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Feeling the Heat: Climate Shocks and Credit Ratings

by Serhan Cevik and João Tovar Jalles

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Feeling the Heat: Climate Shocks and Credit Ratings

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Abstract

Climate change is an existential threat to the world economy like no other, with complex, evolving and nonlinear dynamics that remain a source of great uncertainty. There is a bourgeoning literature on the economic impact of climate change, but research on how climate change affects sovereign risks is limited. Building on our previous research focusing on the impact of climate change on sovereign risks, this paper empirically investigates how climate change may affect sovereign credit ratings. By means of binary-choice models, we find that climate change vulnerability has adverse effects on sovereign credit ratings, after controlling for conventional macroeconomic determinants of credit worthiness. On the other hand, with regards to climate change resilience, we find that countries with greater climate change resilience benefit from higher (better) credit ratings. These findings, robust to a battery of sensitivity checks, also show that impact of climate change is disproportionately greater in developing countries due largely to weaker capacity to adapt to and mitigate the consequences of climate change.

JEL Classification Numbers: C23; C35; C36; G24; Q54; Q56

Keywords: Climate change; vulnerability; resilience; credit ratings

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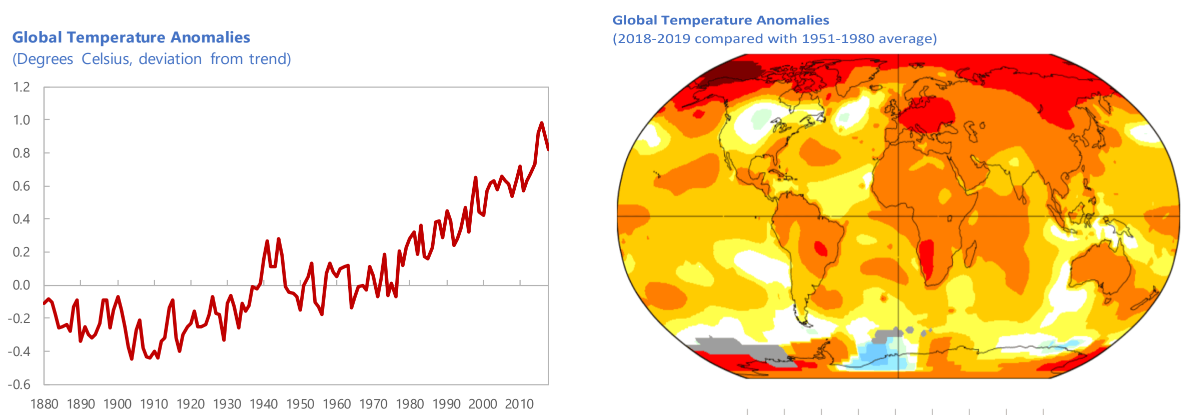
I. Introduction

Climate change is an existential threat to the world economy like no other, with complex, evolving and nonlinear dynamics that remain a source of great uncertainty. The global annual average surface temperature has already increased by 1.1 degrees Celsius since 1880, intensifying the frequency and severity of climate shocks—ranging from heatwaves and droughts to hurricanes and coastal flooding—across the world (Figure 1). Extreme weather events are projected to worsen over the next century, as the global annual mean temperature increase by as much as 4 degrees Celsius (IPCC, 2007; Stern, 2007; IPCC, 2014).[2] The economic consequences of climate change will be felt across the world, but the extent of potential vulnerability depends on the size and composition of economies, the resilience of institutions and physical infrastructure, and the capacity for adaption and mitigation.

There is a bourgeoning literature on the economic impact of climate change (Gallup et al., 1999; Nordhaus, 2006; Dell et al., 2012), but research on how climate change affects sovereign risks is limited. In Cevik and Jalles (2020a), we show that climate change vulnerability and resilience have significant effects on government bond yields and spreads, after controlling for conventional macroeconomic factors, especially in developing countries. In Cevik and Jalles (2020b), we uncover another layer of empirical information by showing the impact of climate change on the probability of sovereign default. In this paper, we focus on how climate change may affect sovereign credit ratings, using a novel dataset of climate change vulnerability and resilience developed by the Notre Dame Global Adaptation Institute (ND-GAIN).[3] This is an area of great

Figure 1. Weather Anomalies Across the World



Source: NOAA.

[2] Climate refers to a distribution of weather outcomes for a given location, and climate change describes environmental shifts in the distribution of weather outcomes toward extremes.

[3] In this paper, we focus on countries' exposure to physical risks that correspond to the potential economic and financial losses caused by climate change. However, it should be noted that transition risks related to the process of adjusting toward a low-carbon economy, such as stranded asset exposures in the financial system, can also amount to a sizable burden.

interest to credit rating agencies, market participants and policymakers, as a better understanding of how climate change affects sovereign credit ratings could provide valuable guidance on the future impact of climate change-related risks on how much governments and firms can safely borrow and how much it will cost them. That is why rating agencies have started building capacity to analyze and how physical risks caused by climate change can factor into the financial stability of governments and firms and incorporate these risks into credit assessments.[4]

This paper contributes to the literature by providing robust empirical evidence on the relationship between climate change and sovereign credit ratings. We employ alternative estimation methodologies—ordinary least squares (OLS) and ordered response models—and control for account conventional determinants of credit ratings such as economic factors and instructional characteristics.[5] Empirical results show that climate change has serious implications for sovereign credit ratings assigned to countries by three leading agencies— Fitch, Moody's and Standard & Poors (S&P)—in a panel of 67 countries during the period 1995–2017. We find that climate change vulnerability has adverse effects on sovereign credit ratings, after controlling for conventional macroeconomic determinants of credit worthiness. On the other hand, with regards to climate change resilience, we find that countries with greater climate change resilience benefit from higher credit ratings. Splitting the sample into country groups, however, reveals a considerable contrast between advanced and developing countries. While climate change vulnerability has no significant impact on credit ratings in advanced economies, the magnitude and statistical significance of the estimated coefficient are much greater in the case of developing countries owing to weaker capacity to adapt to and mitigate the consequences of climate change. Likewise, even though climate change resilience is found to have a statistically significant positive effect on credit rating in both advanced and developing countries, the magnitude of this effect is almost three times greater in emerging markets than advanced economies. These findings remain robust to a battery of sensitivity checks, including alternative measures of debt default, model specifications and estimation methodologies.

The econometric evidence presented in this paper has unambiguous policy implications, especially for developing countries that are relatively more vulnerable to risks associated with climate change. While climate change is an inevitable reality across the world with increasing temperatures, changing weather patterns, melting glaciers, intensifying storms and rising sea levels, the negative coefficient on climate resilience shows that enhancing structural resilience through cost-effective mitigation and adaptation, strengthening financial resilience through fiscal buffers and insurance schemes, and improving economic diversification and policy management can help cope with the consequences of climate change for public finances and thereby reduce the cost of borrowing associated with lower credit ratings.

[4] Major credit rating agencies have developed or acquired assets to measure the exposure of geographical areas and economic sectors to the physical impacts of climate change, as well as which are facing greater transition risks as the demand for renewable energy increases over time.

[5] We follow the literature on the conventional determinants of sovereign credit ratings (Cantor and Packer, 1996; Mulder and Monfort, 2000; Amstad and Packer, 2015).

The remainder of this paper is organized as follows. Section II provides an overview of the related literature. Section III describes the data used in the empirical analysis. Section IV introduces the salient features of our econometric strategy. Section V presents the empirical results, including a series of robustness checks. Finally, Section VI offers concluding remarks with policy implications.

II. A Brief Overview of the Literature

This paper brings together two strands of literature: determinants of sovereign credit ratings and the macroeconomic impact of climate change. First, several studies address the issue of the determinants of sovereign ratings, notably Cantor and Packer (1996), who identify income per capita, GDP growth, inflation, external debt, and default history as important factors in determining a country's credit rating. Afonso (2003) confirms the relevance of these macroeconomic determinants using linear, logistic, and exponential transformations of the rating scales. Mulder and Monfort (2000) show that sovereign ratings tend to react to crisis indicators such as exchange rate overvaluation indicated by the real effective exchange rate. Bissoondoyal-Bheenick (2005), on the other hand, find that macro-financial indicators alone do not determine credit ratings and that the contribution of these variables change across different rating categories (in a sample of 95 countries during the period 1995-1999). Likewise, Mellios and Paget-Blanc (2006) highlight the importance of institutional factors such as corruption, in addition to macroeconomic variables. Amstad and Packer (2015) expand this approach to include a plethora of explanatory variables as proxies for fiscal, economic and institutional strength, monetary regime, external position and default history and conclude that a small set of factors can largely explain the agencies´ sovereign rating scale.

Second, there is a growing literature on the economic and financial effects of climate-related shifts in the physical environment.[6] Starting with Nordhaus (1991; 1992) and Cline (1992), aggregate damage functions have become a mainstay of analyzing the climate-economy nexus. Although identifying the macroeconomic impact of annual variation in climatic conditions remains a challenging empirical task, Gallup et al. (1999), Nordhaus (2006), and Dell et al. (2012) find that higher temperatures result in a significant reduction in economic growth in developing countries. Burke et al.(2015) confirm this finding and conclude that an increase in temperature would have a greater damage in countries that are concentrated in geographic areas with hotter climates. Using expanded datasets, Acevedo et al. (2018), Burke and Tanutama (2019) and Kahn et al. (2019) show that the long-term macroeconomic impact of weather anomalies is uneven across countries and that economic growth responds nonlinearly to temperature. In a related vein, it is widely documented that climate change by increasing the frequency and severity of natural disasters affects economic development (Loyaza et al., 2012; Noy, 2009; Raddatz, 2009; Skidmore and Toya, 2002; Rasmussen, 2004), reduces the accumulation of human capital (Cuaresma, 2010) and worsens a country´s trade balance (Gassebner et al., 2010).

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[6] Tol (2018) provides a recent overview of this expanding literature.

There is, however, no existing research on the relationship between climate change and sovereign default. The closest line of research concerns the impact of climate change on asset prices. Cevik and Jalles (2020a; 2020b) show that climate change vulnerability and resilience have significant effects on government bond yields and spreads and on the probability of sovereign debt default, especially in developing countries. In a similar vein, Bansal et al.(2016) and IMF (2020) find that the risk of climate change—as proxied by temperature rises—has a negative effect on asset valuations, while Bernstein et al.(2019) show that real estate exposed to the physical risk of sea level rise sell at a discount relative to otherwise similar unexposed properties. Likewise, focusing on the U.S., Painter (2020) find that counties more likely to be affected by climate change pay more in underwriting fees and initial yields to issue long-term municipal bonds compared to counties unlikely to be affected by climate change.

III. Data Overview

We use several sources to construct a panel dataset of annual observations covering 67 countries over the period 1995–2017.[7] The data on sovereign credit ratings is drawn from Fitch, Moody's and S&P. The combined database allows us to construct the dependent variable, R_{it}^{*}: a country's average credit rating at the end of each calendar year. In the context of an ordered response model, an unobserved latent variable R_{it}^{*} has a linear form and depends on the same variables as before with several cut-off points to draw up the boundaries of each rating category, and the final rating notation is given by:

$$R_{it} = \begin{cases} AAA\ (Aaa) & if \quad R_{it}{}^{*} > c_{20} \\ AA+\ (Aa1) & if \quad c_{16} > R_{it}{}^{*} > c_{19} \\ AA\ (Aa2) & if \quad c_{15} > R_{it}{}^{*} > c_{18} \\ & \vdots \\ < C & if \quad c_1 > R_{it}{}^{*} \end{cases}.$$

The difference between the cut-off points results in a nonlinear effect (i.e., it might be easier to move from AA to AA+, then the subsequent move to AAA). Similar to Afonso et al. (2011), we group credit ratings in 21 categories by putting together the few observations below C, which are assigned the value of 1, while AAA observations receive the value of 21, as presented in Table 1. In addition to using each rating agency´s assessment separately, we also take three aggregate measures. The first one takes the simple average across the three agencies (Ratings_Avg). The second one uses a Principal Component Analysis (PCA) to extract the common factor (Ratings_PCA). A likelihood ratio (LR) test is used ex-ante to examine the "sphericity" case, allowing for sampling variability in the correlations. This test comfortably rejects sphericity at the 1 percent level. Moreover, the Kaiser-Meyer-Olkin Measure of Sampling Adequacy is equal to 0.79, suggesting that the use of a factor analysis of the variables is appropriate.[8] The first factor

[7] The list of countries is presented in Appendix Table A1.

[8] This is an index for comparing the magnitudes of the observed correlation coefficients to the magnitudes of the partial correlation coefficients.

explains 98 percent of the variance in the standardized data. Given that PCA is based on the classical covariance matrix, which is sensitive to outliers, we take a third measure by basing it on a robust estimation of the covariance (correlation) matrix. A well-suited method is the Minimum Covariance Determinant (MCD) that considers all subsets containing h% of the observations and estimates the variance of the mean on the data of the subset associated with the smallest covariance matrix determinant. To this end, we implement the algorithm proposed by Rousseeuw and Van Driessen (1999). After re-computing the same indices with the MCD version, we obtain similar results, which mean that outliers are not driving our factor analysis.[9]

Table 1. Qualitative Credit Ratings Linear Transformation to Ordinal Scale

	Ordinal scale	**S&P**	**Moody's**	**Fitch**
Highest quality	21	AAA	Aaa	AAA
High quality	20	AA+	Aa1	AA+
	19	AA	Aa2	AA
	18	AA-	Aa3	AA-
Strong payment capacity	17	A+	A1	A+
	16	A	A2	A
	15	A-	A3	A-
Adequate payment capacity	14	BBB+	Baa1	BBB+
	13	BBB	Baa2	BBB
	12	BBB-	Baa3	BBB-
Likely to fulfil obligations, ongoing uncertainty	11	BB+	Ba1	BB+
	10	BB	Ba2	BB
	9	BB-	Ba3	BB-
High credit risk	8	B+	B1	B+
	7	B	B2	B
	6	B-	B3	B-
Very high credit risk	5	CCC+	Caa1	CCC+
	4	CCC	Caa2	CCC
	3	CCC-	Caa4	CCC-
Near default with possibility of recovery	2	CC	Ca	CC
	1	C	C	C
Default	0	SD/D		DDD/DD/D

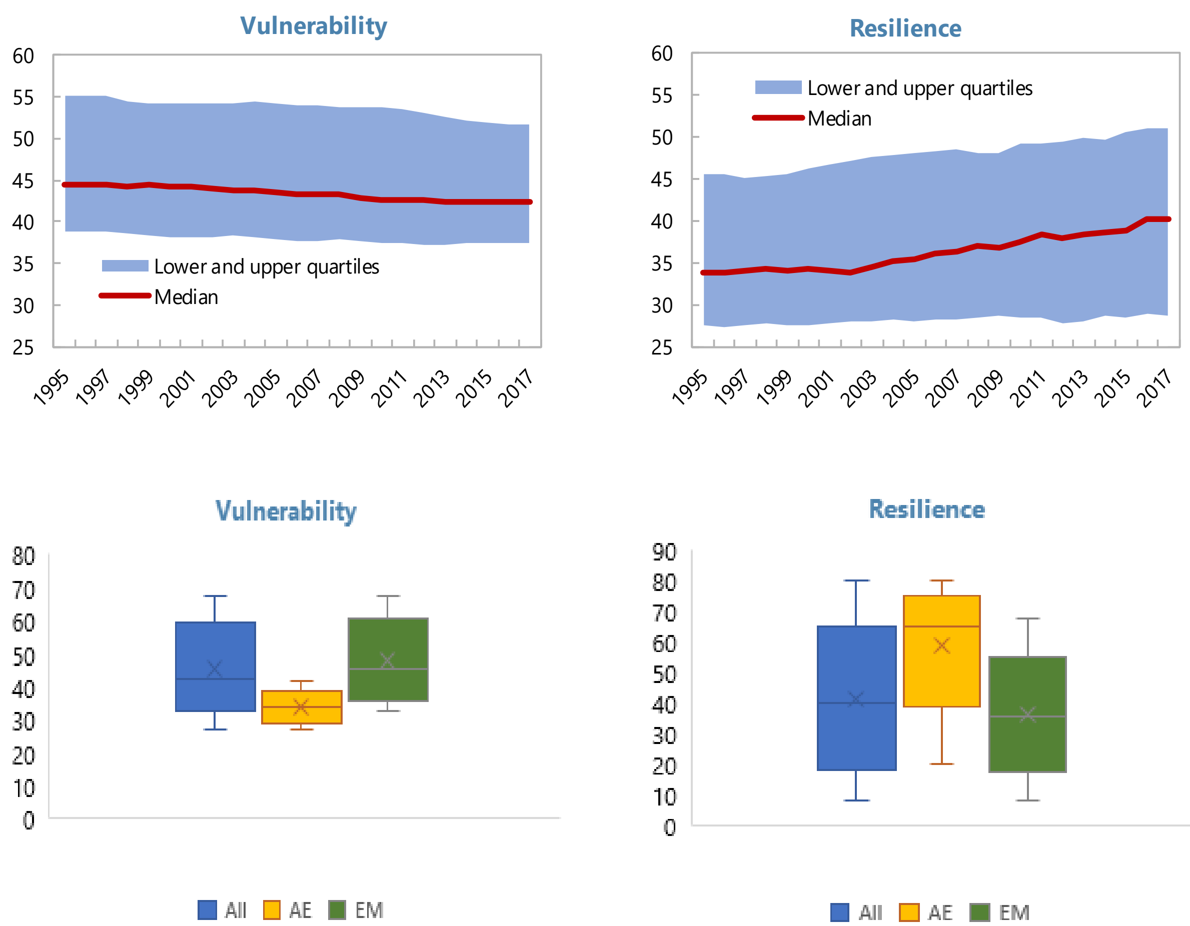
Source: Fitch; Moody's; S&P; authors' calculations.

The main explanatory variables of interest are vulnerability and resilience to climate change as measured by the ND-GAIN indices, which capture a country's overall susceptibility to climate-

[9] The correlation coefficient between Ratings_PCA and the MCD-equivalent (hereafter MDCeq) was equal to 99, statistically significant at the 1 percent level.

related disruptions and capacity to deal with the consequences of climate change, respectively.[10] The composite indices are based on 45 indicators, of which 36 variables contributing to the vulnerability score and 9 variables constituting the resilience score. Vulnerability refers to "a country's exposure, sensitivity, and capacity to adapt to the impacts of climate change" and comprise indicators of six life-supporting sectors—food, water, health, ecosystem services, human habitat and infrastructure. Resilience, on the other hand, assesses "a country's capacity to apply economic investments and convert them to adaptation actions" and covers three areas—economic, governance and social readiness—with nine indicators.[11]

Figure 2. Climate Change Vulnerability and Resilience



Source: ND-GAIN; Bloomberg; authors' calculations.

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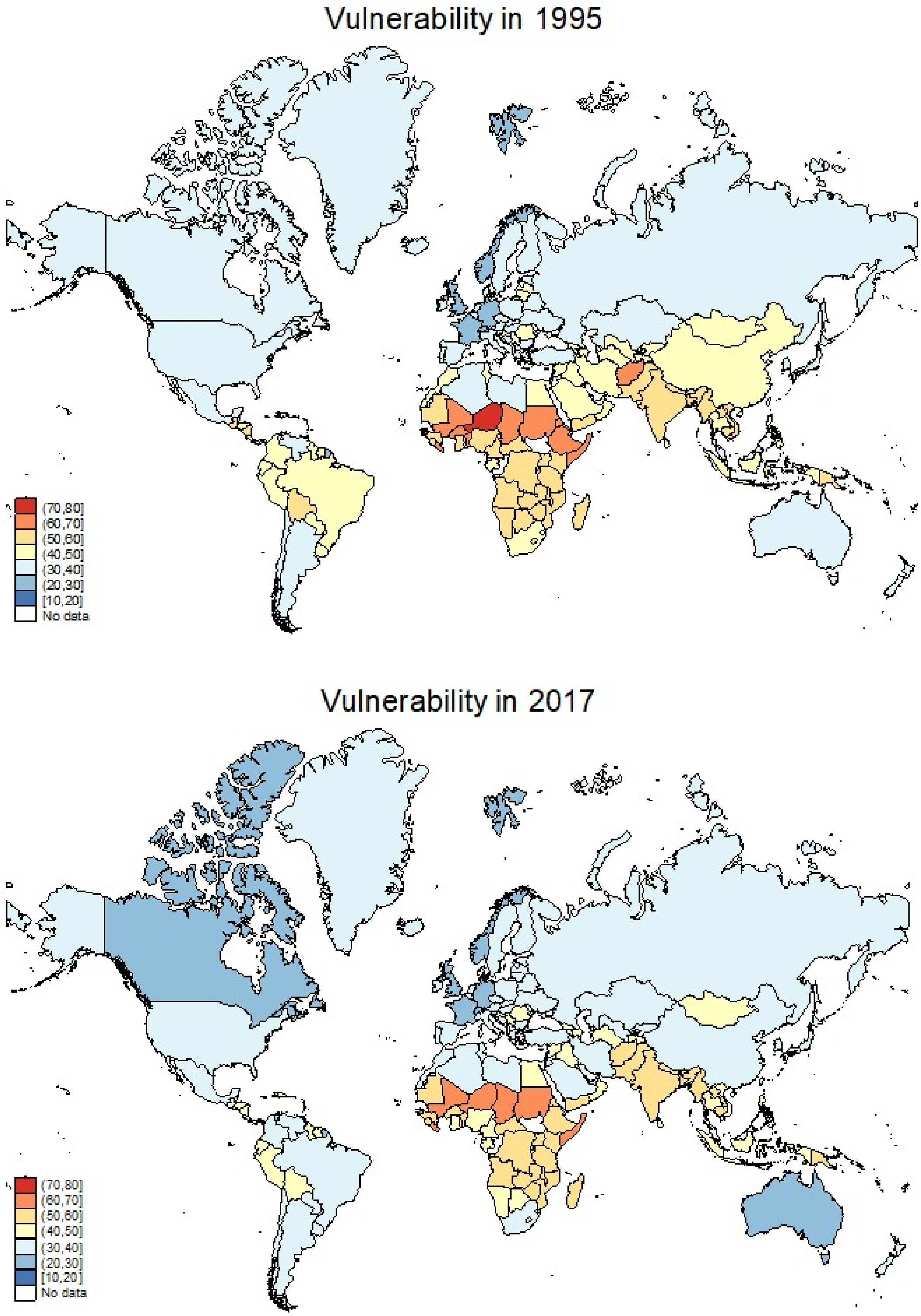
[10] The ND-GAIN database, covering 184 countries over the period 1995–2017, is available at https://gain.nd.edu/.

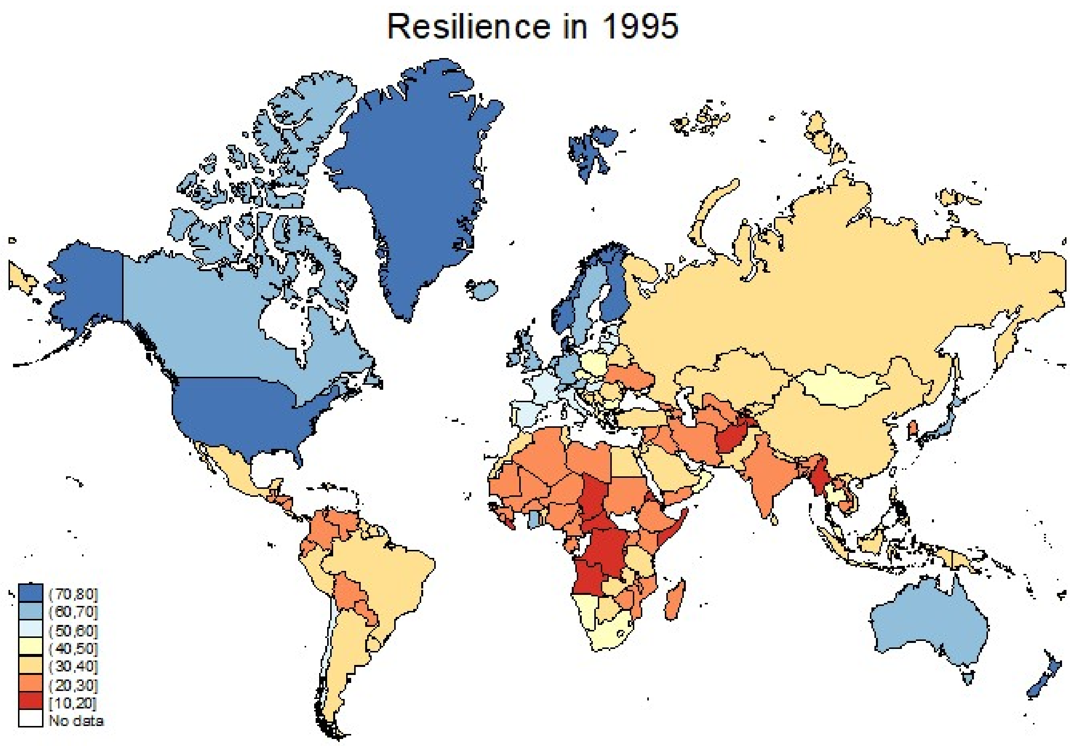
[11] The ND-GAIN database refers to this series as "readiness" for climate change, which we use as a measure of resilience against climate change. In this context, it should also be noted that the ND-GAIN indices do not reflect fiscal insurance schemes for natural disasters that may occur due to climate change.

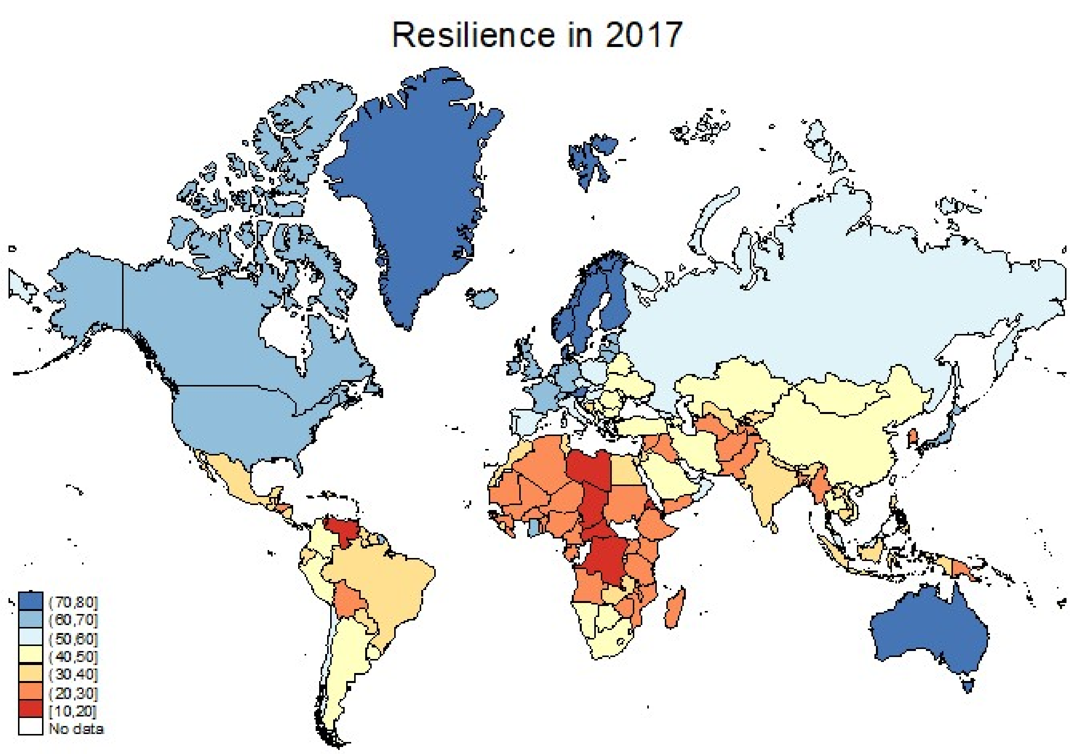
Figure 3a. Climate Change Vulnerability Across the World in 1995 vs 2017



Note: color scheme for less (blue) to more vulnerable to climate change (red).
Source: ND-GAIN; authors' calculations.

Figure 3b. Climate Change Resilience Across the World in 1995 vs 2017





Note: color scheme for less (red) to more resilient to climate change (blue).
Source: ND-GAIN; authors' calculations.

Figure 2 shows the time profile and box-whisker plots for both the climate change vulnerability and resilience indices for the entire sample and income group, respectively. Although the ND-GAIN indices show improvements in climate change vulnerability and resilience in recent years, there is significant heterogeneity across countries. For example, while the mean value of climate change resilience is 33.7, it varies between a minimum of 0.2 and a maximum of 71.3. It is also clear from the data that advanced economies are much less vulnerable to climate change than developing countries. It is important to highlight that the time-series variation in the ND-GAIN indices reflect the changes in countries' levels of vulnerability and resilience (which are not necessarily forward-looking), not from the changes in the projected vulnerability and resilience to physical risks associated with climate change.

Aggregate pictures, however, hide marked heterogeneity across countries that should not go unnoticed. Figure 3a compares the climate change vulnerability index in 1995 with that in 2017. We can see that Canada, Australia, some parts of South America and Asia improved the situation, while Sub-Saharan Africa remained relatively unchanged over the past two decades. In Figure 3b, we do the same for the climate change resilience index. It is interesting to observe a slight deterioration in the case of the US and in some countries in Sub-Saharan Africa, but improvements in Europe, Russia and other parts of South East Asia as well as South America.

Following the literature (Cantor and Packer, 1996; Monfort and Mulder, 2000; Bissoondoyal-Bheenick, 2005), we include conventional determinants of sovereign credit ratings as control variables (with expected sign in parenthesis): real GDP per capita (+), real GDP growth (+), inflation rate (+/-), debt-to-GDP ratio (-), foreign currency reserves (+), the terms-of-trade index (+/-), and unemployment rate (-), which are assembled from the IMF's International Financial Statistics (IFS) and World Economic Outlook (WEO) databases, and the World Bank's World Development Indicators (WDI) database. There is a significant degree of dispersion across countries in terms of climate change vulnerability and resilience as well as macroeconomic performance, as presented in Appendix Table A2.

IV. Econometric Methodology

We investigate the impact of climate change on sovereign credit ratings (R^*_{it}), while controlling for conventional determinants of sovereign defaults identified in the literature, according to the following baseline regression model:

$$R^*_{it} = \alpha_i + \delta_t + \beta CC_{it} + \gamma X'_{it-1} + \varepsilon_{it} \tag{1}$$

where the α_i and δ_t coefficients denote the time-invariant country-specific effects and the time effects controlling for common shocks that may affect sovereign credit ratings across all countries in a given year, respectively; CC_{it} represents the measures of climate change vulnerability and resilience; X_{it-1} is a vector of control variables that are lagged to address potential endogeneity.[12] ε_{it} is an idiosyncratic error term that satisfies the standard assumptions of zero mean and constant variance. To account for possible heteroskedasticity, robust standard errors are clustered at the country level.

There are two econometric approaches commonly used in the literature. The first approach is a linear regression method that estimates a numerical representation of credit ratings (e.g. Cantor and Packer, 1996; Afonso, 2003), which also allows for panel data applications (Mora, 2006). The second approach is based on an ordered response model (e.g. Bissoondoyal-Bheenick 2005) that uses credit ratings as a qualitative ordinal measure. However, treating ordered variables as continuous could cause inference errors due to biased estimations even in large samples (Trevino and Thomas, 2001; Bessis, 2002; Hu et al., 2002; Bissoondoyal-Bheenick, 2005; Mora, 2006; Depken et al., 2007; Afonso et al., 2011). In this paper, we implement a battery of estimation methodologies, including the OLS, two ordered response models (probit and logit) estimated using the maximum likelihood approach, and two-stage least squares (2SLS) methodology with instrumental variable (IV) using the lagged climate change variables to account for potential endogeneity.

V. Empirical Results

The baseline estimation results based on the full sample of countries are presented for each credit rating agency, as well as for the average rating and the PCA-based version, in Table 2 for climate change vulnerability and in Table 3 for climate change resilience. These findings demonstrate a consistent picture across all specifications that is broadly in line with the existing literature. As expected, higher level of income is associated with better sovereign credit ratings. Likewise, the state of economic conditions has the expected effects on credit worthiness, with positive coefficients on real GDP growth and the terms-of-trade index and negative coefficients on inflation and unemployment. We also obtain statistically significant estimates on two rating-critical macroeconomic variables: government debt and foreign currency reserves. While an increase in the debt-to-GDP ratio is associated with lower credit ratings, a higher level of foreign reserves leads to an improvement in credit ratings.

With regards to climate change vulnerability, the results based on the full sample of countries show a mixed picture. Its impact on sovereign credit ratings is not consistently negative and statistically significant. Nevertheless, using the average credit rating and the PCA-based version, we find evidence that greater vulnerability to climate change is associated with lower credit ratings and this negative effect is statistically and economically significant, after controlling for conventional macroeconomic factors. According to the average rating specification, an increase of one percentage point in climate change vulnerability leads to a reduction of 0.23 percent in credit worthiness in the full sample of countries during the period 1995–2017.

With regards to climate change resilience, on the other hand, the results provide an unambiguous picture. Its impact on sovereign credit ratings is positive and statistically significant

[12] We obtain similar results with contemporaneous regressors, which are available upon request.

across all specifications. That is, countries that are more resilient to climate change enjoy higher credit ratings, after controlling for conventional macroeconomic factors, relative to countries with greater vulnerability to risks associated with climate change. According to the average rating specification, an improvement of one percentage point in climate change resilience is associated with an increase of 0.09 percent in sovereign credit rating in the full sample of countries during the period 1995–2017.

Splitting the sample into country groups, however, reveals a considerable contrast between advanced and developing countries, as presented in Table 4. While climate change vulnerability has no significant impact on credit ratings in advanced economies, the magnitude and statistical significance of the estimated coefficient are much greater in the case of developing countries. According to the average rating specification, an increase of one percentage point in climate change vulnerability leads to a reduction of 0.69 percent in credit worthiness in emerging market economies during the period 1995–2017, after controlling for conventional macroeconomic factors. That is three times more than the estimate coefficient (0.23) using the full sample of countries. Climate change resilience, on the other hand, is found to have a statistically significant positive effect on sovereign credit rating in both advanced and developing countries. The magnitude of this effect, however, is almost three times greater in emerging markets (0.20) than advanced economies (0.08).

Table 2. Climate Change Vulnerability and Credit Ratings—Baseline (OLS) Results

Specification	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*
Dependent variable	Moody's	S&P	Fitch	Ratings_Avg	Ratings_PCA
Estimator			OLS		
Sample	All	All	All	All	All
Real GDP per capita (t-1)	3.030***	4.677***	2.765***	2.921***	0.584***
	(1.003)	(0.777)	(0.850)	(0.911)	(0.182)
Real GDP growth (t-1)	0.103***	0.087***	0.064***	0.083***	0.017***
	(0.024)	(0.019)	(0.020)	(0.022)	(0.004)
Inflation (t-1)	-0.001**	-0.002***	-0.001*	-0.001*	-0.000*
	(0.001)	(0.000)	(0.001)	(0.001)	(0.000)
Terms-of-Trade (t-1)	0.011***	0.006**	0.003	0.008**	0.002**
	(0.004)	(0.003)	(0.003)	(0.004)	(0.001)
Debt-to-GDP (t-1)	-0.037***	-0.029***	-0.031***	-0.036***	-0.007***
	(0.005)	(0.003)	(0.003)	(0.004)	(0.001)
Foreign reserves (t-1)	0.537***	0.425***	0.416***	0.441***	0.088***
	(0.118)	(0.097)	(0.106)	(0.108)	(0.022)
Unemployment (t-1)	-0.210***	-0.128***	-0.127***	-0.163***	-0.032***
	(0.033)	(0.028)	(0.030)	(0.030)	(0.006)
Climate vulnerability	0.032	0.094	-0.162	-0.232**	-0.047**
	(0.111)	(0.095)	(0.106)	(0.113)	(0.023)
Number of observations	980	1,140	1,068	898	898
Number of countries	58	67	66	53	53
R-squared	0.930	0.949	0.950	0.944	0.944

Note: Standard errors in parenthesis. Time and country fixed effects included but omitted for reasons of parsimony. Constant estimated but omitted. *, **, *** denote statistical significance at the 10, 5 and 1 percent levels, respectively.

Table 3. Climate Change Resilience and Credit Ratings—Baseline (OLS) Results

Specification	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*
Dependent variable	Moody's	S&P	Fitch	Ratings_Avg	Ratings_PCA
Estimator			OLS		
Sample	All	All	All	All	All
Real GDP per capita (t-1)	2.205**	3.624***	2.530***	2.825***	0.565***
	(1.011)	(0.756)	(0.806)	(0.886)	(0.177)
Real GDP growth (t-1)	0.102***	0.086***	0.069***	0.090***	0.018***
	(0.024)	(0.019)	(0.020)	(0.021)	(0.004)
Inflation (t-1)	-0.001*	-0.002***	-0.001*	-0.001*	-0.000*
	(0.001)	(0.000)	(0.001)	(0.001)	(0.000)
Terms-of-Trade (t-1)	0.008**	0.004	0.001	0.005	0.001
	(0.004)	(0.003)	(0.003)	(0.003)	(0.001)
Debt-to-GDP (t-1)	-0.038***	-0.030***	-0.032***	-0.037***	-0.007***
	(0.005)	(0.003)	(0.003)	(0.004)	(0.001)
Foreign reserves (t-1)	0.553***	0.424***	0.469***	0.519***	0.104***
	(0.112)	(0.091)	(0.099)	(0.102)	(0.020)
Unemployment (t-1)	-0.213***	-0.132***	-0.121***	-0.150***	-0.030***
	(0.033)	(0.028)	(0.029)	(0.029)	(0.006)
Climate resilience	0.085**	0.098***	0.082***	0.086***	0.017***
	(0.038)	(0.029)	(0.030)	(0.033)	(0.007)
Number of observations	980	1,140	1,068	898	898
Number of countries	58	67	66	53	53
R-squared	0.931	0.950	0.951	0.944	0.944

Note: Standard errors in parenthesis. Time and country fixed effects included but omitted for reasons of parsimony. Constant estimated but omitted. *, **, *** denote statistical significance at the 10, 5 and 1 percent levels, respectively.

The baseline results provide robust evidence on the impact of climate change on sovereign credit ratings, but the OLS method may suffer from the problem of reverse causality. We deal with potential endogeneity by estimating two ordered response models (probit and logit) and using the 2SLS-IV estimator, which is validated by the Kleibergen-Paap and Hansen statistics.[13] These results for the average credit rating, presented in Table 5, confirm that climate change vulnerability has a detrimental effect on sovereign credit ratings across all countries, while climate change resilience helps improve credit worthiness.

[13] Looking at the diagnostic statistics to assess the validity of the instrumental variable strategy, the underidentification test p-values generally reject the null that the different equations are underidentified. Also, the Hansen test statistics reveal that the instrument sets contain valid instruments (i.e., uncorrelated with the error term, and that the excluded instruments are correctly excluded from the estimated equation).

Table 4. Climate Change Resilience and Credit Ratings—Country Groups

Specification	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*
Dependent variable	Ratings_Avg				Ratings_PCA			
Estimator	OLS							
Sample	AE	EM	AE	EM	AE	EM	AE	EM
Real GDP per capita (t-1)	5.626***	-0.029	5.565***	-0.609	1.129***	-0.012	1.117***	-0.128
	(1.661)	(1.272)	(1.644)	(1.140)	(0.333)	(0.254)	(0.329)	(0.228)
Real GDP growth (t-1)	0.170***	0.027	0.168***	0.042*	0.034***	0.005	0.034***	0.008*
	(0.051)	(0.021)	(0.051)	(0.022)	(0.010)	(0.004)	(0.010)	(0.004)
Inflation (t-1)	-0.166***	-0.001	-0.154***	-0.001	-0.033***	-0.000	-0.031***	-0.000
	(0.044)	(0.001)	(0.043)	(0.001)	(0.009)	(0.000)	(0.009)	(0.000)
Terms-of-Trade (t-1)	0.010*	0.011***	0.007	0.006*	0.002*	0.002***	0.001	0.001*
	(0.006)	(0.004)	(0.006)	(0.004)	(0.001)	(0.001)	(0.001)	(0.001)
Debt-to-GDP (t-1)	-0.034***	-0.037***	-0.035***	-0.043***	-0.007***	-0.007***	-0.007***	-0.009***
	(0.005)	(0.006)	(0.005)	(0.006)	(0.001)	(0.001)	(0.001)	(0.001)
Foreign reserves (t-1)	0.367***	1.090***	0.410***	1.094***	0.073***	0.219***	0.082***	0.219***
	(0.128)	(0.204)	(0.128)	(0.202)	(0.026)	(0.041)	(0.026)	(0.040)
Unemployment (t-1)	-0.259***	-0.064**	-0.261***	-0.009	-0.052***	-0.013**	-0.052***	-0.002
	(0.046)	(0.033)	(0.045)	(0.030)	(0.009)	(0.007)	(0.009)	(0.006)
Climate resilience			0.083**	0.202***			0.017**	0.040***
			(0.037)	(0.040)			(0.007)	(0.008)
Climate vulnerability	0.219	-0.690***			0.044	-0.138***		
	(0.172)	(0.176)			(0.034)	(0.035)		
Number of observations	492	406	492	406	492	406	492	406
Number of countries	25	28	25	28	25	28	25	28
R-squared	0.866	0.875	0.867	0.878	0.866	0.876	0.867	0.878

Note: Standard errors in parenthesis. Time and country fixed effects included but omitted for reasons of parsimony. Constant estimated but omitted. *, **, *** denote statistical significance at the 10, 5 and 1 percent levels, respectively.

Table 5. Climate Change and Credit Ratings—Robustness Checks

Specification	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*
Dependent variable	Ratings_Avg							
Estimator	Ordered_Probit		Ordered_Logit		IV (1 lag)	IV (2 lag)	IV (1 lag)	IV (2 lag)
Sample	All	All	All	All	All	All	All	All
Real GDP per capita (t-1)	1.768**	1.695**	3.199**	3.906**	0.665	0.449	0.588	0.558
	(0.773)	(0.805)	(1.608)	(1.712)	(0.495)	(0.524)	(0.514)	(0.559)
Real GDP growth (t-1)	0.049***	0.039**	0.081***	0.058*	0.078***	0.074***	0.078***	0.074***
	(0.016)	(0.016)	(0.031)	(0.031)	(0.014)	(0.014)	(0.014)	(0.014)
Inflation rate (t-1)	-0.001	-0.001	-0.002*	-0.002	0.000	0.000	-0.000	-0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Terms-of-Trade (t-1)	0.008**	0.012***	0.016***	0.023***	0.003	0.004	0.003	0.005
	(0.003)	(0.003)	(0.006)	(0.006)	(0.004)	(0.004)	(0.004)	(0.004)
Debt-to-GDP ratio (t-1)	- 0.041***	-0.038***	-0.082***	-0.075***	-0.046***	-0.045***	- 0.047***	- 0.046***
	(0.004)	(0.004)	(0.009)	(0.009)	(0.003)	(0.003)	(0.003)	(0.003)
Foreign reserves (t-1)	0.461***	0.330***	0.758***	0.528***	0.465***	0.385***	0.461***	0.401***
	(0.081)	(0.085)	(0.183)	(0.189)	(0.073)	(0.077)	(0.075)	(0.079)
Unemployment rate (t-1)	- 0.162***	-0.186***	-0.240***	-0.284***	-0.176***	-0.190***	- 0.191***	- 0.200***
	(0.024)	(0.025)	(0.054)	(0.054)	(0.023)	(0.024)	(0.023)	(0.024)
Climate change resilience	0.127***		0.263***		0.057*		0.058*	
	(0.028)		(0.064)		(0.030)		(0.030)	
Climate change vulnerability		-0.384***		-0.627**		-0.267**		-0.201*
		(0.109)		(0.246)		(0.117)		(0.122)
Number of observations	898	898	898	898	875	875	843	843
Pseudo R-squared	0.406	0.404	0.414	0.411				
R-squared					0.524	0.522	0.539	0.536
Kleibergen-Paap statistic (p-value)					*0.000*	*0.000*	*0.000*	*0.000*
Hansen statistic (p-value)					*0.434*	*0.641*	*0.352*	*0.147*

Note: Standard errors in parenthesis. Time and country fixed effects included but omitted for reasons of parsimony. Constant estimated but omitted. For the IV one or two lags of climate change indices are used as instruments (IV1 and IV2, respectively). The Kleibergen-Paap rk Wald F statistic of weak exogeneity tests the validity of the instruments used. The null hypothesis of the Kleibergen-Paap test is that the structural equation is underidentified (i.e., the rank condition fails) and tests that the excluded instruments are "relevant". Stock-Yogo critical values were applied. The Hansen test is a test of overidentifying restrictions. *, **, *** denote statistical significance at the 10, 5 and 1 percent levels, respectively.

VI. Conclusion

Climate change has become an existential threat to the world economy like no other, with complex, evolving and nonlinear dynamics that remain a source of great uncertainty. There is a growing body of literature on the economic consequences of climate change, but research on the link between climate change and sovereign risks remains limited. Building our previous contributions, this paper aims to fill another gap in the literature by focusing in the impact of climate change on sovereign credit ratings.

Using a panel of 67 countries over the period 1995–2017, we find that climate change vulnerability has adverse effects on sovereign credit ratings, after controlling for conventional macroeconomic determinants of credit worthiness. An increase of one percentage point in climate change vulnerability leads to a reduction of 0.23 percent in credit worthiness. On the other hand, with regards to climate change resilience, we find that an improvement of one percentage point in climate change resilience is associated with an increase of 0.09 percent in sovereign credit rating. Splitting the sample into country groups, however, reveals a considerable contrast between advanced and developing countries. While climate change vulnerability has no significant impact on credit ratings in advanced economies, the magnitude and statistical significance of the estimated coefficient are much greater in the case of developing countries due largely to weaker capacity to adapt to and mitigate the consequences of climate change. According to the average rating specification, an increase of one percentage point in climate change vulnerability leads to a reduction of 0.69 percent in credit worthiness in emerging market economies. That is three times more than the estimate coefficient using the full sample of countries. Climate change resilience, on the other hand, is found to have a statistically significant positive effect on sovereign credit rating in both advanced and developing countries. The magnitude of this effect, however, is almost three times greater in emerging markets than advanced economies.

The econometric evidence presented in this paper has unambiguous policy implications, especially for developing countries that are relatively more vulnerable to risks associated with climate change. While climate change is an inevitable reality across the world with increasing temperatures, changing weather patterns, melting glaciers, intensifying storms and rising sea levels, the negative coefficient on climate resilience shows that enhancing structural resilience through cost-effective mitigation and adaptation, strengthening financial resilience through fiscal buffers and insurance schemes, and improving economic diversification and policy management can help cope with the consequences of climate change for public finances and thereby reduce the cost of borrowing associated with lower credit ratings.

Appendix Table A1. List of Countries

Africa: Cameroon, Gabon, Ghana, Kenya, Libya, Mali, Morocco, Mozambique, Nigeria, Seychelles, South Africa, Tunisia, Uganda

Americas: Argentina, Barbados, Belize, Brazil, Canada, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Jamaica, Mexico, Panama, Peru, Trinidad and Tobago, Uruguay, United States

Asia: Australia, China, Fiji, India, Indonesia, Japan, Korea, Malaysia, Mongolia, New Zealand, Papua New Guinea, Thailand, Vietnam

Europe: Albania, Austria, Azerbaijan, Belarus, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, France, Georgia, Germany, Hungary, Italy, Kazakhstan, Luxembourg, Netherlands, Norway, Russia, Slovenia, Sweden, Switzerland, Finland, Greece, Iceland, Ireland, Philippines, Poland, Portugal, Spain, Turkey, Ukraine, United Kingdom

Middle East: Bahrain, Egypt, Israel, Jordan, Kuwait, Lebanon, Oman, Pakistan, Qatar, Saudi Arabia, Sri Lanka, United Arab Emirates

Appendix Table A2. Summary Statistics

Variables	Observations	Mean	Std. Dev.	Min.	Max.
Credit ratings					
Fitch	1476	14.50	5.22	1	21
Moody's	1782	14.09	5.27	0	21
S&P	1418	14.12	5.08	2	21
Real GDP per capita (log)	1771	4.19	2.27	-0.22	10.46
Real GDP growth	1770	3.40	4.54	-96.95	71.53
Inflation rate	1580	6.78	52.74	-4.86	2075.88
Terms-of-Trade	1756	104.31	27.90	19.69	321.35
Debt-to-GDP ratio	1359	52.91	32.01	2.48	245.48
Foreign reserves (log)	1753	9.37	1.73	3.87	15.16
Unemployment rate	1589	8.00	4.81	0.30	28.1
Climate change vulnerability	1602	39.05	7.17	25.98	62.25
Climate change resilience	1602	47.94	15.34	19.10	80.05

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