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This Changes Everything: Climate Shocks and Sovereign Bonds

by Serhan Cevik and João Tovar Jalles

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This Changes Everything: Climate Shocks and Sovereign Bonds

Prepared by Serhan Cevik and João Tovar Jalles[1]

Authorized for distribution by Manuela Goretti

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Abstract

Climate change is already a systemic risk to the global economy. While there is a large body of literature documenting potential economic consequences, there is scarce research on the link between climate change and sovereign risk. This paper therefore investigates the impact of climate change vulnerability and resilience on sovereign bond yields and spreads in 98 advanced and developing countries over the period 1995–2017. We find that the vulnerability and resilience to climate change have a significant impact on the cost government borrowing, after controlling for conventional determinants of sovereign risk. That is, countries that are more resilient to climate change have lower bond yields and spreads relative to countries with greater vulnerability to risks associated with climate change. Furthermore, partitioning the sample into country groups reveals that the magnitude and statistical significance of these effects are much greater in developing countries with weaker capacity to adapt to and mitigate the consequences of climate change.

JEL Classification Numbers: C23; C83; E30; E43; F41; G15; H60

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Author's E-Mail Address: scevik@imf.org; joaojalles@gmail.com

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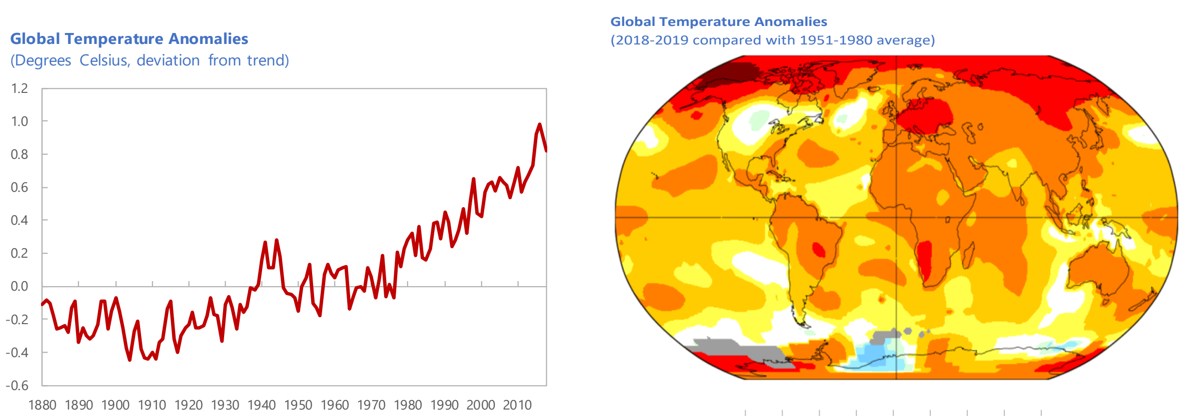
Contents **Page**

I. Introduction

Climate change already poses a systemic risk to the global economy. With the global average surface temperature rising by 1.1 degrees Celsius since 1880, the frequency and severity of climate shocks—ranging from heatwaves and droughts to hurricanes and coastal flooding—have intensified across the world (Figure 1). Looking ahead, extreme weather events are projected to worsen as the global annual mean temperatures increase by as much as 4 degrees Celsius over the next century (IPCC, 2007; Stern, 2007; IPCC, 2014).[2] The socioeconomic consequences of climate change will be felt across the world, but potential vulnerability to weather anomalies 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 large body of literature documenting significant negative effects of climate-related shifts in the physical environment on economic growth (Gallup, Sachs, and Mellinger, 1999; Nordhaus, 2006; Dell, Jones, and Olken, 2012), but research on the link between climate change and sovereign risk remains scarce and it is not clear whether financial markets efficiently price climate-related risks. Accordingly, this paper contributes to the literature by providing a comprehensive analysis of how vulnerability and resilience to climate change affect the cost of sovereign borrowing in 98 advanced and developing countries over the period 1995–2017.[3] We extend the conventional determinants of government bond yields and spreads to empirically investigate the impact of climate change on the pricing of sovereign risk across countries and over time, taking advantage of a new dataset of climate change vulnerability and resilience developed by the Notre Dame Global Adaptation Institute (ND-GAIN).

Figure 1. Weather Anomalies Across the World



Source: NOAA.

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[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 associated with climate change, but it should be noted that transition risks related to climate change, such as stranded asset exposures in the financial system, can also amount to a sizable burden.

We employ alternative estimation methodologies and take into account conventional macroeconomic factors. The results show that climate change vulnerability has a statistically and economically significant impact on government bond yields and spreads, after controlling for conventional macroeconomic and institutional determinants of sovereign risk. We also find that climate change resilience has a similarly significant dampening effect on the cost of government borrowing. That is, countries that are more resilient to climate change have lower bond yields and spreads relative to countries with greater vulnerability to risks associated with climate change. Furthermore, partitioning the sample into country groups reveals that the magnitude and statistical significance of these effects are much greater in developing countries with weaker capacity to adapt to and mitigate the consequences of climate change. These findings remain robust to a battery of sensitivity checks, including alternative measures of bond spreads and yields, empirical specifications, and estimation methodologies. The key policy takeaway from this paper is that while climate change is inevitable, policymakers can still enhance resilience to absorb shocks to economic activity and manage public finances better.

The remainder of this study is organized as follows. Section II provides an overview of the related literature. Section III describes the data used in the 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 draws from two major threads of the literature—determinants of sovereign bond yields and spreads and the macroeconomic impact of climate change. First, most studies find empirical support to the theoretical prediction that the level and composition of government debt and other macroeconomic factors have an impact on government bond yields and spreads (Engen and Hubbard, 2004; Kinoshita, 2006; Ardagna and others, 2007; Laubach, 2009; Hischer and Nosbusch, 2010; Gómez-Puig and others, 2014). More specifically, the economics literature suggests that government's borrowing costs depend on macroeconomic fundamentals and institutional factors (Attinasi and others, 2009; Afonso 2010; Poghosyan, 2012; Beirne and Fratzscher, 2013; Afonso and Nunes, 2015; Godl and Kleinert, 2016; de Grauwe, Ji and Macchiarelli, 2017; Jalles, 2019).[4]

Second, there is a growing literature on the economic and financial effects of climate-related shifts in the physical environment.[5] 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, Sachs, and Mellinger (1999), Nordhaus (2006), and

[4] For example, as governments debt rises, sovereign bond yields should go up in recognition of the higher risk (default, monetization-driven depreciation and inflation) carried by investors holding government securities. The successful elimination of fears of a looming Eurozone break-up following the Global Financial Crisis, can be partly attributed to improvements in economic fundamentals (Muellbauer, 2014).

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

Dell, Jones, and Olken (2012) find that higher temperatures result in a significant reduction in economic growth in developing countries. Burke, Hsiang, and Miguel (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 and others (2018), Burke and Tanutama (2019) and Kahn and others (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 and others, 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 and others, 2010).

There is, however, scarce research in terms quantity and intensity on how risks associated with climate change are priced in financial markets. Bansal, Kiku, and Ochoa (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, Gustafson, and Lewis (2019) show that real estate exposed to the physical risk of sea level rise sell at a discount relative to otherwise similar unexposed properties. Similarly, focusing on the US, Painter (2019) 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. Our paper is most closely related to Kling and others (2018) that find higher exposure to climate vulnerability, as measured by the ND-GAIN index, results in a higher cost of borrowing in a group of 20 low-income countries, which may yield irregular estimates due to the idiosyncrasy of sovereign debt in low-income countries. To avoid possible sample selection bias due to the idiosyncrasy of sovereign debt in low-income countries and endogeneity concerns, we broaden the sample of countries and employ alternative specifications and estimation methodologies.

III. DATA OVERVIEW

We use several sources to construct a panel dataset of annual observations covering 98 advanced and developing countries over the period 1995–2017.[6] Economic and financial

[6] The full list of countries covered in the analysis includes Angola, Argentina, Armenia, Austria, Australia, Azerbaijan, Belarus, Belgium, Belize, Bolivia, Brazil, Cameroon, Canada, Chile, China, Colombia, Cote d'Ivoire, Costa Rica, Croatia, Cyprus, Czech Republic, Denmark, Dominican Republic, Egypt, Ecuador, El Salvador, Ethiopia, France, Finland, Gabon, Georgia, Germany, Ghana, Greece, Guatemala, Honduras, Hungary, Iceland, India, Indonesia, Iraq, Ireland, Israel, Italy, Jamaica, Japan, Jordan, Kazakhstan, Kenya, Korea, Latvia, Lebanon, Lithuania, Luxembourg, Malta, Malaysia, Mexico, Mongolia, Morocco, Mozambique, Namibia, Netherlands, New Zealand, Nigeria, Norway, Pakistan, Panama, Paraguay, Peru, Philippines, Poland, Portugal, Romania, Russia, Senegal, Serbia, Singapore, Slovak Republic, Slovenia, South Africa, Spain, Sri Lanka, Suriname, Sweden, Switzerland, Tajikistan, Tanzania, Thailand, Trinidad and Tobago, Tunisia, Turkey, Ukraine, United Kingdom, United States, Uruguay, Venezuela, Vietnam, and Zambia. However, bond data drawn from Bloomberg and J.P Morgan EMBIG cover different subsets of countries—54 advanced and developing countries in the case of Bloomberg and 44 emerging market economies in the case of EMBIG.

statistics 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. Our dependent variables are government bond yields and spreads as measured by 10-year foreign-currency-denominated government bond yields and spreads vis-à-vis the U.S. benchmark, which are drawn from Bloomberg. We also use sovereign bond spreads on external U.S. dollar-denominated debt using data from J.P. Morgan Emerging Market Bond Index Global (EMBIG) as alternative measure to broaden the coverage of emerging market economies and developing countries and check the robustness of our baseline results.

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-related disruptions and capacity to deal with the consequences of climate change, respectively.[7] 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.[8]

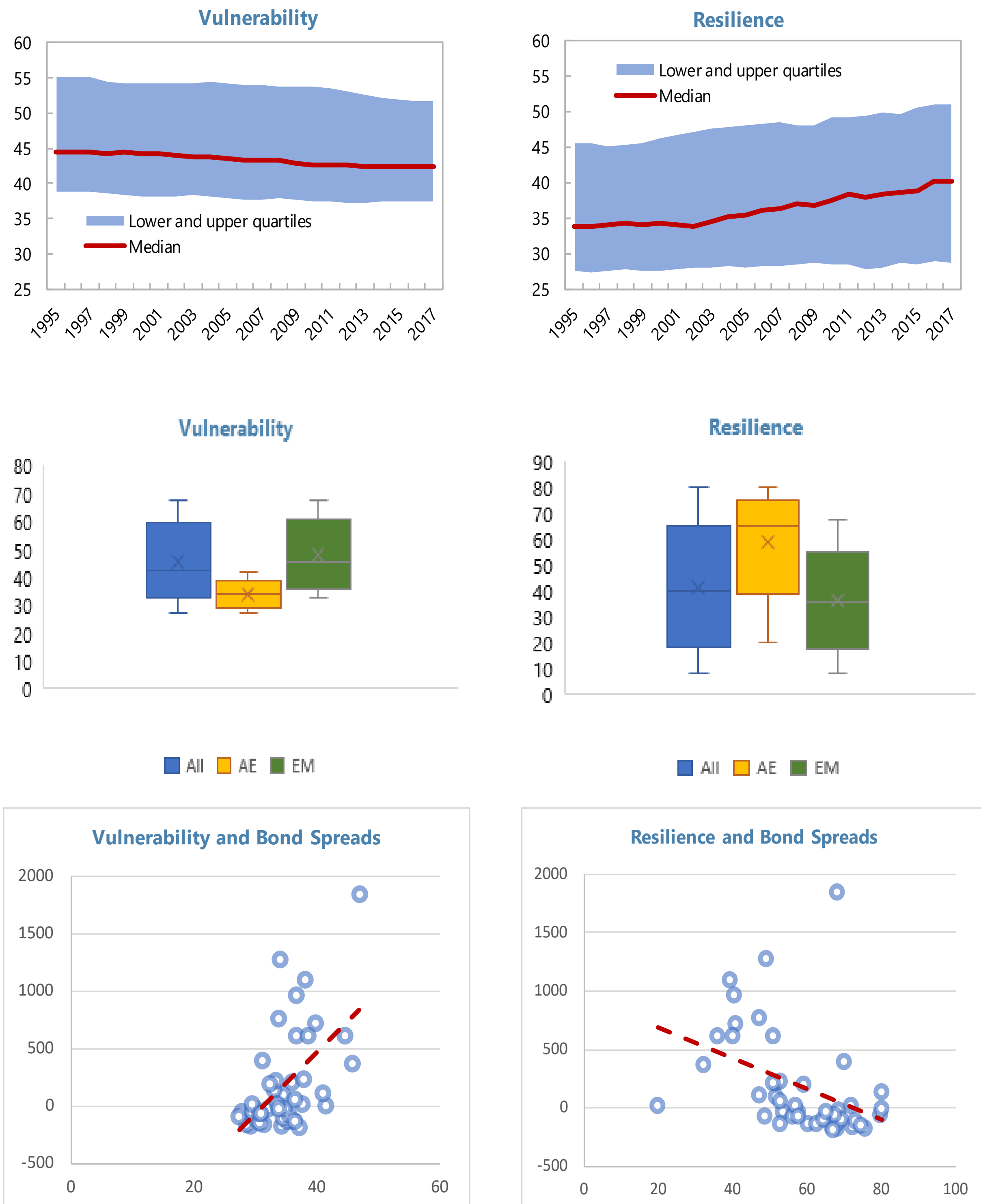
Figure 2 shows the time profile and box-whisker plots for both the vulnerability and resilience indices for the entire sample and income group, respectively. It also presents in the bottom panel the scatter plot showing unconditional correlations between these climate change indices and sovereign bonds. We can observe that resilience to climate change shocks has been increasing, particularly since the early 2000s. It is also clear from the data that advanced economies are much less vulnerable to climate change than developing countries. The bottom panel of Figure 2 hints to the positive (negative) bivariate relationship between the vulnerability (resilience) index and sovereign bond spreads (an aspect that will be properly analyzed—econometrically speaking—in the following section).

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 their situation, while Sub-Saharan Africa remained relatively unchanged over almost 20 years. 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. Finally, it is important to highlight that the time-series variation in the ND-GAIN indices reflect the changes in countries' levels of vulnerability and readiness (which are not necessarily forward

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

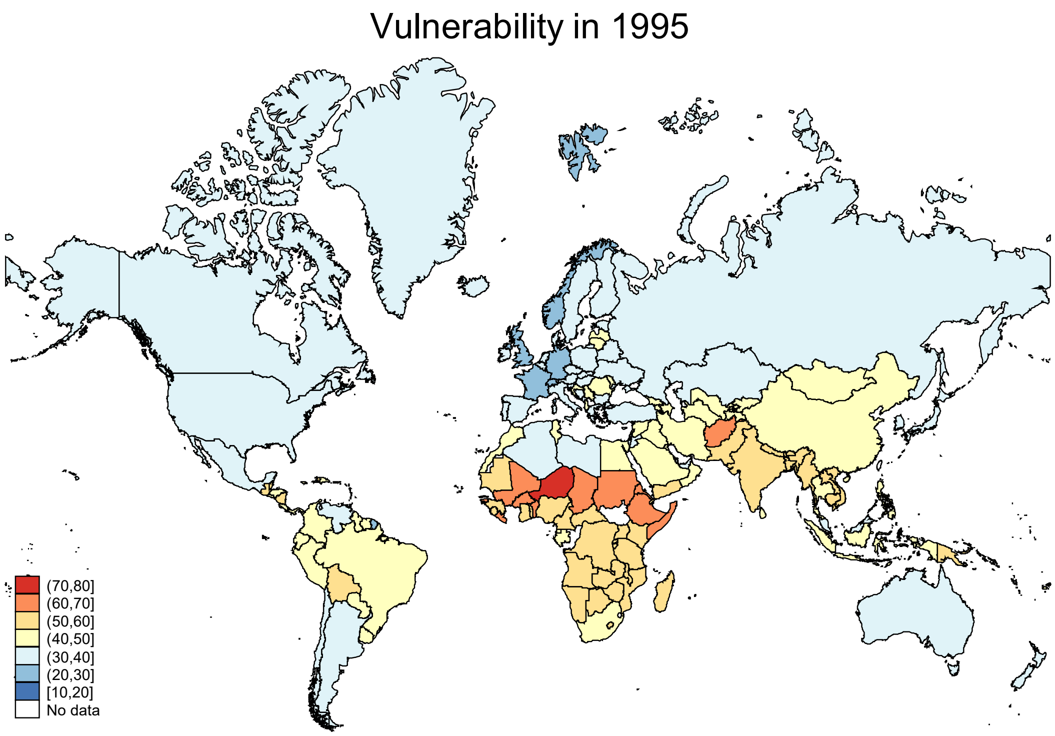
[8] The ND-GAIN database refers to this series as "readiness" for climate change, which we use as a measure of resilience against climate change.

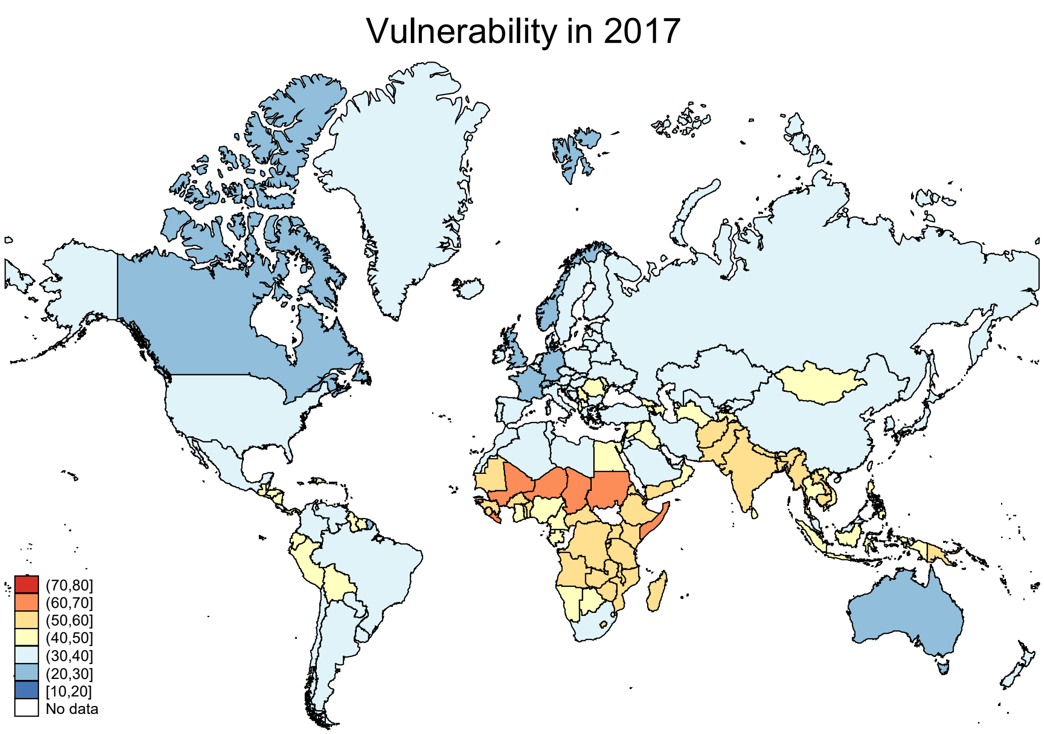
Figure 2. Climate Change and Government Bond Spreads



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

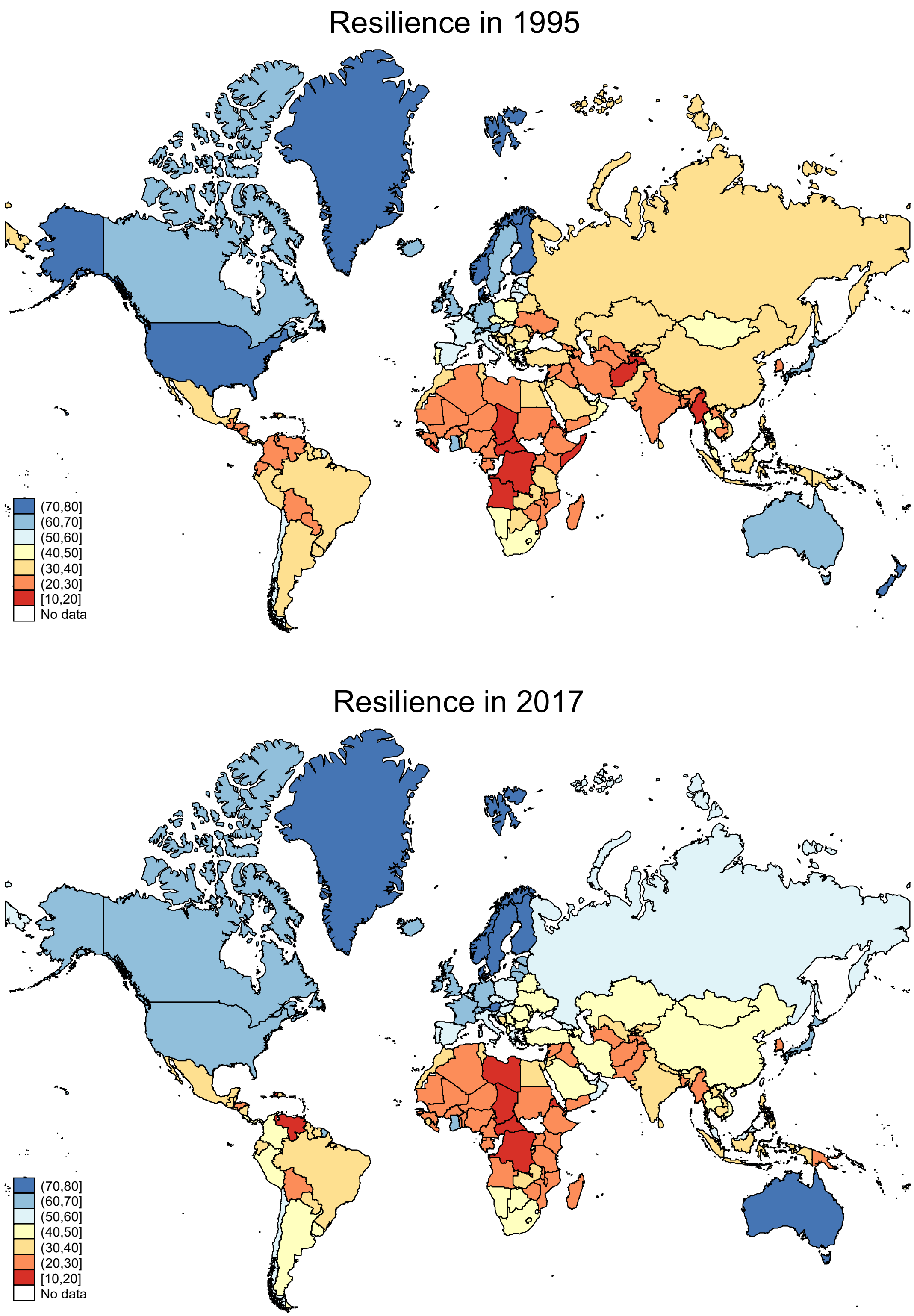
Figure 3a. Climate Change Vulnerability Across the World in 1995 vs 2017





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.

looking), not from the changes in the projected vulnerability and readiness to physical risks associated with climate change.

Following the empirical literature, we introduce a set of control variables, including the level and growth rate of real GDP, consumer price inflation, the public debt-to-GDP ratio, the budget balance-to-GDP ratio, international reserves as a share of GDP, and measures of institutional development (government effectiveness and bureaucratic quality). There is a significant degree of dispersion across countries in terms of government bond yields and spreads as well as overall macroeconomic and institutional performance. It is essential to analyze the time-series properties of the data to avoid spurious results by conducting panel unit root tests. We check the stationarity of all variables by applying the Im-Pesaran-Shin (2003) procedure, which is widely used in the empirical literature to conduct a panel unit root test. The results, available upon request, indicate that the variables used in the analysis are stationary after logarithmic transformation. Also, econometric problems may arise when dealing with time-series cross-sectional data are autocorrelation and cross-sectional correlation or, groupwise heteroscedasticity. Using the Durbin–Watson statistics and the log-likelihood ratio test, we conclude that there is no significant first-order autocorrelation and presence of cross-sectional correlation in our dataset.

IV. Empirical Strategy and Results

We empirically investigate the impact of climate change on sovereign bond yields and spreads vis-à-vis the U.S. benchmark by applying different model specifications in the following baseline form:

$$y_{it} = \beta_1 + \beta_2 y_{it-1} + \beta_3 vul_{it} + \beta_4 res_{it} + \beta_5 X_{i,t} + \eta_i + \mu_t + \varepsilon_{i,t} \quad (1)$$

in which the dependent variable, y_{it}, denotes government bond spreads or yields in country i and time *t* and y_{it-1} is the lagged dependent variable included in the dynamic model later on. vul_{it} and res_{it} are the composite measures of climate change vulnerability and resilience, respectively. $X_{i,t}$ is a set of control variables including the level and growth rate of real GDP, consumer price inflation, the debt-to-GDP ratio, the government budget balance as a share of GDP, international reserves as a share of GDP, and measures of institutional quality. The η_i and μ_t coefficients denote the time-invariant country-specific effects and the time effects controlling for common shocks that may affect financial conditions across all countries in a given year, respectively. $\varepsilon_{i,t}$ 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.

We begin the empirical analysis with the standard fixed effects model. The model above is reduced-form and therefore does not allow making causal statements or even quantifying the clean effect of climate change on sovereign spreads. Adding covariates partly corrects for these biases, but endogeneity can still arise from other omitted variables (unobserved heterogeneity and selection effects), measurement errors in variables, and reverse causality (simultaneity).

Because causality can run in both directions, some of the right-hand-side regressors may be correlated with the error term. In view of potential endogeneity and the persistence of bond spreads, however, we check the sensitivity of our baseline results by estimating the static model with the Two Stage Least Squares (2SLS) estimator. We use lagged climate change indices as instruments, which are validated by the Kleibergen-Paap and Hansen statistics.[9] Further, even though it is a very demanding estimator, especially with limited number of unbalanced observations, we use the system Generalized Method of Moments (GMM) approach developed by Arellano and Bover (1995) and Blundell and Bond (1998) approach to estimate the dynamic version of our model. The system GMM approach, on the other hand, involves constructing two sets of equations, one with first differences of the endogenous and pre-determined variables instrumented by suitable lags of their own levels, and one with the levels of the endogenous and pre-determined variables instrumented with suitable lags of their own first differences. We apply the one-step version of the system GMM estimator to ensure the robustness of the results, as the standard errors from the two-step variant of the system GMM method are known to be downward biased in small samples.

The use of all available lagged levels of the variables in the GMM estimation leads to a proliferation in the number of instruments, which reduces the efficiency of the estimator in finite samples, and potentially leads to over-fitting. A further issue is that the use of a large number of instruments significantly weakens the Hansen *J*-test of over-identifying restrictions, and so the detection of over-identification is hardest when it is most needed. Conversely, however, restricting the instrument set too much results in a loss of information that leads to imprecisely estimated coefficients. Estimation of such models therefore involves a delicate balance between maximizing the information extracted from the data on the one hand, and guarding against over-identification on the other. To this end, we follow the strategy suggested by Roodman (2009) to deal with the problem of weak and excessively numerous instruments. We also validate the system GMM identification assumptions by applying a second-order serial correlation test for the residuals and the Hansen J-test for the overidentifying restrictions. The values reported for AR(1) and AR(2) in the Tables that follow (where applicable) are the *p*-values for first- and second-order autocorrelated disturbances in the first-differenced equation. As expected, we find that there is high first-order autocorrelation, but no evidence for significant second-order autocorrelation. Similarly, the Hansen *J*-test result indicate the validity of internal instruments used in the dynamic model estimated via the system GMM approach.

As a baseline, we estimate Equation (1) using the standard fixed effects model and start with a specification including only macroeconomic and institutional variables in column (1) of Table 1 as a point of reference. We then present parsimonious specifications with only climate change vulnerability and resilience as explanatory variables in columns (2) and (3) individually and column (4) together, and introduce the control variables into the regression in columns (5), (6)

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[9] 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).

and (7). While these results demonstrate a consistent picture, we consider the model in column (7) with climate change vulnerability and resilience indicators and macroeconomic variables as our benchmark specification. Vulnerability to climate change has a statistically and economically significant effect on long-term (10-year) government bond spreads relative to the US benchmark in our sample of countries during the period 1995–2017. The coefficient on climate change vulnerability ranges between 0.579 and 2.526 depending on the model specification, but always remaining positive and statistically significant. This means that greater vulnerability to climate change is associated with higher cost of government borrowing. According to our benchmark specification, a one percentage point increase in climate change vulnerability is associated with an increase of 0.58 percent in long-term government bond spreads.

Table 1. Climate Change and Sovereign Risk—Baseline Estimations

Specification	1	2	3	4	5	6	7
Dependent Variable	Bond spreads	Bond spreads	Bond spreads	Bond spreads	Bond spreads	Bond spreads	Bond spreads
Climate vulnerability		2.526***		2.301***	0.661**		0.579**
		(0.765)		(0.694)	(0.296)		(0.347)
Climate resilience			-0.405***	-0.296**		-0.164***	-0.151**
			(0.144)	(0.115)		(0.063)	(0.060)
Real GDP	0.906				2.722*	1.189	2.756*
	(1.236)				(1.553)	(1.225)	(1.566)
Real GDP growth	-0.171**				-0.183***	-0.192***	-0.200***
	(0.071)				(0.070)	(0.069)	(0.069)
Inflation	0.365***				0.357***	0.358***	0.352***
	(0.129)				(0.127)	(0.127)	(0.125)
Debt	0.057***				0.057***	0.057***	0.057***
	(0.010)				(0.010)	(0.01)	(0.01)
Budget balance	0.075*				0.093	0.082	0.097
	(0.044)				(0.044)	(0.043)	(0.044)
International reserves	-0.002				-0.003	-0.006	-0.007
	(0.011)				(0.011)	(0.011)	(0.011)
Government effectiveness	-1.619**				-1.363*	-1.093*	-0.910*
	(0.741)				(0.725)	(0.687)	(0.690)
Bureaucratic quality	-0.366				-0.486*	-0.148*	-0.271*
	(0.716)				(0.724)	(0.721)	(0.724)
Number of countries	53	54	54	54	53	53	53
Number of observations	823	995	995	995	823	823	823
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.72	0.47	0.49	0.49	0.72	0.72	0.72

Note: Robust standard errors reported in brackets. A constant is included in each regression, but not shown in the table. *** p<0.01, ** p<0.05, * p<0.1

We also find that investing in adaptation and mitigation helps improve climate change resilience and, thereby, lowers government bond spreads in our sample of countries during the period 1995–2017. The coefficient on climate change resilience ranges between -0.164 and -0.405 depending on the model specification, but always remaining negative and statistically significant. In other words, countries that are more resilient to climate change have lower bond yields and spreads relative to countries with greater vulnerability to risks associated with climate change. According to our benchmark specification, 1 percent improvement in climate change resilience is associated with a decrease of 0.15 percent in long-term government bond spreads. These effects of climate change vulnerability and resilience remain robust when we introduce control variables for solvency (real GDP growth, budget balance and debt), liquidity (international reserves) and economic stability (inflation), for which we obtain coefficients that are as expected and broadly comparable to the findings in previous studies.

When the sample is partitioned into country groups, we observe a substantial contrast between advanced and developing countries, as presented in Table 2. Both climate change vulnerability and resilience have no pronounced impact on government bond spreads in advanced economies, while the magnitude and statistical significance of the estimated coefficients are much greater in the case of developing countries. According to our benchmark specification controlling for conventional macroeconomic factors, 1 percent increase in climate change vulnerability leads to an increase of 3.11 percent in long-term government bond spreads of emerging market economies, while 1 percent improvement in climate change resilience lowers bond spreads by 0.75 percent. With long-term government bond spreads in our sample of developing countries averaging about 500 basis points, these estimated coefficients imply that a

Table 2. Climate Change and Sovereign Risk—Country Groups

Specification	1	2	3	4	5	6
Dependent Variable	Bond spreads	Bond spreads	Bond spreads	Bond spreads	Bond spreads	Bond spreads
Country Group	Advanced	Advanced	Advanced	Developing	Developing	Developing
Climate vulnerability	0.063		0.069	2.516***		3.105***
	(0.181)		(0.173)	(0.937)		(0.913)
Climate resilience		-0.006	-0.008		-0.612***	-0.750***
		(0.046)	(0.045)		(0.175)	(0.185)
Real GDP	-1.409	-1.366	-1.440	15.170***	8.488***	17.660***
	(1.368)	(1.369)	(1.387)	(3.834)	(2.515)	(3.701)
Real GDP growth	-0.289***	-0.291***	-0.290***	0.078	0.005	0.015
	(0.068)	(0.069)	(0.07)	(0.128)	(0.118)	(0.114)
Inflation	0.040	0.038	0.038	0.333***	0.349***	0.324***
	(0.054)	(0.058)	(0.058)	(0.124)	(0.126)	(0.112)
Debt	0.018***	0.018***	0.018***	0.146***	0.133***	0.153***
	(0.006)	(0.006)	(0.006)	(0.042)	(0.04)	(0.044)
Budget balance	0.054	0.056	0.054	0.098	0.022	0.117
	(0.037)	(0.038)	(0.038)	(0.131)	(0.137)	(0.122)
International reserves	0.007	0.007	0.007	-0.266**	-0.153**	-0.180**
	(0.007)	(0.007)	(0.007)	(0.104)	(0.105)	(0.096)
Government effectiveness	-0.251	-0.217	-0.236	-0.979**	-1.070**	-1.337**
	(0.54)	(0.501)	(0.501)	(1.873)	(2.068)	(2.153)
Bureaucratic quality	-0.807*	-0.807*	-0.797*	-2.170*	-1.907*	-2.002*
	(0.474)	(0.495)	(0.489)	(2.091)	(1.906)	(1.769)
Number of countries	32	32	32	21	21	21
Number of observations	532	532	532	291	291	291
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.63	0.63	0.63	0.72	0.72	0.74

Note: Robust standard errors reported in brackets. A constant is included in each regression, but not shown in the table. *** p<0.01, ** p<0.05, * p<0.1

one percentage point increase in climate change vulnerability (or resilience) would increase (or decrease) sovereign debt risk premia by 15.55 basis points (or 3.75 basis points). These may seem small, but the difference between countries in the 25th and 75th quintile amounts to 233 basis points for climate change vulnerability and 56 basis points for climate change resilience.

We perform several sensitivity checks to validate the robustness of our baseline empirical results. First, we replace government bond spreads with 10-year bond yields for a sample of 53 advanced and developing countries and with EMBIG spreads for a group of 44 emerging market economies as alternative measures of sovereign risk. These results, presented in Appendix Table A1, are broadly in line with the baseline findings and confirm that the impact of climate change is significant, especially among emerging market economies and developing countries. Second, we truncate the sample at the 5th and 95th percentiles to exclude potential outliers and obtain similar results, as presented in Appendix Table A2. Third, we deal with potential endogeneity by estimating the model using the 2SLS estimator with lagged climate change indices as instruments. These results, presented in Appendix Table A3, confirm that climate vulnerability has a detrimental effect on the cost of borrowing, while climate resilience helps lower sovereign risk. Finally, taking into consideration the potential persistence of bond spreads, we estimate a dynamic specification of the model using the system GMM approach and obtain a set of results, presented in Appendix Table A4, that are broadly consistent with our baseline findings, but the coefficient on climate change resilience does not appear to be robust. It should be noted that the system GMM a very demanding estimator, especially with limited number of unbalanced observations, as it is the case with our panel dataset.

V. CONCLUSION

In this paper, we analyze the effects of climate change on sovereign risk as measured by government bond yields and spreads in 98 countries during the period 1995–2017. The results show that climate vulnerability has a highly significant effect on the cost of government borrowing, even after controlling for conventional macroeconomic and institutional determinants of sovereign risk. That is, countries with greater vulnerability to climate change pay a higher interest rate on government bonds. We also find that climate resilience has a similarly significant negative impact on the cost of borrowing. That is, countries that are more resilient to climate change have lower bond yields and spreads relative to countries with greater vulnerability to climate change. Furthermore, partitioning the sample into country groups reveals that the magnitude and statistical significance of these effects are much greater in developing countries with weaker capacity to adapt to and mitigate the consequences of climate change. These findings remain robust to a battery of sensitivity checks, including alternative measures of government bond spreads and yields, specifications and estimation methodologies.

Econometric evidence presented in this paper has clear policy implications, especially for developing countries that are relatively more vulnerable to risks associated with climate change. Although climate change is inevitable, the negative coefficient on climate resilience shows that enhancing structural resilience through 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 in particular and economic development in general.

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Appendix Table A1. Climate Change and Sovereign Risk—Alternative Measures

Specification	1	2	3	4	5	6
Dependent Variable	Bond yields	Bond yields	Bond yields	EMBIG spread	EMBIG spread	EMBIG spread
Country Group	All	All	All	Developing	Developing	Developing
Climate vulnerability	0.661*		0.579*	2.730***		3.150***
	(0.360)		(0.347)	(0.950)		(0.961)
Climate resilience		-0.164***	-0.151**		-0.610***	-0.740***
		(0.063)	(0.060)		(0.160)	(0.175)
Real GDP	2.722*	1.189	2.756*	17.100**	10.485**	19.650**
	(1.553)	(1.225)	(1.566)	(0.309)	(0.282)	(0.327)
Real GDP growth	-0.183***	-0.192***	-0.200***	-0.034***	-0.034***	-0.034***
	(0.07)	(0.069)	(0.069)	(0.008)	(0.008)	(0.009)
Inflation	0.357***	0.358***	0.352***	0.004**	0.004**	0.004**
	(0.127)	(0.127)	(0.125)	(0.002)	(0.002)	(0.002)
Debt	0.057***	0.057***	0.057***	0.018***	0.017***	0.018***
	(0.010)	(0.010)	(0.010)	(0.002)	(0.002)	(0.002)
Budget balance	0.093	0.082	0.097	0.013	0.013	0.013
	(0.044)	(0.043)	(0.044)	(0.010)	(0.010)	(0.010)
International reserves	-0.003	-0.006	-0.007	-0.066**	-0.015**	-0.017**
	(0.011)	(0.011)	(0.011)	(0.010)	(0.009)	(0.009)
Government effectiveness	-1.363*	-1.093	-0.910	-0.671***	-0.649***	-0.642***
	(0.725)	(0.687)	(0.69)	(0.128)	(0.141)	(0.143)
Bureaucratic quality	-0.486	-0.148	-0.271	-0.376**	-0.368**	-0.351**
	(0.724)	(0.721)	(0.724)	(0.172)	(0.182)	(0.181)
Number of countries	53	53	53	44	44	44
Number of observations	823	823	823	518	518	518
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.73	0.73	0.73	0.83	0.83	0.83

Note: Robust standard errors reported in brackets. A constant is included in each regression, but not shown in the table. *** p<0.01, ** p<0.05, * p<0.1

Appendix Table A2. Climate Change and Sovereign Risk—Excluding Outliers

Specification	1	2	3	4	5	6
Dependent Variable	Bond spreads	Bond spreads	Bond spreads	Bond spreads	Bond spreads	Bond spreads
Climate vulnerability	2.844***		2.949***	0.751**		0.885**
	(0.85)		(0.837)	(0.428)		(0.472)
Climate resilience		-0.546***	-0.530***		-0.203***	-0.223***
		(0.183)	(0.183)		(0.072)	(0.083)
Real GDP				3.684**	2.463*	5.595***
				(1.764)	(1.300)	(2.084)
Real GDP growth				-0.190**	-0.213***	-0.227***
				(0.074)	(0.073)	(0.075)
Inflation				0.354***	0.355***	0.342***
				(0.128)	(0.129)	(0.125)
Debt				0.066***	0.071***	0.081***
				(0.012)	(0.013)	(0.014)
Budget balance				0.092	0.066	0.080
				(0.05)	(0.054)	(0.058)
International reserves				-0.038*	-0.007	-0.041*
				(0.023)	(0.015)	(0.024)
Government effectiveness				-1.689**	-1.491*	-1.634*
				(0.801)	(0.797)	(0.863)
Bureaucratic quality				-0.719	-0.472	-0.722
				(0.872)	(0.871)	(0.979)
Number of observations	804	817	687	671	686	587
% excluded	19%	18%	31%	18%	17%	29%
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.48	0.46	0.49	0.71	0.72	0.72

Note: Robust standard errors reported in brackets. A constant is included in each regression, but not shown in the table. *** p<0.01, ** p<0.05, * p<0.1

Appendix Table A3. Climate Change and Sovereign Risk—2SLS Estimations

Specification	1	2	3	4	5	6
Dependent Variable	Bond spreads	Bond spreads	Bond spreads	Bond spreads	Bond spreads	Bond spreads
Climate vulnerability	3.024***		2.727***	0.806***		0.686***
	(0.894)		(0.815)	(0.429)		(0.41)
Climate resilience		-0.438***	-0.302**		-0.171***	-0.161***
		(0.150)	(0.122)		(0.06)	(0.058)
Real GDP				3.6495**	1.774*	3.6331**
				(1.725)	(1.265)	(1.722)
Real GDP growth				-0.192***	-0.200***	-0.210***
				(0.067)	(0.066)	(0.066)
Inflation				0.352***	0.354***	0.347***
				(0.121)	(0.121)	(0.119)
Debt				0.064***	0.064***	0.064***
				(0.011)	(0.01)	(0.011)
Budget balance				0.090	0.085	0.102
				(0.043)	(0.042)	(0.043)
International reserves				-0.005	-0.007	-0.009
				(0.011)	(0.011)	(0.011)
Government effectiveness				-1.598**	-1.265**	-1.082**
				(0.723)	(0.684)	(0.686)
Bureaucratic quality				-0.181	0.172	0.049
				(0.715)	(0.716)	(0.717)
Number of countries	54	54	54	53	53	53
Number of observations	938	938	938	801	801	801
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Kleibergen-Paap statistic (p-value)	0.00	0.00	0.00	0.00	0.00	0.00
Hansen statistic (p-value)	0.17	0.03	0.10	0.62	0.47	0.78
R-squared	0.47	0.49	0.50	0.72	0.73	0.73

Note: Robust standard errors reported in brackets. A constant is included in each regression, but not shown in the table. 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. *** p<0.01, ** p<0.05, * p<0.1

Appendix Table A4. Climate Change and Sovereign Risk—Dynamic Estimations

Specification	1	2	3	4	5	6
Dependent Variable	Bond spreads	Bond spreads	Bond spreads	EMBIG	EMBIG	EMBIG
Country Group	All	All	All	Developing	Developing	Developing
Estimator	S-GMM	S-GMM	S-GMM	S-GMM	S-GMM	S-GMM
Lagged Dependent Variable	0.6049***	0.6134***	0.6063***	0.6350***	0.5032***	0.5130***
	(0.034)	(0.034)	(0.028)	(0.067)	(0.095)	(0.093)
Vulnerability	0.1840***		0.1945***	0.1324*		0.1635**
	(0.059)		(0.045)	(0.080)		(0.077)
Resilience		0.0063	0.0052		-0.0072	0.0598
		(0.071)	(0.039)		(0.078)	(0.060)
Real GDP	-0.1001	-0.1033	-0.1615	-0.1337	0.0982	-0.0090
	(0.231)	(0.220)	(0.154)	(0.160)	(0.213)	(0.164)
Real GDP growth	-0.1812**	-0.0507	-0.1075	-0.4032***	-0.5515***	-0.4139***
	(0.073)	(0.080)	(0.081)	(0.127)	(0.126)	(0.087)
Inflation	0.1372**	0.1246	0.1213**	-0.0183	-0.0082	0.0118
	(0.069)	(0.082)	(0.059)	(0.036)	(0.031)	(0.028)
Debt	-0.0099	-0.0050	-0.0077	0.0565	0.1383*	0.1066*
	(0.012)	(0.008)	(0.007)	(0.051)	(0.071)	(0.063)
Budget balance	-0.1149	-0.2420	-0.1268	-0.2363	-0.0873	0.0185
	(0.115)	(0.181)	(0.117)	(0.181)	(0.139)	(0.129)
International reserves	0.0090	-0.0113	0.0088	0.0000	0.0000	0.0000
	(0.082)	(0.099)	(0.046)	(0.000)	(0.000)	(0.000)
Government effectiveness	-2.4385	-1.7067	-1.9778	-1.9058	-2.6397	-2.3126
	(0.804)	(1.787)	(1.051)	(1.068)	(1.884)	(1.214)
Bureaucratic quality	-2.4316**	-2.2399*	-1.8838**	-2.6051**	-5.4923***	-5.4290***
	(1.197)	(1.198)	(0.889)	(1.094)	(1.661)	(1.933)
Number of countries	52	52	52	44	44	44
Number of observations	810	810	810	495	495	495
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
AR1 (p-value)	0.002	0.002	0.002	0.083	0.024	0.063
AR2 (p-value)	0.399	0.380	0.442	0.297	0.394	0.466
Hansen statistic (p-value)	0.369	0.416	0.992	0.755	0.891	0.804

Note: Robust standard errors reported in brackets. A constant is included in each regression, but not shown in the table. The Hansen test is a test of overidentifying restrictions. AR1 and AR2 test for first and second autocorrelation, respectively. *** p<0.01, ** p<0.05, * p<0.1