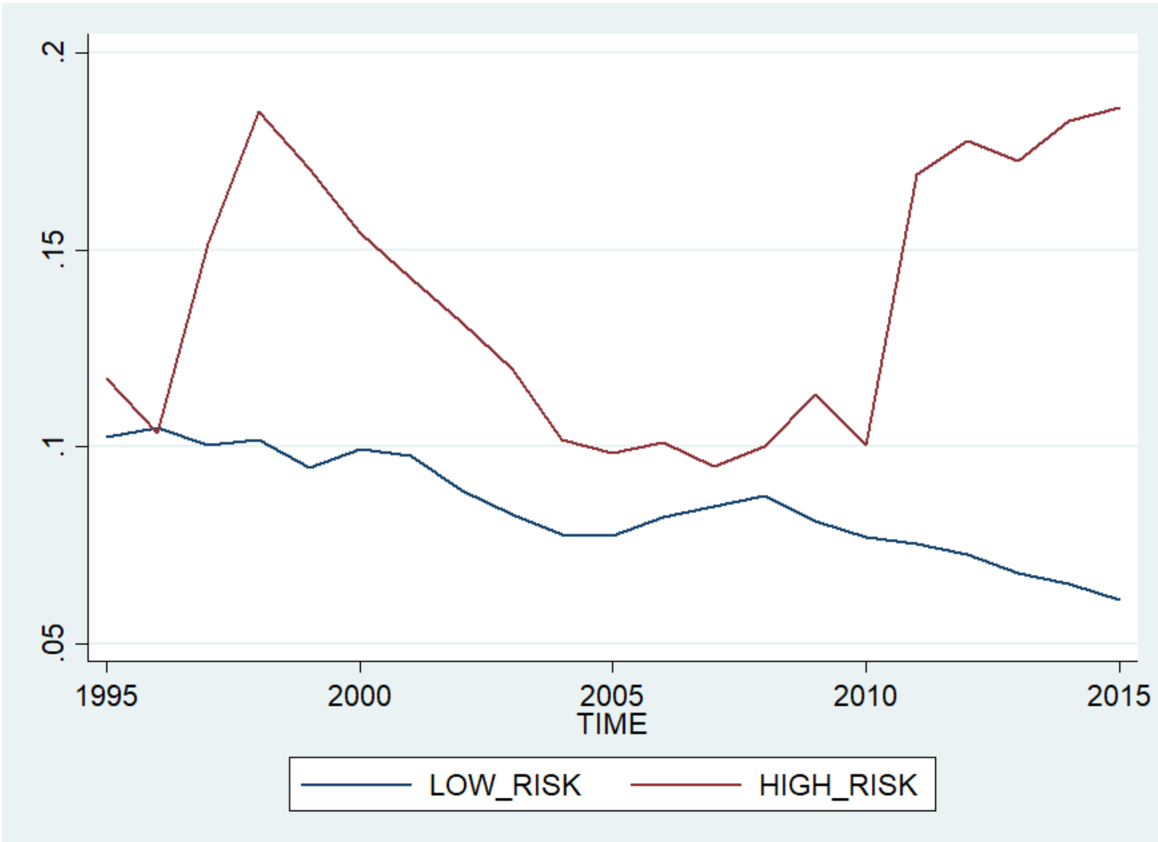

Figure 2: Simplified structure of the SEM

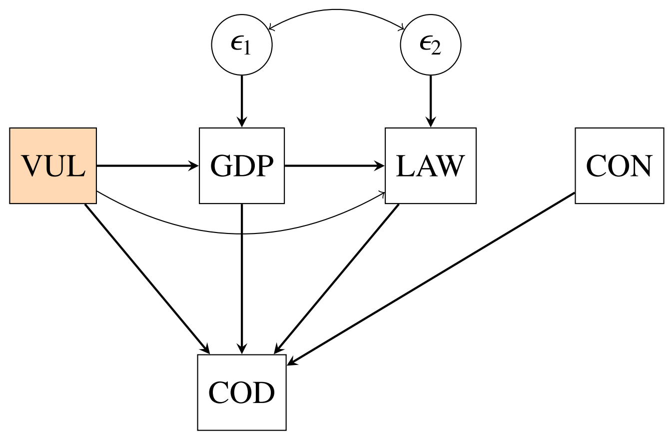

Table 1: Descriptive statistics

	N	mean	sd	min	p25	p50	p75	max
Low-risk countries								
COD	200,104	0.240	0.441	0.015	0.043	0.078	0.173	1.894
LEV	200,093	0.168	0.146	0.000	0.043	0.129	0.260	0.474
WC	194,463	0.136	0.227	-0.408	-0.003	0.123	0.277	0.701
COVER	131,186	38.129	100.447	0.442	2.468	7.211	22.812	612.850
High-risk countries								
COD	42,484	0.355	0.527	0.015	0.070	0.132	0.322	1.894
LEV	42,482	0.185	0.158	0.000	0.043	0.143	0.308	0.474
WC	42,034	0.142	0.228	-0.408	0.003	0.130	0.288	0.701
COVER	26,910	33.615	100.897	0.442	1.465	4.437	14.865	612.850

Table 2: Decomposed cost of debt

	N	mean	sd	min	p25	p50	p75	max
Low-risk countries								
FIRM COMP	200,070	1.477	1.441	0.163	0.560	1.006	1.764	6.050
COUNTRY COMP	200,070	1.043	0.259	0.577	0.892	1.012	1.151	1.729
LONGRUN COMP	200,104	0.147	0.155	0.026	0.048	0.087	0.183	0.724
High-risk countries								
FIRM COMP	42,450	1.568	1.484	0.163	0.602	1.112	1.882	6.050
COUNTRY COMP	42,450	1.064	0.359	0.577	0.729	1.035	1.371	1.729
LONGRUN COMP	42,484	0.228	0.201	0.026	0.089	0.154	0.285	0.724

Table 3: Descriptive statistics

	N	mean	sd	min	p25	p50	p75	max
COD	264,315	0.258	0.458	0.015	0.045	0.084	0.194	1.894
FIRM COMP	243,399	0.005	0.906	-1.813	-0.568	0.025	0.579	1.800
COUNTRY COMP	369,456	0.010	0.274	-0.549	-0.136	0.014	0.164	0.548
LONGRUN COMP	406,143	-2.147	0.921	-3.639	-2.874	-2.204	-1.503	-0.323
COE	1,019,784	0.036	0.025	-0.003	0.019	0.034	0.048	0.097
BETA	1,462,377	0.464	0.359	-0.621	0.172	0.435	0.763	2.067
MRP	1,072,734	0.075	0.029	0.045	0.055	0.064	0.088	0.320
SPREAD	1,072,734	1.594	1.933	0.000	0.000	0.800	2.500	18.000
VUL	1,384,284	0.377	0.072	0.260	0.333	0.363	0.414	0.596
LEV	613,990	0.107	0.143	0.000	0.000	0.033	0.174	0.474
WC	562,962	0.173	0.275	-0.408	0.003	0.157	0.353	0.701
COVER	210,132	63.807	145.177	0.442	2.691	8.740	35.139	612.850
SIZE	614,651	18.531	2.421	13.732	16.934	18.579	20.204	22.930
CASH	225,857	0.089	0.138	0.000	0.005	0.030	0.101	0.526
DIV	502,228	0.010	0.016	0.000	0.000	0.000	0.013	0.059
R D	135,254	0.094	0.165	0.000	0.005	0.023	0.088	0.641
TANG	585,497	0.277	0.246	0.003	0.053	0.219	0.442	0.810
ROA	339,552	-0.032	0.220	-0.779	-0.037	0.024	0.076	0.198
GDP	1,515,343	9.501	1.513	6.055	8.166	10.494	10.724	11.626
GROWTH	1,514,535	2.987	4.204	-34.898	1.046	2.348	4.784	92.123
POP	1,501,613	236.395	719.322	1.457	32.879	125.523	263.908	7915.730
LAW	971,470	0.782	0.965	-1.852	-0.140	1.299	1.627	2.100
IND RISK	1,577,550	0.095	0.293	0.000	0.000	0.000	0.000	1.000
VOL	1,577,550	482.543	1140.026	0.307	1.954	13.541	167.650	4508.168

Table 4: Determinants of cost of debt

	[A1]	[A2]	[A3]	[A4]	[A5]
VUL	0.595***	0.534***	0.534***	-1.367***	
MEDIUM					0.039***
LEV		-1.212***	-1.213***	-1.128***	-1.125***
WC		-0.134***	-0.132***	-0.107***	-0.128***
COVER		-0.000***	-0.000***	-0.000***	-0.000***
SIZE		-0.023***	-0.023***	-0.018***	-0.018***
DIV		1.151***	1.133***	0.440***	0.939***
TANG		-0.130***	-0.134***	-0.130***	-0.156***
ROA		0.215***	0.214***	0.125***	0.152***
IND_RISK			0.014***	0.010***	0.013***
VOL			0.000	0.000**	0.000**
GDP				-0.116***	-0.032***
GROWTH				-0.004***	0.001
POP				0.000***	0.000
LAW				0.009**	-0.011**
ll	-1.55e+05	-5.93e+04	-5.92e+04	-4.14e+04	-4.19e+04
aic	3.09e+05	1.19e+05	1.19e+05	82779.843	83870.028
bic	3.09e+05	1.19e+05	1.19e+05	82923.217	84013.402
r2_a	0.007	0.184	0.184	0.200	0.191
N	242588	137248	137248	104635	104635

Note: All models refer to OLS regressions with year dummies and robust standard errors.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 5: Structural equation models

	[S1]	[S2]	[S3]
COD			
GDP	-0.113***	-0.113***	-0.113***
LAW	0.011***	0.011***	0.011***
VUL	-1.340***	-1.340***	-1.340***
LEV	-1.126***	-1.126***	-1.126***
WC	-0.107***	-0.107***	-0.107***
COVER	-0.000***	-0.000***	-0.000***
SIZE	-0.019***	-0.019***	-0.019***
DIV	0.443***	0.443***	0.443***
TANG	-0.128***	-0.128***	-0.128***
ROA	0.132***	0.132***	0.132***
IND_RISK	0.010**	0.010**	0.010**
VOL	0.000	0.000	0.000
GROWTH	-0.002***	-0.002***	-0.002***
POP	0.000***	0.000***	0.000***
GDP			
VUL	-17.730***	-16.221***	-16.236***
COVER		0.001***	0.001***
DIV		-6.002***	-6.532***
GROWTH		-0.106***	-0.106***
POP		0.000***	0.000***
LAW			
VUL	-9.161***	2.893***	3.504***
GDP		0.695***	0.727***
LEV		0.575***	0.606***
SIZE		-0.029***	-0.032***
DIV			2.976***
N	104635	104635	104635
RMSEA	0.239	0.056	0.047
CFI	0.625	0.987	0.991

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 6: Total effects based on SEM

	ALL	FIRM	COUNTRY	LONGRUN
GDP	-0.335	-0.061	-0.340	-0.675
LAW	0.023	0.118	-0.039	-0.090
VUL	0.061	0.107	0.003	0.059
LEV	-0.372	-0.345	-0.169	-0.274
WC	-0.052	-0.098	-0.071	-0.003
COVER	-0.108	-0.183	-0.087	0.062
SIZE	-0.093	0.274	-0.011	-0.433
DIV	0.049	0.014	-0.006	0.079
TANG	-0.070	-0.085	0.012	-0.036
ROA	0.018	-0.007	0.002	0.036
IND RISK	0.009	0.006	0.002	0.027
VOL	0.005	0.004	-0.027	0.008
GROWTH	0.066	0.035	-0.124	0.130
POP	-0.004	0.007	-0.002	-0.010

Table 7: Determinants of cost of equity

	[B1]	[B2]	[B3]	[B4]
VUL	0.022^{*}	-1.794^{***}	0.152^{***}	0.226
BETA	0.073^{***}			
MRP	0.288^{***}			
LEV				0.534
WC				0.066
COVER				0.000
SIZE				0.012
TANG				0.230
ROA				0.284
IND_RISK				0.195
VOL				-0.000
GDP	0.002^{**}			0.035
GROWTH	0.000			-0.002
POP	-0.000			-0.000
LAW	-0.002^{***}			-0.044
ll	2792.901	-121.806	2587.238	-4.57e+05
aic	-5569.803	247.611	-5170.477	9.14e+05
bic	-5531.945	257.899	-5160.218	9.15e+05
r2_a	0.890	0.312	0.188	0.000
N	839	1266	1248	124669

Note: All models refer to OLS regressions with year dummies and robust standard errors. Model [*B*1] explains country-level cost of equity, whereas [*B*2] uses country betas as dependent variable. Model [*B*3] has market risk premiums as dependent variable, and [*B*4] explains firm level measures of cost of equity.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 8: Estimating profit functions

	[P1]	[P2]	[P3]	[P4]	[P5]
MEDIUM					-1.082***
ln_TA	0.839***	0.834***	0.841***	0.829***	0.827***
MEDIUMxln_TA					0.073***
ln_EMP	0.115***	0.117***	0.117***	0.107***	0.122***
MEDIUMxln_EMP					-0.034***
ll	-2.49e+05	-2.49e+05	-2.45e+05	-2.47e+05	-2.34e+05
aic	4.99e+05	4.98e+05	4.89e+05	4.94e+05	4.68e+05
bic	4.99e+05	4.98e+05	4.89e+05	4.94e+05	4.68e+05
r2_a	0.752	0.753	0.755	0.760	0.752
N	162750	162750	160785	162750	152306

Note: All models refer to OLS regressions with year dummies and robust standard errors.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$