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Impact of climate vulnerability on fiscal risk: Do religious tensions and financial development matter?[☆]

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ABSTRACT

Using data from around 100 countries between 1995 and 2019, we examine the impact of climate vulnerability on fiscal risk. We also explore the transmission channels that are important for the relationship between climate vulnerability and fiscal risk. Our results show that in highly climate-vulnerable economies, increased vulnerability leads to higher government bond yields by 0.5 to 1.5 percentage point and lower sovereign debt ratings by up to one notch over two years. These effects are exacerbated by religious tensions as a form of political instability but mitigated by well-developed financial markets. Therefore, even though fiscal consolidation is crucial for containing fiscal risks in the case of climate vulnerability, political stability and financial development also matter.

1. Introduction

Climate vulnerability, which refers to the potential adverse socioeconomic impacts of climate change, leads to significant fiscal risks.[1] For example, a major natural disaster caused by climate change may require substantial fiscal expenditures for relief and recovery efforts. Additionally, extreme heat from global warming can result in widespread agricultural damage, necessitating government subsidies for affected farmers. More broadly, public spending on climate change adaptation and mitigation is becoming a large and growing fiscal demand around the world. Along with other significant fiscal demands, such as those associated with population aging, climate change-related fiscal expenditures will present a substantial challenge to fiscal sustainability in the future.

Our paper provides a unique contribution to literature by empirically examining the link between climate vulnerability and fiscal risk. We first explore whether climate vulnerability affects fiscal risk and if this effect depends on the vulnerability level. Next, we assess how political stability and financial development mitigate climate-related fiscal risks. Political stability promotes sustainable fiscal policies, thus reducing the impact of climate shocks on fiscal sustainability. We are the first to provide empirical evidence that religious tensions, as a form of political instability amplify the climate risk premium. Moreover, it encourages rational government planning in response to climate shocks, further contributing to healthy public finances. Financial development also contributes by providing firms and households with insurance and credit, lessening the need for large fiscal outlays and thus mitigating the negative effects on fiscal risk.

Political stability and financial development can also reduce the impact of uncertainty on the economy. Political stability minimizes political uncertainty, enabling economic agents to respond more rationally to shocks. Financial development offers households and firms various instruments such as futures contracts to protect themselves against economic uncertainty. Therefore, both political stability and financial development can mitigate the negative economic effects of uncertainty related to climate change.

Against this backdrop, we empirically analyze the impact of political stability and financial development on climate-related fiscal risks using

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[1] In the rest of the text, we will use fiscal risk to designate adverse development of two measures, namely sovereign bond yields and ratings on foreign currency long-term sovereign debt, to ease the reading.

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panel data from around 100 countries between 1995 and 2019. Our central objective is to investigate whether politically stable and financially developed economies are less prone to climate-related fiscal risks. Our analysis employs two measures of fiscal risk, namely sovereign bond yields and ratings on foreign currency long-term sovereign debt, which reflect the assessment of the financial markets about an economy's fiscal sustainability.

Our empirical analysis uses a two-stage estimation. First, we examine how climate vulnerability impacts fiscal risk. We find a negative effect in countries most at risk from climate change, re-confirming the evidence from the previous literature but with a larger sample. Second, we explore how political stability and financial development mitigate these negative impacts, and this is our primary novel contribution to literature.

Our literature review identifies one major study that is especially relevant to our paper. You et al. (2015) empirically investigate the relationship between democracy, financial openness, and global carbon dioxide emissions. They also examine whether the effect of these independent variables on CO_2 emissions changes across different levels of CO_2 emissions. Specifically, they analyze whether their impact depends on a country's CO_2 emission level. Their cross-country empirical analysis is based on a global sample of approximately 100 advanced and developing economies, covering the period from 1995 to 2019. The authors find that, among the highest emitting countries, more democracy correlates with less CO_2 emissions, but greater financial openness does not have a significant effect either way.

Our paper presents a fundamentally distinct approach, despite some superficial similarities with previous studies such as You et al. (2015).

First, we focus on multiple dimensions of political stability, defined as the absence of domestic and external conflict, rather than solely on democracy. Second, our study examines climate vulnerability, which encompasses a wide range of potentially negative impacts of climate change, instead of concentrating solely on CO_2 emissions. Climate vulnerability is a broader concept than CO_2 emissions, which is merely one aspect of the global environmental crisis. Another significant difference lies in our treatment of climate vulnerability as an independent variable rather than a dependent variable. Lastly, the primary variable of interest in our research is fiscal risk, not climate vulnerability. Specifically, we analyze how political stability and financial development influences the adverse effects of climate vulnerability on fiscal risk. Given the substantial challenge that climate change poses to fiscal sustainability, our paper aims to identify the factors that can help mitigate this challenge. Additionally, we explore possible non-linearity in terms of fiscal risk rather than climate vulnerability. Specifically, we evaluate whether the impact of fiscal risk on climate vulnerability varies depending on a country's fiscal health.

Our empirical analysis of the roles of financial development and political stability as mitigating factors is grounded in the literature. Economies with more developed financial systems can cope better with external shocks (Caballero and Krishnamurthy, 2004; Klomp, 2014) due to better access to finance, deeper capital markets, and sophisticated risk-sharing mechanisms. For example, governments in financially developed economies can issue debt to ease the fiscal burdens stemming from climate shocks. Political stability also buffers the fiscal effects of economic shocks due to stronger public financial management institutions and better access to international capital markets (Kahn, 2005; Cavallo and Noy, 2011). Furthermore. politically stable economies tend to invest more in disaster preparedness and resilience (Keefer et al., 2011).

We find that political stability reduces the negative fiscal impacts of climate vulnerability. Our research shows that in highly climate-vulnerable economies, increased vulnerability raises government bond yields by 0.5 to 1.5 percentage point and lowers sovereign debt ratings by one notch over two years. These effects are exacerbated by political instability but mitigated by deeper financial markets. In fact, financially developed countries do not face climate-related bond risk premium. Furthermore, the most fiscally constrained economies suffer the largest climate-related risk premia. Therefore, financial development and political stability reinforce healthy fiscal positions as buffers against the adverse fiscal impacts of climate change.

Our causal identification shows that government bond yields and sovereign ratings on foreign currency debt do not affect changes in ND-GAIN vulnerability scores. Our empirical results are confirmed by various robustness checks, including panel VAR analysis for vulnerable countries, panel local projections for natural disaster shocks, and panel VAR analysis for large disasters.

The rest of our paper is structured as follows. Section 2 reviews the literature; Section 3 presents the data and empirical methodology; Section 4 reports and discusses our empirical findings; and Section 5 concludes.

2. Literature review

This paper examines how climate change vulnerability affects fiscal risk, impacting economic growth and exacerbating inequality, especially in developing countries. Prior research highlights that climate change significantly hampers economic development (Oppenheimer et al., 2014; Tol et al., 2003; Mendelsohn et al., 2006; Diffenbaugh and Burke, 2019; Dasgupta et al., 2023). To enhance resilience, it is critical for these countries to allocate resources strategically, implement adaptation policies, and increase access to precautionary resources and health services (Paglialunga et al., 2022; Cevik and Jalles, 2023). Strengthening social safety nets and redistribution mechanisms is also essential to support those severely affected by climate shocks (Cevik and Jalles, 2023).

Climate change insurance funds, strategic investments in economic development, and cross-national compensation mechanisms are important for low-latitude countries that are more vulnerable to climate-induced shocks, aiding in economic resilience (Mendelsohn et al., 2006). To adapt to and mitigate the socioeconomic impacts of climate change and rising temperatures, countries require substantial adaptive capacity (Tol et al., 2003), diversified economic structures (Dissart, 2003), political stability (Dell et al., 2012), and strong institutional governance (Pike et al., 2010). However, developing countries often lack these conditions due to financial limitations and challenging geographical circumstances. Additionally, these nations usually face stronger fiscal constraints, limiting governmental ability to provide adequate assistance to populations affected by climate-related shocks (Cevik and Jalles, 2023).

Literature reveals that climate vulnerability and resilience asymmetrically affect sovereign risk and public finance. Beirne et al. (2021) study forty economies, finding that climate vulnerability significantly raises sovereign borrowing costs, more so than resilience factors. Cevik and Jalles (2022), analyzing data from ninety-eight countries between 1995 and 2017, confirm that both factors impact government borrowing costs, especially in developing nations due to their higher sovereign risk and weaker adaptive capacities.

Boitan and Marchewka-Bartkowiak (2022) study the effect of climate change metrics on EU government borrowing costs from 2000 to 2020. They discover that nations with higher climate vulnerability and lower disaster management capacity face elevated sovereign risk premiums. Zenios (2022) examines the impact of climate risks on fiscal stability in advanced economies, revealing varied climate risks and how they affect public finance. Both studies highlight the necessity of effective climate risk management.

Carattini et al. (2023) examine how macroeconomic stability affects climate risk. They investigate if ambitious climate policies cause instability and suggest efficient climate and macroprudential policies for managing risks over time. Their findings indicate that well-designed climate policies can mitigate long-term fiscal risks without destabilizing the economy.

Various studies have examined the implications of climate risk. For

Table 1
Descriptive statistics for the variables involved.

Variables	Count	Mean	First Quartile	Median	Third Quartile	Standard Deviation	Minimum	Maximum
Climate vulnerability variable								
ND-GAIN overall vulnerability	4784	0.442	0.372	0.430	0.517	0.0955	0.244	0.696
Fiscal risk variables								
Government bonds, yields %	2052	6.078	3.970	5.256	7.351	3.656	0.438	23.31
Sovereign debt ratings, index	3300	12.36	8	11.87	16.67	5.181	1	21
Domestic controls								
Current Account Balance	4510	−2.276	−7.167	−2.773	1.739	14.01	−148.0	311.7
Gov. Net Lending/Borrowing	4859	−2.020	−4.613	−2.335	0.0160	6.551	−59.74	125.1
General Gov. Gross Debt	4694	55.83	29.48	46.25	69.83	44.59	0	600.1
CPI % year-on-year	3607	0.501	0.132	0.291	0.592	0.843	−1.223	8.925
Banking crises dummy	4356	0.0119	0	0	0	0.109	0	1
Currency crises dummy	4356	0.0177	0	0	0	0.132	0	1
Debt crises dummy	4356	0.00620	0	0	0	0.0785	0	1

Source: authors' calculations. See appendix A for more details.

example, Cevik and Jalles (2023) investigated the social dimension of climate vulnerability by analyzing the relationship between climate risk and economic inequality. Their research indicates that a 1% increase in climate change vulnerability leads to a 1.5% rise in inequality, as measured by the Gini coefficient. Yang et al. (2024) examined climate transition risk spillovers among six major financial markets from 2013 to 2021. They found that the U.S. is the main net contributor to climate transition risk, while Japan and China are net risk recipients. Their study shows that climate risk spillovers fluctuate over time and depend on the types of climate transition risk shocks. Overall, their findings illustrate the interconnectedness of global financial markets concerning climate transition risks.

Despite existing literature on climate change's impact on sovereign risk and borrowing, there is little empirical research on the link between climate vulnerability and fiscal risk. This gap is significant, as climate risks threaten fiscal sustainability. Zenios (2022) is the only study exploring the climate-fiscal relationship, focusing on advanced economies through descriptive analysis.

We conceptualize the link between climate vulnerability and fiscal space through three reinforcing channels. First, vulnerability raises direct fiscal costs (e.g., damage to public assets, disaster relief, and social transfers) that deteriorate budget balances and debt dynamics (Noy, 2009,; Hsiang and Jina, 2014). Second, vulnerability depresses tax bases by lowering activity and long-run growth, eroding fiscal capacity (Dell et al., 2012; Burke et al., 2015). Third, markets embed a climate risk premium in required returns, so higher vulnerability translates into tighter sovereign financing conditions. This effect is consistent with asset-pricing evidence on climate risk in municipal and corporate bonds and discount rates (Bansal et al., 2016; Painter, 2020; Giglio et al., 2015; Bolton and Kacperczyk, 2021). These mechanisms motivate our two empirical proxies for fiscal space (bond yields and sovereign ratings) and our heterogeneity tests. In particular, stronger political stability (proxied by ICRG components, with religious tensions as our baseline) and deeper financial development should mitigate the fiscal and financial transmission, in line with work linking state capacity and institutions to taxation and sovereign risk (Besley and Persson, 2009; Acemoglu et al., 2001) and finance to risk sharing and external premia (Levine, 2005).

A rise in climate vulnerability increases expected fiscal outlays (disaster relief, reconstruction, and adaptation investment), while weakening tax bases through lower growth and sectoral disruptions. Forward-looking investors capitalize these risks into sovereign borrowing costs, tightening fiscal space. Political-economy frictions can amplify this transmission: where societal cleavages are pronounced, governments face greater obstacles to coordinating credible policy responses (e.g., resilience spending, tax reform), so the same vulnerability shock elicits a larger financing premium. Historical evidence that communities exposed to higher environmental risk developed distinct religious organization and dense religious networks (Ager and Ciccone, 2018) is consistent with this mechanism: when such cleavages become salient as “religious tensions,” they can hinder collective action and policy implementation (Sharma et al., 2021) precisely when adaptation needs rise, strengthening the vulnerability–yield link we estimate.

Our main contribution to literature is systematically examining the impact of climate vulnerability on fiscal risk for approximately 100 countries from 1995 to 2019. We also assess how political stability and financial development buffer the adverse effects of climate vulnerability on fiscal risk. Unlike You et al. (2015), who focused on the relationship between democracy, financial openness, and CO2 emissions, we investigate how political and financial factors influence the impact of climate risk on fiscal openness. Our primary interest lies in understanding how these factors affect fiscal risk in the face of climate change, providing a more complete understanding of this relationship.

3. Methodology and data

3.1. Data

A database has been constructed for a sample of approximately 100 countries observed between 1995 and 2019 (refer to Appendices A and B).[2] In Table 1, the main variables used to measure fiscal risk are bond yields and foreign currency long-term sovereign debt ratings. The bond variable reflects government bond yields and is derived from the JPM EMBI bond index, supplemented by the IMF IFS database. Included bonds have a maturity of at least 2.5 years.[3] The second variable is an annual average of foreign currency long-term sovereign debt ratings provided by Moody's, Standard & Poor's, and Fitch Ratings, sourced from Bloomberg daily.

The data utilized in this study is sourced from Kose et al. (2022). It is noted that the authors assign a score of one to represent the worst rating and twenty-one for the best, subsequently calculating a simple average across three ratings. The impulse variable examined in this research is the change in ND-GAIN overall vulnerability score, multiplied by one hundred. This score assesses “The propensity or predisposition of human societies to be negatively impacted by climate hazards.” A higher score

[2] The complete list of countries involved in bond (98 countries) and sovereign rating (121 countries) regressions is provided in the Appendix B.

[3] To improve distributional characteristics, the bond variable is transformed using the formula *100 x / (x + 100)*, and then winsorized. The results are not affected by this transformation.

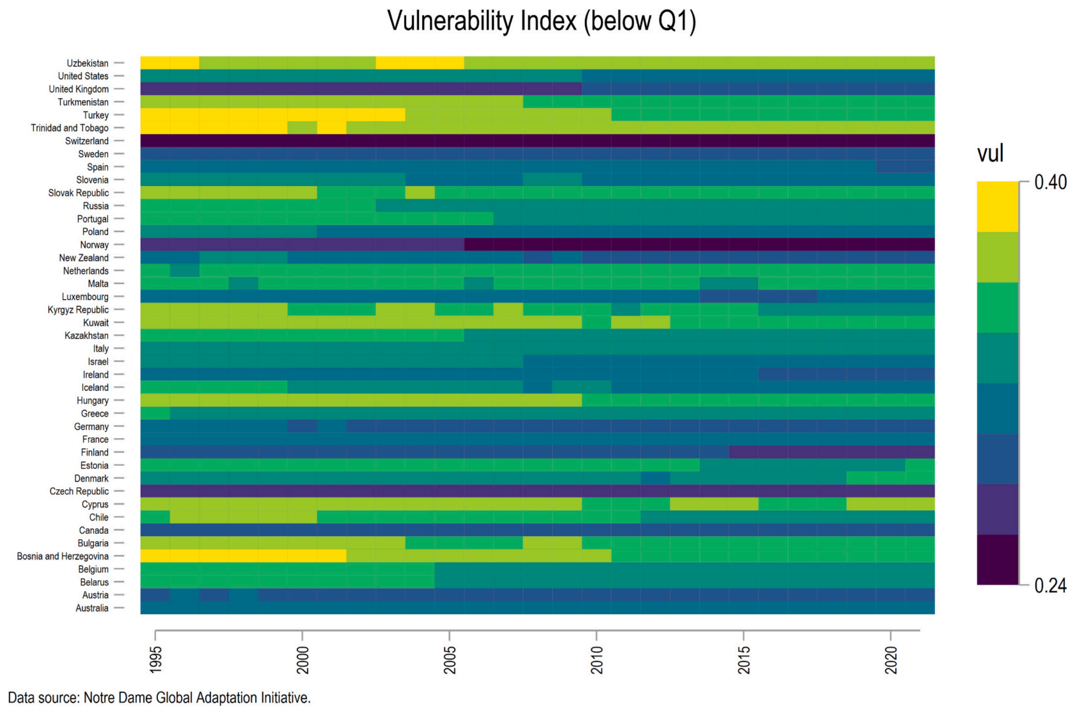

Fig. 1. Heat plot for the low vulnerability score.
(Source: authors' calculations.)

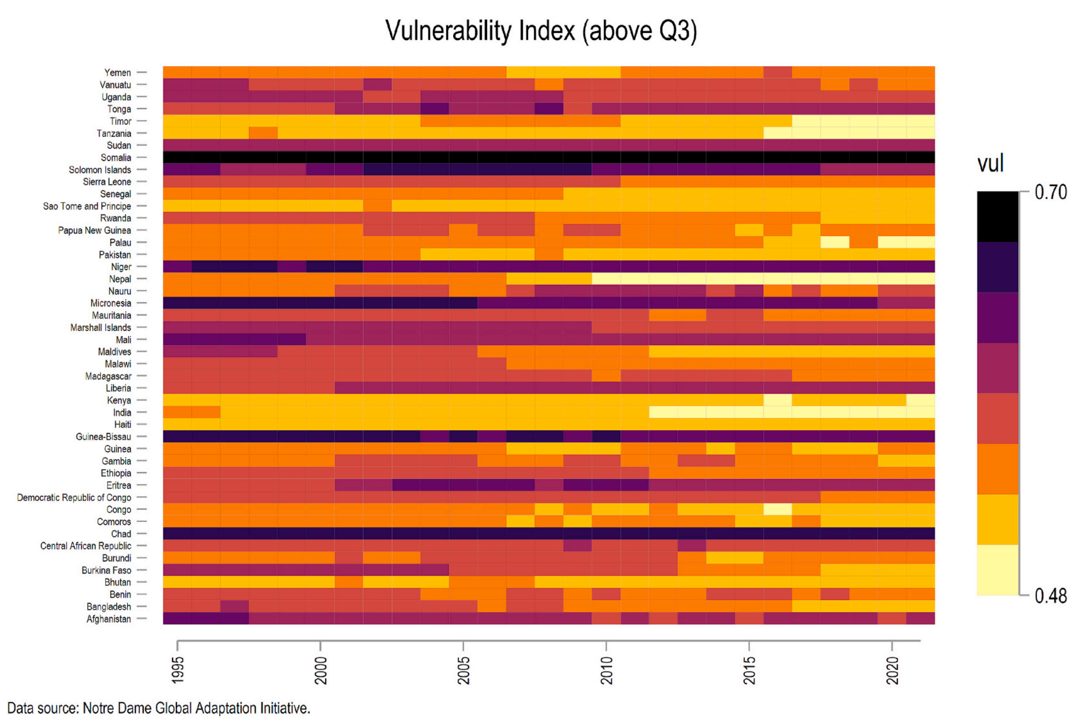

Fig. 2. Heat plot for the high vulnerability score.
(Source: authors' calculations.)

indicates greater vulnerability to climate risks. Figs. 1 and 2 display heat maps for the lowest and highest quartiles, respectively.

The results will first be presented without any controls, using the Teulings and Zubanov (2014) correction to account for the impact of future climate risk shocks at future horizons. Teulings and Zubanov (2014) demonstrate that not considering future shocks can introduce substantial bias in the impulse response functions. Additionally, following Beirne et al. (2021) and Kling et al. (2021), we include control variables for domestic factors such as the current account balance, government debt and deficit, and CPI inflation. Furthermore, all the estimates included country- and time-fixed effect. The time fixed-effects control for common shocks.

Fig. 1 shows the mean vulnerability score for each country. We retain countries with a mean value below the first quartile. The first quartile

Table 2
Comparing fundamentals and institutional features for different levels of vulnerability.

	VUL High (Above Q3 of VUL)	VUL Low (Below Q3 of VUL)	Total	Test
	1196 (25.0%)	3588 (75.0%)	4784 (100.0%)	
ND-GAIN overall vulnerability	0.57 (0.04)	0.40 (0.06)	0.44 (0.10)	<0.001
ND-GAIN overall readiness	0.31 (0.07)	0.43 (0.13)	0.40 (0.13)	<0.001
Government bonds, yields %	7.67 (3.55)	5.93 (3.63)	6.08 (3.66)	<0.001
Treasury Bills, yields %	9.83 (6.34)	6.36 (6.03)	7.01 (6.24)	<0.001
Foreign currency sovereign debt ratings	7.30 (1.38)	12.64 (5.14)	12.23 (5.15)	<0.001
Chinn-Ito index, normalized	0.34 (0.32)	0.57 (0.37)	0.52 (0.37)	<0.001
Exchange Rate Stability Index	0.57 (0.28)	0.62 (0.31)	0.61 (0.31)	<0.001
Financial Institution index	0.18 (0.07)	0.45 (0.21)	0.38 (0.22)	<0.001
Financial Market index	0.03 (0.08)	0.26 (0.26)	0.20 (0.25)	<0.001
ICRG index: External Conflict	9.11 (1.64)	10.10 (1.32)	9.92 (1.44)	<0.001
ICRG index: Corruption	1.95 (0.78)	2.91 (1.22)	2.74 (1.21)	<0.001
ICRG index: Bureaucracy Quality	1.22 (0.81)	2.44 (1.03)	2.22 (1.10)	<0.001
ICRG index: Democratic Accountability	3.19 (1.32)	4.22 (1.65)	4.03 (1.64)	<0.001
ICRG index: Ethnic Tensions	3.08 (1.06)	4.24 (1.19)	4.03 (1.25)	<0.001
ICRG index: Government Stability	8.09 (1.66)	8.17 (1.58)	8.16 (1.60)	0.258
ICRG index: Internal Conflict	7.76 (1.62)	9.48 (1.64)	9.17 (1.76)	<0.001
ICRG index: Law and Order	2.80 (0.98)	3.98 (1.29)	3.77 (1.32)	<0.001
ICRG index: Military in Politics	2.08 (1.32)	4.24 (1.56)	3.85 (1.73)	<0.001
ICRG index: Religious Tensions	3.67 (1.34)	4.78 (1.21)	4.58 (1.30)	<0.001

In the top row of this table, we have the number of observations and the frequency in percentage in parentheses. For the variable in the rows behind the top row, we have the average, followed by the standard deviation in parentheses. Finally, we have the p-value from a pooled *t*-test for equality of means in the last column. We use the *de jure* Chinn-Ito index for financial openness for comparability with previous works. VUL stands for the ND-GAIN overall vulnerability. Source: authors' calculations.

includes both advanced and developing economies. These countries are not affected by high temperatures due to their location, do not rely on energy imports, and have invested in infrastructure. While some countries are advanced, others are not as developed economically but show strong resilience to climate risks due to excellent scores in certain ND-GAIN sub-categories. For instance, Russia excels in infrastructure with widespread electricity access, energy independence, and limited impact from sea level changes. Similarly, Uzbekistan, Turkmenistan, and Kazakhstan share these infrastructure strengths. However, other sub-categories like agriculture capacity show higher vulnerability, as seen in Russia's difficulty in adopting new and ecological agricultural technologies. Hence, economic development levels vary within this group.

Fig. 2 shows that countries with high vulnerability (above the third quartile) are usually in the early stages of economic and institutional development and have less developed financial markets. These more homogeneous countries include those in Sub-Saharan Africa and South Asia, where paved roads, electricity, and reliable drinking water are scarce. For instance, Chad and Afghanistan show high vulnerability in both agricultural capacity and medical staff coverage. Table 2 compares the fundamental and institutional characteristics for different vulnerability levels to climate risks. We divided the sample into countries with high and low vulnerability, based on ND-GAIN scores. Highly vulnerable countries differ significantly from less vulnerable ones, particularly showing much lower ND-GAIN overall readiness.

They have lower fiscal risks. Yields on bonds and bills are higher. Public and external deficits are higher. There is more consumer price inflation. The occurrence of crises is lower due to limited financial and trade integration. They are more dependent on fuel imports and export less fuel. The level of de jure financial openness is lower. They tend to have more flexible exchange rates. The level of financial institution development is lower. For the institutional variables, they have lower scores in almost all dimensions, indicating higher institutional risks. Specifically, they have lower risk ratings for religious and ethnic tensions, internal and external conflicts (that is, more political instability). Overall, they tend to be less investable compared to other emerging countries. Figs. 3 and 4 show a positive correlation between climate vulnerability risks and bond yields, and a negative correlation between these risks and sovereign ratings. These results align with empirical findings in the literature (Beirne et al., 2021; Cevik and Jalles, 2022).

3.2. Methodology

We employ the local projections (LP) methodology (Jordà, 2005; Jordà and Taylor, 2025) to empirically analyze the effects of vulnerability shocks on two measures of fiscal risk. The LP methodology offers several advantages, including (i) the estimation of impulse responses directly at each horizon without cross-period restrictions, (ii) straightforward inference for impulse response coefficients, (iii) ease of application to nonlinear frameworks, and (iv) scalability to panel data. Regarding our research question, all these features of the LP methodology will enable us to provide dynamic evidence on the impact of vulnerability change shocks on fiscal-risk variables. The LP approach can be formulated as follows:

$$y_{i,t+h} = \alpha_i^h + \tau_t^h + b_h \Delta S_{i,t} + \gamma_h y_{i,t-1} + \mathbf{f}_h^{'} \mathbf{F}_{i,t+1:t+L} + \alpha^{'} \mathbf{z}_{i,t-1} + v_{i,t+h} \qquad \text{IRF}(h) = \widehat{b} \tag{1}$$

where y is the dependent variable of interest, $\alpha_i^h$and τ_t^h are country- and time-fixed effects, $\mathbf{F}_{i,t+1:t+L}$ are forward shocks (Teulings-Zubanov correction), h is the time horizon, ΔS is the impulse variable (a unit shock on the change in the vulnerability score), $\mathbf{z}$ is a vector of control variables, IRF denotes the impulse response function, and v is the error term. In our case, the dependent variable (one of two measures of fiscal risk) will be either government bond yields or sovereign ratings (Kose et al., 2022). The control variables will be based on Beirne et al. (2021) and include domestic factors: the current account balance, the consumer price inflation, the government debt, and deficit; global factors: the US bond yields, the MSCI World index, and the VIX.[4] To improve identification and reduce the risk of omitted variable bias, we also control for three types of crises (banking, current, and debt), drawn from Laeven and Valencia (2020).

3.3. Discussions about reverse causality

Introduced by Chen et al. (2015), the ND-GAIN vulnerability score consists of three components across six dimensions (Food, Water, Health, Ecosystem Services, Human Habitat, Infrastructure), each dimension is measured by two variables:

[4] The inclusion of global controls is standard in the literature and is further justified by the fact that sovereign bonds and sovereign rating comove during financial crises. Thus, global controls capture the influence of global common shocks may be more informative than simple time fixed effects, but less complete. In the empirical results, we will replace the inclusion global controls by time fixed effects to capture the effect of common shocks.

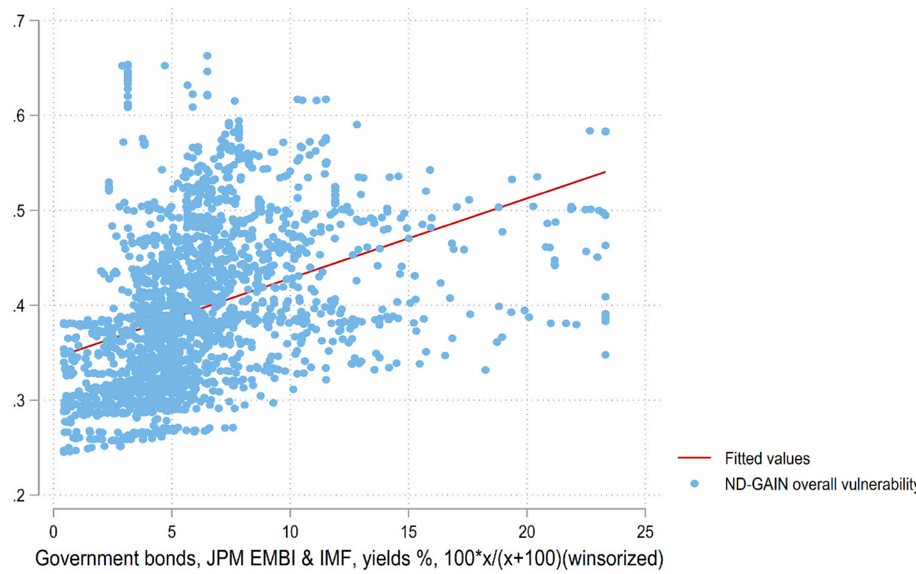

Fig. 3. Scatter plot for the vulnerability score and bond yields.
(Source: authors' calculations.)

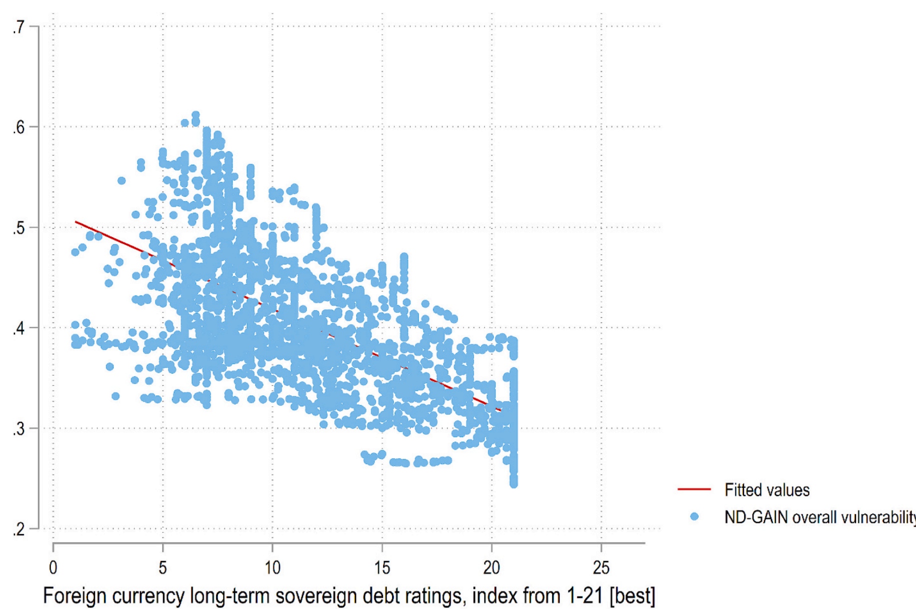

Fig. 4. Scatter plot for the vulnerability score and the sovereign ratings.
(Source: authors' calculations.)

(i) The extent to which an economy is exposed to significant climate change from a biophysical perspective. This exposure to climate change is time-invariant.
(ii) The degree to which an economy depends on sectors that are particularly sensitive to climate change. The sensitivity is time-varying.
(iii) The extent of an economy's adaptive capacity to climate change. The adaptive capacity is time-varying.

This measure can therefore be interpreted as an overall measure reflecting both physical and transition climate risks. In the subsequent sections, the local projection estimates will incorporate country- and time-fixed effects and concentrate on variations in vulnerability scores. Consequently, changes in the ND-GAIN vulnerability scores were examined, with the time-invariant exposure component being removed. The shock reflects the alterations in climate change sensitivity and adaptive capacity. Are these changes contemporaneously correlated with the explanatory variables in our analysis? Fig. 5a and 5b illustrates the temporal distribution of changes in ND-GAIN vulnerability scores for groups with low and high vulnerability.

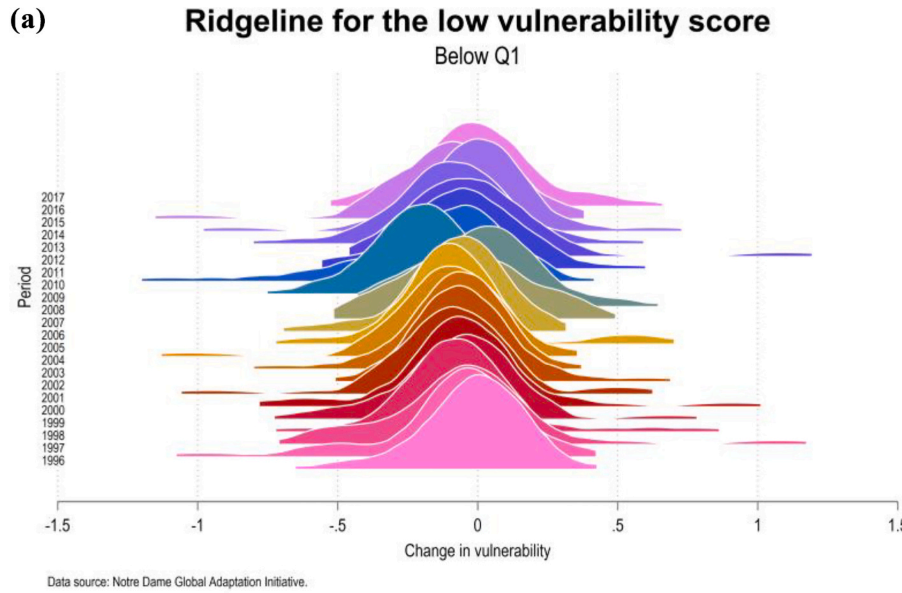

Fig. 5a. Ridgeline for the changes in climate vulnerability scores.
(Source: authors' calculations. In the estimates, we use up to five observations in the temporal dimensions to plot the IRF at the horizons 0 to 4.)

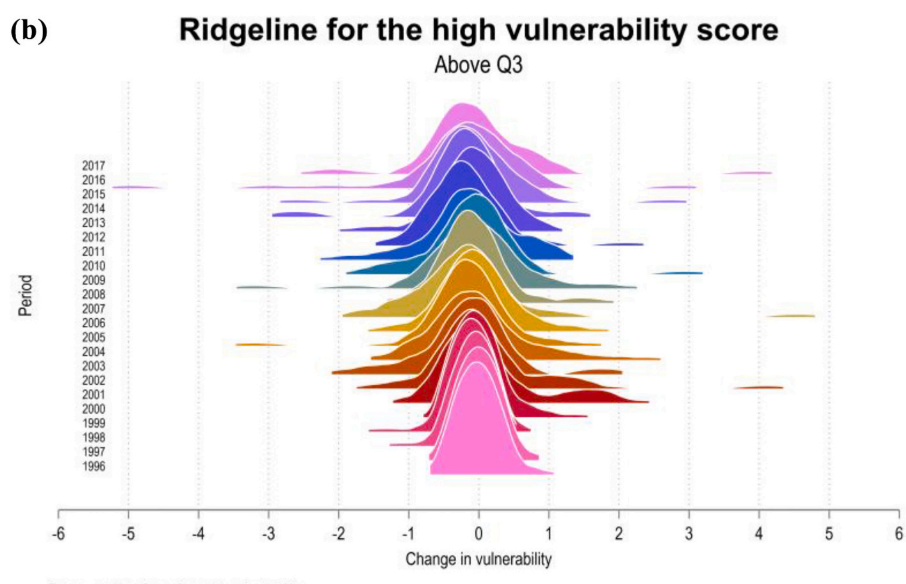

Fig. 5b. Joyplots for the changes in climate vulnerability scores.
(Source: authors' calculations. In the estimates, we use up to five observations in the temporal dimensions to plot the IRF at the horizons 0 to 4.)

Firstly, the contemporaneous correlation between government bond yields and changes in vulnerability scores is −0.05, while the contemporaneous correlation between sovereign ratings on foreign currency long-term debt is 0.09. There is no significant contemporaneous correlation between changes in sensitivity and adaptive capacity with our fiscal risk variables. Secondly, the contemporaneous correlation with measures of financial development and political stability variables is below 0.05. To eliminate the possibility of reverse causality, it is also necessary to estimate the impact of changes in vulnerability scores on our fiscal risk variables.

Table 3 shows that our fiscal risk variables are not impacted by reverse causality at any time. Using Local Projections, we estimate baseline results with the shock as the change in vulnerability score. Besides, natural disasters, which cannot be affected by reverse causality and relate to ND-GAINS, likely influence investor perceptions. We will provide additional estimates in the appendix C to E on how natural disasters impact bond yields using the EM-DAT database. As per Klomp (2015), we will select 630 large-scale natural disasters that may affect investor perceptions.

4. Empirical results

4.1. Panel local projections regressions

Fig. 6 shows that across all countries, there is a significant premium on sovereign bond yields due to climate risk vulnerability, indicating investors demand higher returns for such debt. Bi-variate panel VAR estimates suggest a unit increase in vulnerability raises bond yields by

Table 3
Reverse causality.

	Changes in vulnerability		Changes in vulnerability
Bonds$_t$	0.01	*Ratings*$_t$	−0.01
	(−0.34)		(0.25)
Bonds$_{t-1}$	−0.01	*Ratings*$_{t-1}$	0.01
	(−0.41)		(0.51)
Bonds$_{t-2}$	0.01	*Ratings*$_{t-2}$	−0.01
	(−0.32)		(0.72)
Bonds$_{t-3}$	−0.01	*Ratings*$_{t-3}$	0.02
	(−0.22)		(0.16)
Bonds$_{t-4}$	0.00	*Ratings*$_{t-4}$	−0.01
	(−0.73)		(0.27)
Constant	−0.09	Constant	−0.11**
	(−0.13)		(0.04)
Observations	1670	Observations	2632
R-squared	0.02	R-squared	0.05

Authors' calculations. *P*-values in parentheses. Country- and time-fixed effects included. Robust standard errors.

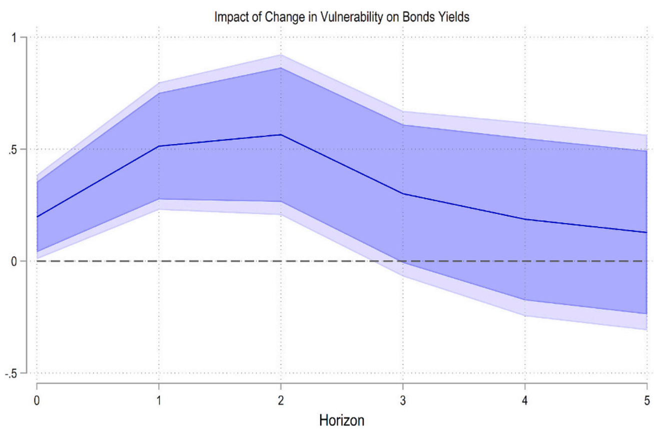

Fig. 6. Panel LP - impact of change in vulnerability on bond yields (Baseline). Authors' calculations. The shock is a unit-shock on the change in vulnerability variable. Country- and time-fixed effects are included, and standard errors are clustered at the country level. 90 and 95% confidence Intervals in dark and light blue, respectively. We include the future climate risk shocks up to 5 years, following Teulings and Zubanov (2014), and no controls.

0.5 to 1 percentage point.[5,6] Fig. 7 uses state-dependent local projections *à la* Ramey and Zubairy (2018) based on vulnerability scores. Less vulnerable countries do not show a significant effect, which aligns with the expectation that low climate exposure will not affect bond yields. Highly vulnerable countries display a significant impact, similar in magnitude to the overall panel, suggesting they drive the results.

To ensure the entire sample is analyzed rather than a subsample, State-Dependent Local Projections as described by Ramey and Zubairy (2018) will be utilized. Using the previous notations in Eq. (1), the model can be formulated as follows for Figs. 7, 9, and 10 to 13:

$$y_{i,t+h} = \alpha_i^h + \tau_t^h + \mathbb{1}\left([x_{i,t-1} > Qx_{i,t-1}]\left(b_h^{high}\Delta S_{i,t}\right)\right) + \mathbb{1}\left([x_{i,t} \le Qx_{i,t}]\left(b_h^{low}\Delta S_{i,t}\right)\right) + \gamma_h y_{i,t-1} + + \mathbf{f}_h^{'}\mathbf{F}_{i,t+1:t+L} + \alpha^{'}\mathbf{z}_{i,t-1} + \nu_{i,t+h} \tag{2}$$

$$\text{IRF}\left(h^{high}\right) = \widehat{b}_h^{high};\ \text{IRF}\left(h^{low}\right) = \widehat{b}_h^{low}$$

where, $\mathbb{1}$, is an indicator function; Qx, is a specific quartile (or decile) for the threshold variables. Figs. 8 and 9 show that climate vulnerability shock causes a persistent decline in sovereign ratings for both the full sample and highly climate-vulnerable countries. However, less vulnerable countries do not experience this persistent decline. We will examine the influence of institutional variables and financial development based on preliminary evidence from Table 2. Notably, financial development and institutional levels are lower in highly vulnerable countries. We extend the literature (e.g., Beirne et al., 2021; Cevik and Jalles, 2022) by exploring nonlinearities in climate-related premiums on sovereign bond yields and ratings.

4.2. Interactions with financial institutions development

Fig. 10 examines the effect of financial institution development on how vulnerability shocks influence fiscal risk using the Financial Institution Development index (Svirydzenka, 2016). In countries with well-established financial institutions, climate vulnerability shocks do not lead to an increase in bond yields. While the climate risk premium is observed in countries with less mature financial institutions.

Fig. 11 illustrates that climate vulnerability shocks do not significantly affect sovereign ratings for countries with a high level of financial institution development. Conversely, such shocks lead to a persistent decline in sovereign ratings for countries with low financial institution development and for the entire sample, highlighting the critical importance of robust financial institutions. The mitigating effect of advanced financial development on the climate-fiscal nexus aligns with the logical assumption that deeper and more liquid local financial markets and well-developed insurance markets contribute to resilience.

Observations can be made on this new result in the literature. Compared to the baseline results for the bond premium shown in Fig. 6, the upper bound of the impulse response functions for low levels of financial institution development is slightly above 1 percentage point at a horizon of 2 years. Therefore, an increase of 1 in the vulnerability score corresponds to an increase in bond yields up to the two-year horizon. In contrast, for countries with higher levels of financial institution development, vulnerability shocks do not correlate with any increase in bond yields. This result has significant implications. Sound financial institutions help maintain fiscal stability amid climate risk. Aizenman et al. (2024) noted that these institutions also reduce exchange rate instability. These findings complement each other, as securing hard currency is crucial for vulnerable countries.

4.3. Interactions with political stability

This section examines the influence of political stability as a mitigating factor for climate-related premiums on sovereign bond yields and ratings. Specifically, it investigates how political factors can reduce the impact of climate vulnerability on fiscal risks. The political risk variable considered is a measure of religious tensions, sourced from the International Country Risk Guide (ICRG) database, available at https://www.prsgroup.com/. Our panel LP impulse responses depicted in Figs. 12 and 13 present notable findings. Countries with high religious tensions have a significantly higher climate-related risk premium on sovereign bonds. High political risk intensifies the fiscal constraints caused by climate vulnerability, doubling the impact compared to countries with lower

[5] Using a bi-variate panel VAR and large-scale disasters coming from the EM-DAT database, we also find that a large-scale natural disaster causes an increase in bond yields of 1 percentage point during multiple years.

[6] In Appendix F, we provide empirical evidence that the key sources of endogeneity are addressed in our design. Reverse causality is ruled out empirically, as lagged bond yields do not forecast changes in vulnerability ($F(2,100) = 0.53$, $p = 0.59$). Anticipation effects are controlled for through the inclusion of forward shocks, which are jointly insignificant at short horizons, indicating no pre-trend in yields. Potential omitted-variable bias from common macro-financial factors is mitigated by the use of country- and time-fixed effects together with a rich set of macroeconomic controls. These features ensure that the estimated impulse responses capture the causal impact of changes in climate vulnerability on fiscal space rather than spurious correlations driven by reverse causality, anticipation, or omitted variables.

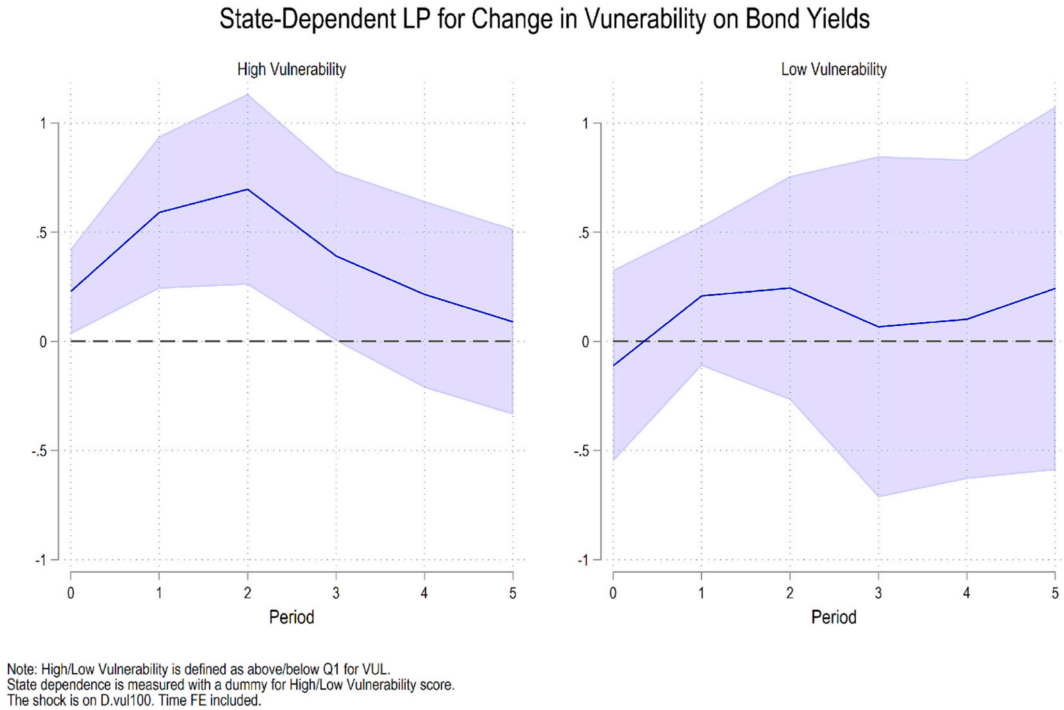

Fig. 7. Impact of change in vulnerability on bond yields (Climate vulnerability).
Authors' calculations. The shock is a unit-shock on the change in vulnerability variable. Country- and time-fixed effects are included, and standard errors are clustered at the country level. 95% confidence Intervals in light blue. We include the future climate risk shocks up to 5 years, following Teulings and Zubanov (2014), and no controls.

religious tensions. This pattern is also evident in sovereign ratings (Fig. 13).[7]

4.4. Further discussions about endogeneity

To further tackle endogeneity, we follow the principal component approach of Kling et al. (2021). We created our climate vulnerability measure by using seven dimensions from the ND-GAIN index that showed moderate correlation with macroeconomic indicators and were not time-invariant. These include food import dependency, freshwater withdrawal rate, ecological footprint, protected biome coverage, engagement in international environmental conventions, dependency on imported energy, and population living below five meters above sea level. Using principal component analysis (PCA), we derived three principal components. Our climate vulnerability shock, denoted as VUL_N, is defined as the change in the first principal component. This measure has a strong correlation (about 82%) with the broader ND-GAIN vulnerability score and lower correlation with macroeconomic outcomes, making it suitable for our empirical analysis.

Figs. 14 and 15 corroborate our baseline findings, indicating that a unit shock in vulnerability changes leads to an increase in bond yields ranging from 1 to 2.5% over a two-year horizon. Additionally, sovereign ratings are downgraded by up to one notch within a four-year period. These results reinforce the primary conclusion of this research: climate risks have the potential to increase fiscal risks, resulting in greater fiscal limitations for countries following changes in vulnerability. Consequently, our baseline estimates can be considered conservative.

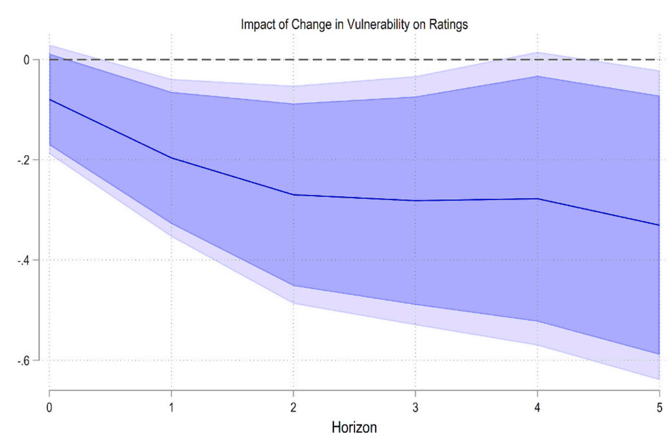

Fig. 8. Panel LP - impact of change in vulnerability on sovereign ratings (Baseline).
Authors' calculations. The shock is a unit-shock on the change in vulnerability variable. Country- and time-fixed effects are included, and standard errors are clustered at the country level. 90 and 95% confidence Intervals in dark and light blue, respectively. We include the future climate risk shocks up to 5 years, following Teulings and Zubanov (2014), and no controls.

5. Conclusion

Climate change poses a major risk to fiscal sustainability because it requires governments to lead adaptation and mitigation. Such leadership requires significant public spending, which may adversely affect fiscal risks. However, empirical research on how climate vulnerability affects fiscal risks is limited at the present. This paper addresses this gap in the literature by empirically analyzing the climate-fiscal relationship we look at how political stability and financial development influence the negative impact of climate vulnerability on fiscal risk.

More specifically, our analysis uses panel local projections to study

[7] The results for other institutional variables are broadly consistent with those of the religious tensions, albeit the differences between states is less significant. This may indicate that religious tension is more scrutinized by economic actors and rating agencies, than other forms of political instability. These results are available upon request.

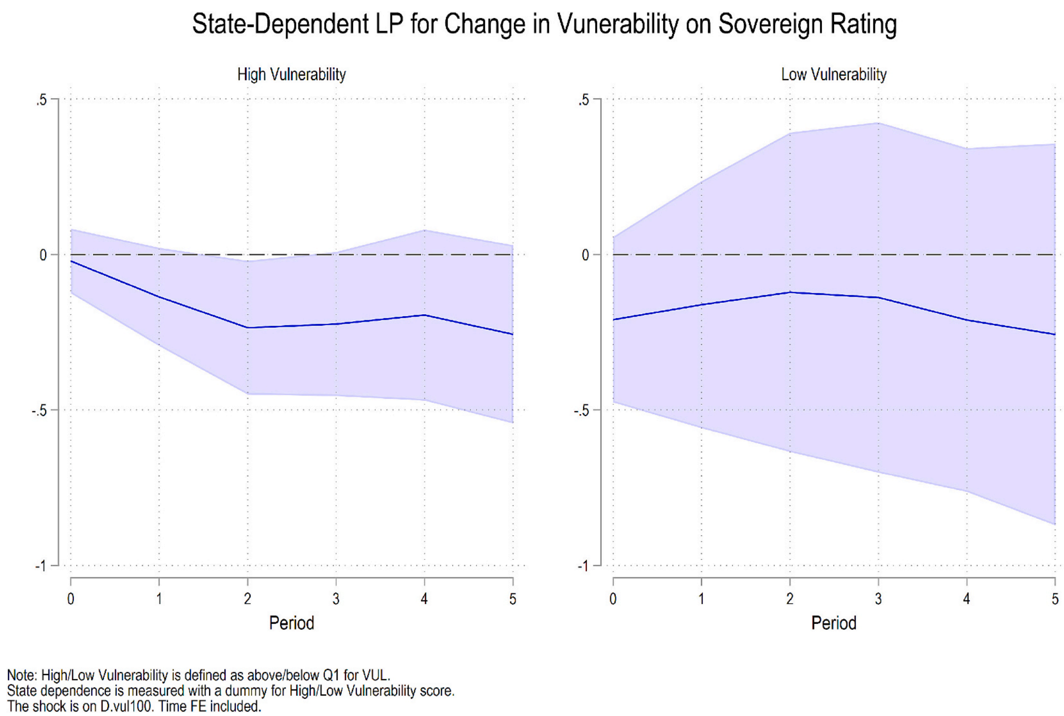

Fig. 9. Impact of change in vulnerability on sovereign ratings (Climate vulnerability).
Authors' calculations. The shock is a unit-shock on the change in vulnerability variable. Country- and time-fixed effects are included, and standard errors are clustered at the country level. 95% confidence Intervals in light blue. We include the future climate risk shocks up to 5 years, following Teulings and Zubanov (2014), and no controls.

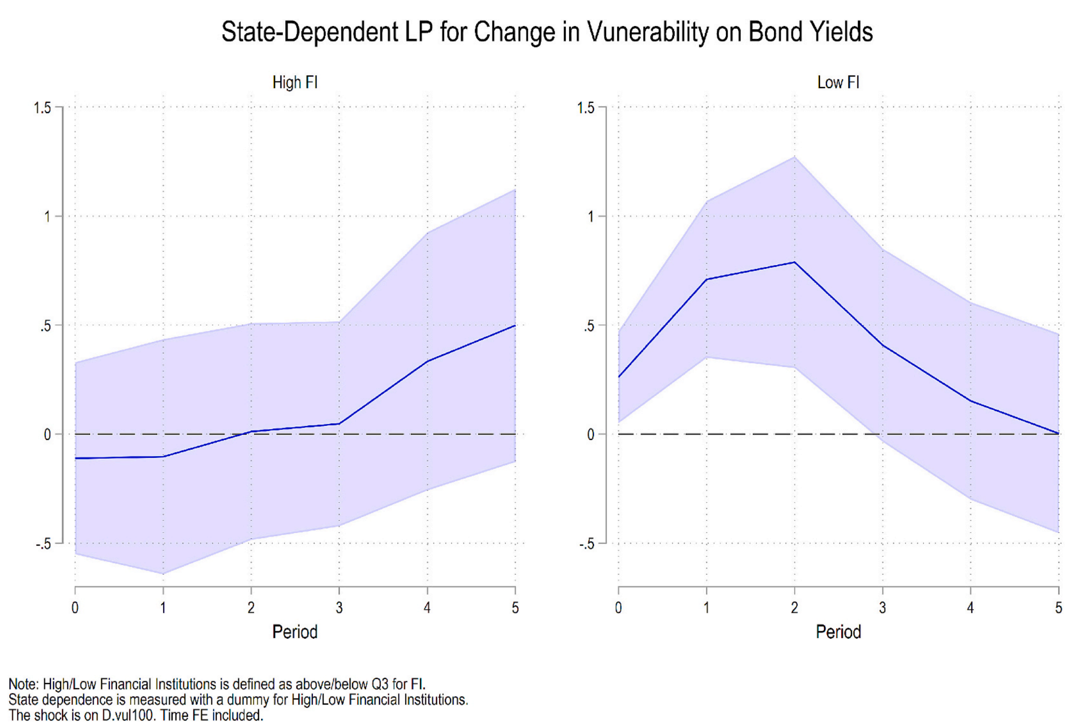

Fig. 10. Panel LP - impact of change in vulnerability on bond yields (Financial Institutions).
Authors' calculations. The shock is a unit-shock on the vulnerability change. Country- and time-fixed effects are included, and standard errors are clustered at the country level. 95% confidence Intervals in light blue. We include the future climate risk shocks up to 5 years, following Teulings and Zubanov (2014), and no controls.

how religious tensions as a form of political stability and financial development affect the relationship between climate vulnerability and fiscal risk. We find that in economies highly vulnerable to climate change, increased vulnerability raises government bond yields by 0.5 to 1.5 percentage points and lowers sovereign debt ratings by up to one notch over two years. These effects are stronger in politically unstable countries but weaker in countries with well-developed financial markets. Therefore, promoting political stability and financial development

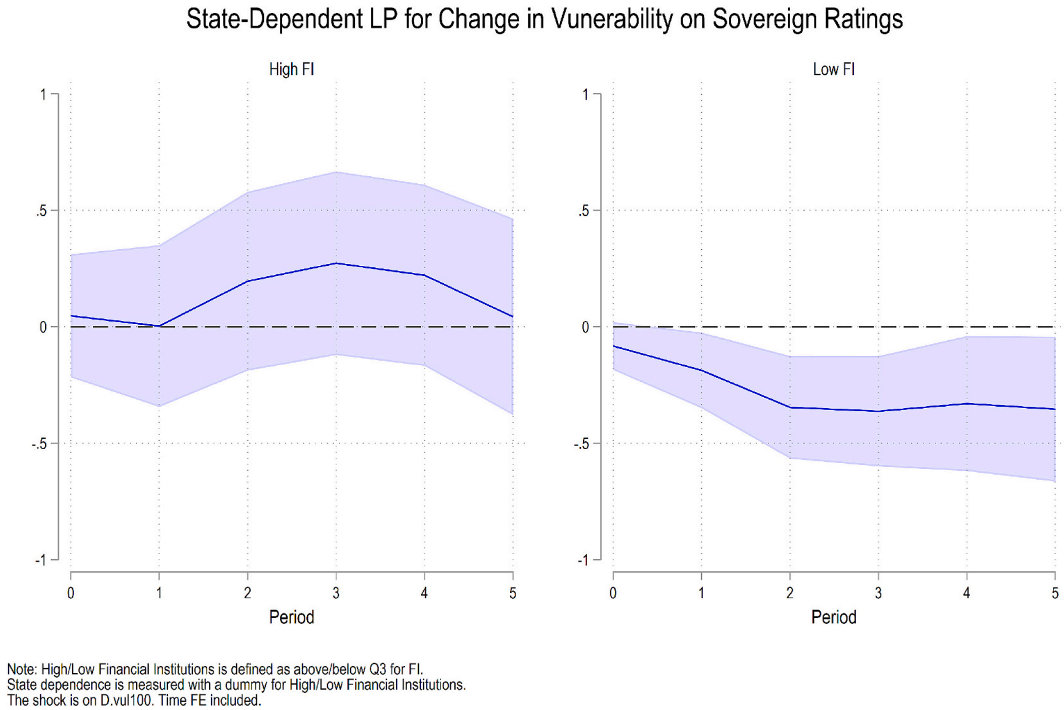

Fig. 11. Panel LP - impact of change in vulnerability on sovereign ratings (Financial Institutions).
Authors' calculations. The shock is a unit-shock on the vulnerability change. Country- and time-fixed effects are included, and standard errors are clustered at the country level. 95% confidence Intervals in light blue. We include the future climate risk shocks up to 5 years, following Teulings and Zubanov (2014), and no controls.

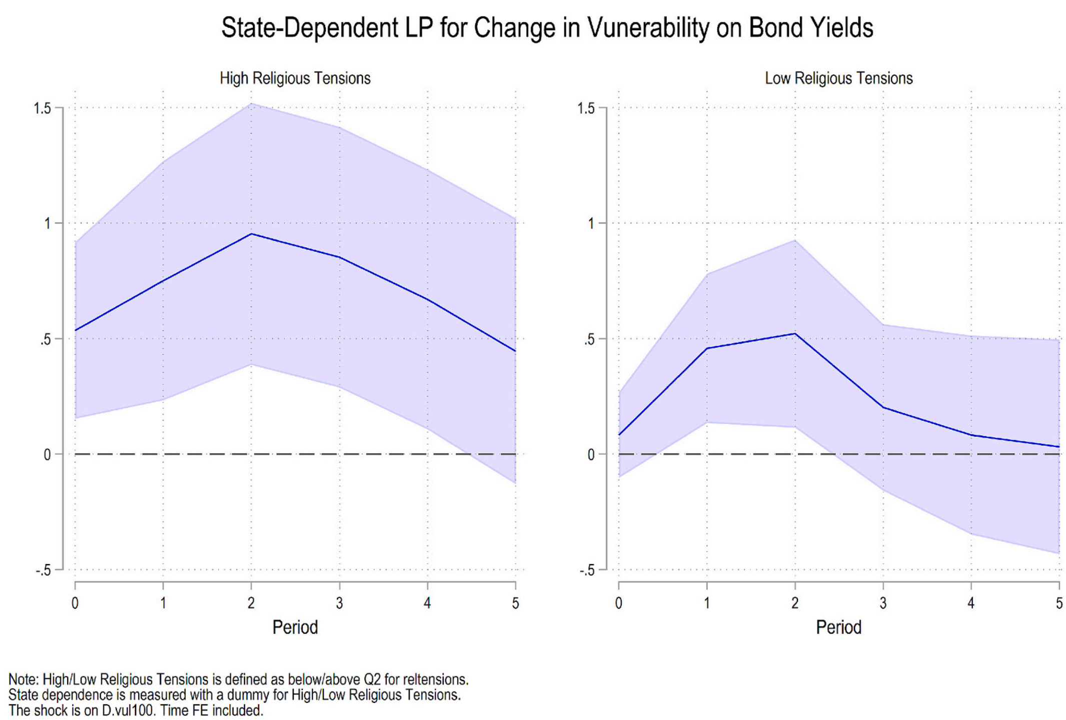

Fig. 12. Panel LP - impact of change in vulnerability on bond yields (Religious Tensions).
Authors' calculations. The shock is a unit-shock on the vulnerability change. Fixed effects are included, and standard errors are clustered at the country level. 95% confidence Intervals in light blue. We include the future climate risk shocks up to 5 years, following Teulings and Zubanov (2014), and no controls. A Wald test indicates that the IRFs in the high and low religious tension states are statistically different at the 95% level.

can complement fiscal consolidation in containing climate-related fiscal risks.

While fiscal consolidation is central for mitigating the adverse effects of climate vulnerability on fiscal risk, our findings indicate that political stability and financial development can also play significant roles. Political stability is inherently valuable, but our analysis demonstrates that an additional advantage is its capacity to safeguard fiscal sustainability from climate change. Similarly, while financial development is

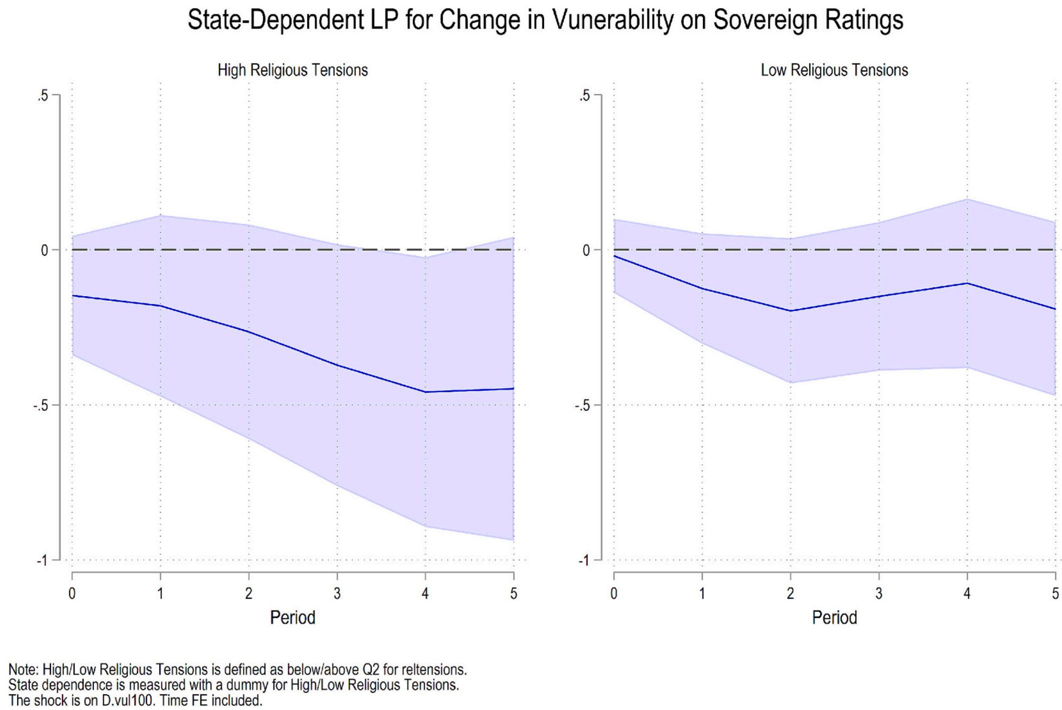

Fig. 13. Panel LP - impact of change in vulnerability on sovereign ratings (Religious Tensions).
Authors' calculations. The shock is a unit-shock on the vulnerability change. Fixed effects are included, and standard errors are obtained through bootstrapping. Confidence Intervals in light blue. We include the future climate risk shocks up to 5 years, following Teulings and Zubanov (2014), and no controls.

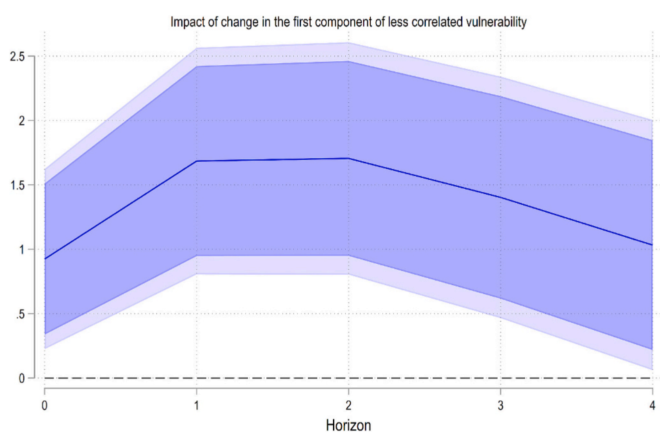

Fig. 14. Panel LP - impact of change in VUL_N on bond yields.
Authors' calculations. The shock is a unit-shock on the change in vulnerability variable. Country- and time-fixed effects are included, and standard errors are clustered at the country level. 90 and 95% confidence Intervals in dark and light blue, respectively. We include the future climate risk shocks up to 5 years, following Teulings and Zubanov (2014), with controls.

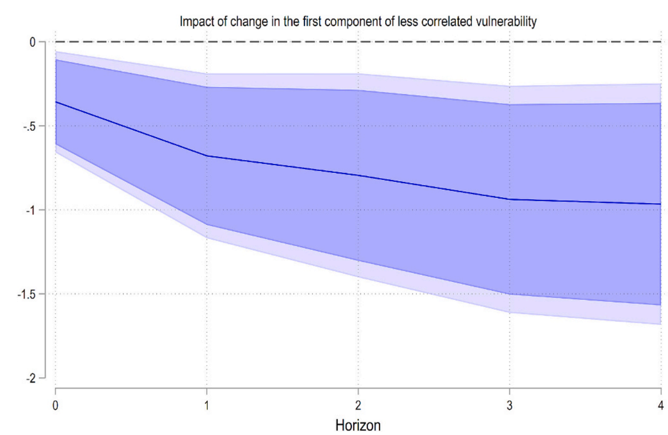

Fig. 15. Panel LP - impact of change in VUL_N on sovereign ratings.
Authors' calculations. The shock is a unit-shock on the change in vulnerability variable. Country- and time-fixed effects are included, and standard errors are clustered at the country level. 90 and 95% confidence Intervals in dark and light blue, respectively. We include the future climate risk shocks up to 5 years, following Teulings and Zubanov (2014), with controls

intrinsically beneficial, our empirical evidence strengthens the case for governments to take measures to develop financial markets. By shedding light on how political stability and financial development influences the relationship between climate vulnerability and fiscal risk, our study provides a more comprehensive and accurate understanding of this important dynamic across a broad range of countries. Our findings imply that strengthening political stability and financial institutions not only enhances economic resilience by lowering fiscal financing costs in a warming world.

CRediT authorship contribution statement

Jamel Saadaoui: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **John Beirne:** Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Project administration, Methodology, Funding acquisition, Conceptualization. **Donghyun Park:** Writing – review & editing, Resources, Project administration, Funding acquisition. **Gazi Salah Uddin:** Writing – original draft, Visualization, Validation, Supervision, Methodology, Data curation, Conceptualization.

Declaration of competing interest

None.

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Appendix A. Data sources and definitions

Variable name	Source, identifier
ND-GAIN overall vulnerability	https://gain.nd.edu/our-work/country-index/download-data/
ND-GAIN overall readiness	https://gain.nd.edu/our-work/country-index/download-data/
Government bonds, yields %	JPM EMBI & IMF, 100*x/(x + 100) (winsorized)
Foreign currency sovereign debt ratings	Kose et al. (2022), https://doi.org/10.1016/j.jimonfin.2022.102682, index from 1 to 21 [best]
Current Account Balance in % of GDP	World Bank, WDI, BN.CAB.XOKA.GD.ZS
CPI inflation, year-on-year %	World Bank, WDI, FP.CPI.TOTL.ZG
General Gov. Gross Debt in % of GDP	IMF, WEO, GGXCNL_NGDP
Gov. Net Lending/Borrowing in % of GDP	IMF, WEO, GGXWDG_NGDP
Laeven-Valencia's dummy: banking crisis	Laeven & Valencia (2018), https://doi.org/10.1057/s41308-020-00107-3
Laeven-Valencia's dummy: currency crisis	Laeven & Valencia (2018), https://doi.org/10.1057/s41308-020-00107-3
Laeven-Valencia's dummy: debt crisis	Laeven & Valencia (2018), https://doi.org/10.1057/s41308-020-00107-3
Total reserves minus gold (% of GDP)	World Bank, WDI, FI.RES.XGLD.CD, own calculations with current GDP from World Bank
Fuel Export on Total Exports	World Bank, WDI, TX.VAL.FUEL.ZS.UN
Fuel Import on Total Imports	World Bank, WDI, TM.VAL.FUEL.ZS.UN
Chinn-Ito index, normalized	Chinn and Ito (2006), https://web.pdx.edu/~ito/Chinn-Ito_website.htm
Exchange Rate Stability Index	Aizenman et al. (2013), https://web.pdx.edu/~ito/trilemma_indexes.htm
Financial Institution index	Svirydzenka (2016), IMF, FDI, FD_FI_IX
Financial Market index	Svirydzenka (2016), IMF, FDI, FD_FM_IX
ICRG index: External Conflict	https://www.prsgroup.com/
ICRG index: Corruption	https://www.prsgroup.com/
ICRG index: Democratic Accountability	https://www.prsgroup.com/
ICRG index: Ethnic Tensions	https://www.prsgroup.com/
ICRG index: Government Stability	https://www.prsgroup.com/
ICRG index: Internal Conflict	https://www.prsgroup.com/
ICRG index: Law and Order	https://www.prsgroup.com/
ICRG index: Military in Politics	https://www.prsgroup.com/
ICRG index: Religious Tensions	https://www.prsgroup.com/
ICRG index: Socioeconomic Conditions	https://www.prsgroup.com/
ICRG index: Investment Profile	https://www.prsgroup.com/
Natural disasters (selected as in Klomp, 2015)	https://www.emdat.be/

Appendix B. Composition of the samples in the unbalanced panel regressions

B.1. Bond yields regressions' sample composition

1 Angola; 2 Austria; 3 Bangladesh;4 Belgium; 5 Belize; 6 Bolivia; 7 Botswana; 8 Brazil; 9 Bulgaria; 10 Canada; 11 Chile; 12 China; 13 Colombia; 14 Costa Rica; 15 Côte D'ivoire; 16 Croatia; 17 Cyprus; 18 Czech Republic; 19 Denmark; 20 Dominican Republic; 21 Ecuador; 22 Egypt; 23 El Salvador; 24 Estonia; 25 Ethiopia; 26 Fiji; 27 Finland; 28 France; 29 Gabon; 30 Georgia; 31 Germany; 32 Ghana; 33 Greece; 34 Guatemala; 35 Honduras; 36 Hungary; 37 Iceland; 38 India; 39 Indonesia; 40 Iraq; 41 Ireland; 42 Italy; 43 Jamaica; 44 Japan; 45 Jordan; 46 Kazakhstan; 47 Korea; 48 Kyrgyz Republic; 49 Latvia; 50 Lebanon; 51 Lithuania; 52 Luxembourg; 53 Malaysia; 54 Maldives; 55 Malta; 56 Mauritius; 57 Mexico; 58 Moldova; 59 Mongolia; 60 Morocco; 61 Mozambique; 62 Myanmar; 63 Namibia; 64 Nepal; 65 Netherlands; 66 Nigeria; 67 Norway; 68 Pakistan; 69 Panama; 70 Paraguay; 71 Peru; 72 Philippines; 73 Poland; 74 Portugal; 75 Romania; 76 Russia; 77 Samoa; 78 Senegal; 79 Serbia; 80 Seychelles; 81 Singapore; 82 Slovak Republic; 83 Slovenia; 84 Solomon Islands; 85 South Africa; 86 Spain; 87 Sri Lanka; 88 Sweden; 89 Switzerland; 90 Thailand; 91 Trinidad and Tobago; 92 Tunisia; 93 Turkey; 94 United Kingdom; 95 United States; 96 Uruguay; 97 Vietnam; 98 Zambia

B.2. Sovereign ratings regressions' sample composition

1 Albania; 2 Angola; 3 Austria; 4 Bahamas; 5 Bahrain; 6 Bangladesh; 7 Barbados; 8 Belgium; 9 Belize; 10 Benin; 11 Bolivia; 12 Bosnia and Herzegovina; 13 Botswana; 14 Brazil; 15 Bulgaria; 16 Burkina Faso; 17 Cambodia; 18 Cameroon; 19 Canada; 20 Cape Verde; 21 Chile; 22 China; 23 Colombia; 24 Congo, rep; 25 Costa Rica; 26 Côte D'ivoire; 27 Croatia; 28 Cyprus; 29 Czech Republic; 30 Denmark; 31 Dominican Republic; 32 Ecuador; 33 Egypt; 34 El Salvador; 35 Estonia; 36 Ethiopia; 37 Fiji; 38 Finland; 39 France; 40 Gabon; 41 Georgia; 42 Germany; 43 Ghana; 44 Greece; 45 Grenada; 46 Guatemala; 47 Honduras; 48 Hungary; 49 Iceland; 50 India; 51 Indonesia; 52 Iran; 53 Iraq; 54 Ireland; 55 Israel; 56 Italy; 57 Jamaica; 58

Japan; 59 Jordan; 60 Kazakhstan; 61 Kenya; 62 Korea; 63 Kuwait; 64 Kyrgyz Republic; 65 Latvia; 66 Lebanon; 67 Lesotho; 68 Lithuania; 69 Luxembourg; 70 Malawi; 71 Malaysia; 72 Maldives; 73 Malta; 74 Mauritius; 75 Mexico; 76 Moldova; 77 Mongolia; 78 Montenegro; 79 Morocco; 80 Mozambique; 81 Namibia; 82 Netherlands; 83 Nicaragua; 84 Nigeria; 85 North Macedonia; 86 Norway; 87 Oman; 88 Pakistan; 89 Panama; 90 Paraguay; 91 Peru; 92 Philippines; 93 Poland; 94 Portugal; 95 Qatar; 96 Romania; 97 Russia; 98 Rwanda; 99 Saudi Arabia; 100 Senegal; 101 Serbia; 102 Seychelles; 103 Singapore; 104 Slovak Republic; 105 Slovenia; 106 South Africa; 107 Spain; 108 Sri Lanka; 109 Suriname; 110 Sweden; 111 Switzerland; 112 Thailand; 113 Trinidad and Tobago; 114 Tunisia; 115 Turkey; 116 Uganda; 117 United Kingdom; 118 United States; 119 Uruguay; 120 Vietnam; 121 Zambia

Appendix C. Panel VAR analysis for the most vulnerable countries

This appendix provides a detailed explanation of the estimation of a Panel Vector Autoregressive (Panel VAR) model. The analysis focuses on a subsample of countries with high climate vulnerability, defined as those with a vulnerability index exceeding 0.372 (the first quartile of vulnerability). The model incorporates bond yields (*bonds_tw*) and vulnerability shocks (*Dvul100*), includes 3 lags, and employs first differences. The number of instruments is equal to 16 and the number of countries is equal to 72. Hansen's test of overidentifying restrictions (4 restrictions) has a p-value of 22%. Results indicate that the VAR is stable and there is a significant Granger causality from vulnerability shocks to bond yields, with a p-value below 5%. Impulse Response Functions (IRFs) further demonstrate that a unit increase in climate vulnerability leads to an increase in bond yields ranging between 0.5% and 1%, thus corroborating the main findings obtained through local projections.

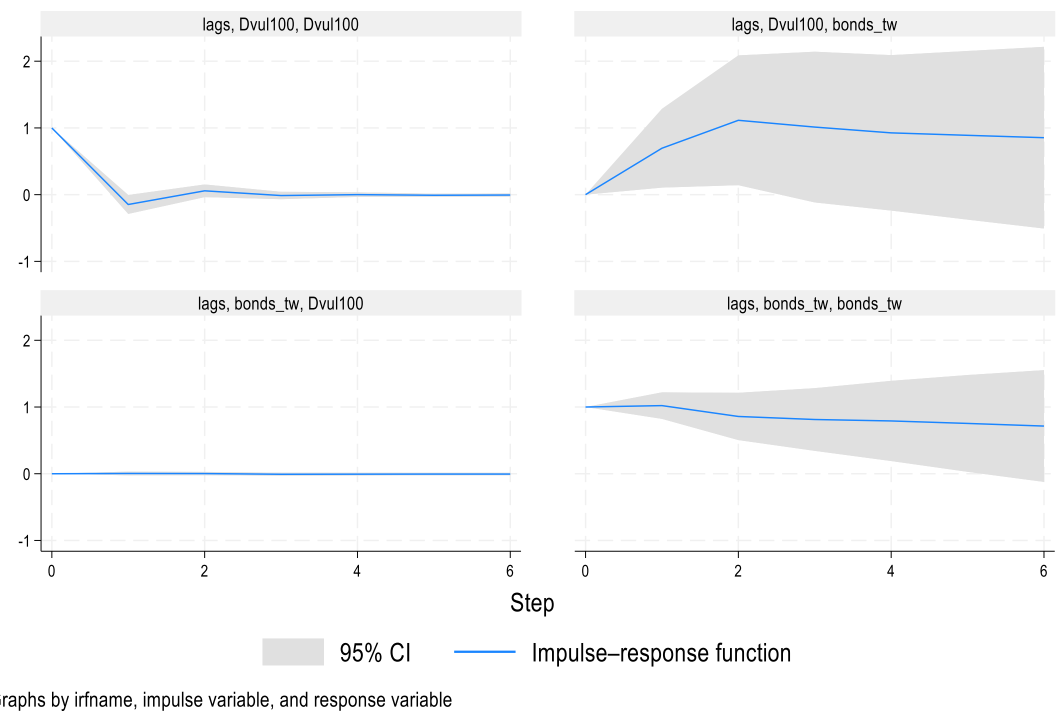

Fig. C1. Panel LP - impact of change in vulnerability on bond yields.
Authors' calculations. The shock is a unit change in the vulnerability variable. 95% confidence intervals in gray. 'lags' is the name of the impulse response dataset.

Appendix D. Panel LP with natural disasters

We use the EM-DAT database to analyze how 630 major natural disasters from 1995 to 2019 affect bond yields. Following Klomp (2015), we create a dummy variable for these disasters, defined as: "investors view natural disasters as shocks that undermine government debt sustainability, potentially causing sovereign default." In the local projection exercise, we add the forward shocks up to seven years following the correction of Teulings and Zubanov, and to consider that large-scale natural disasters are rare events. If we exclude the high-income countries group, the effect of large-scale natural disasters generates a stronger premium.

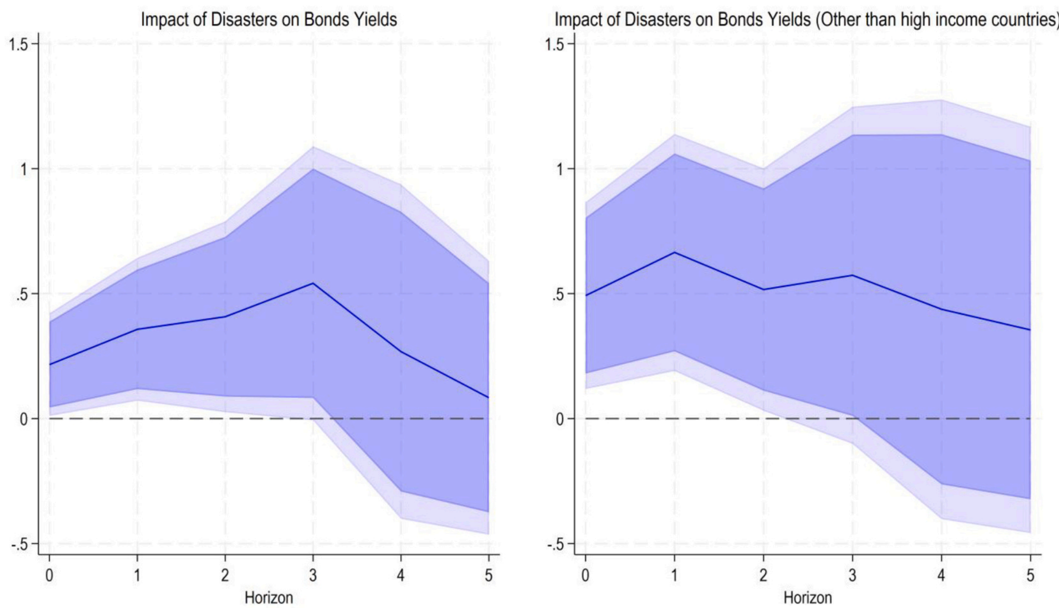

Fig. D1. Panel LP - impact of change in vulnerability on bond yields.
Authors' calculations. The shock is a unit change in the vulnerability variable. 95% confidence intervals in gray. Country groups are defined according to the World Bank's classification.

Appendix E. Panel VAR analysis for natural disasters

This appendix details the estimation of a Panel Vector Autoregressive (Panel VAR) model, which includes bond yields (*bonds_tw*) and large-scale natural disasters (*disaster*), incorporates 3 lags, and employs first differences. The number of instruments is equal to 32 and the number of countries is equal to 90. Hansen's test of overidentifying restrictions (20 restrictions) has a p-value of 6%. Results indicate that the VAR is stable and a significant Granger causality from natural disasters to bond yields, with a p-value below 1%. Impulse Response Functions (IRFs) show that a large-scale natural disaster leads to an increase in bond yields ranging between 1% and 2%, thereby supporting the main findings obtained through local projections.

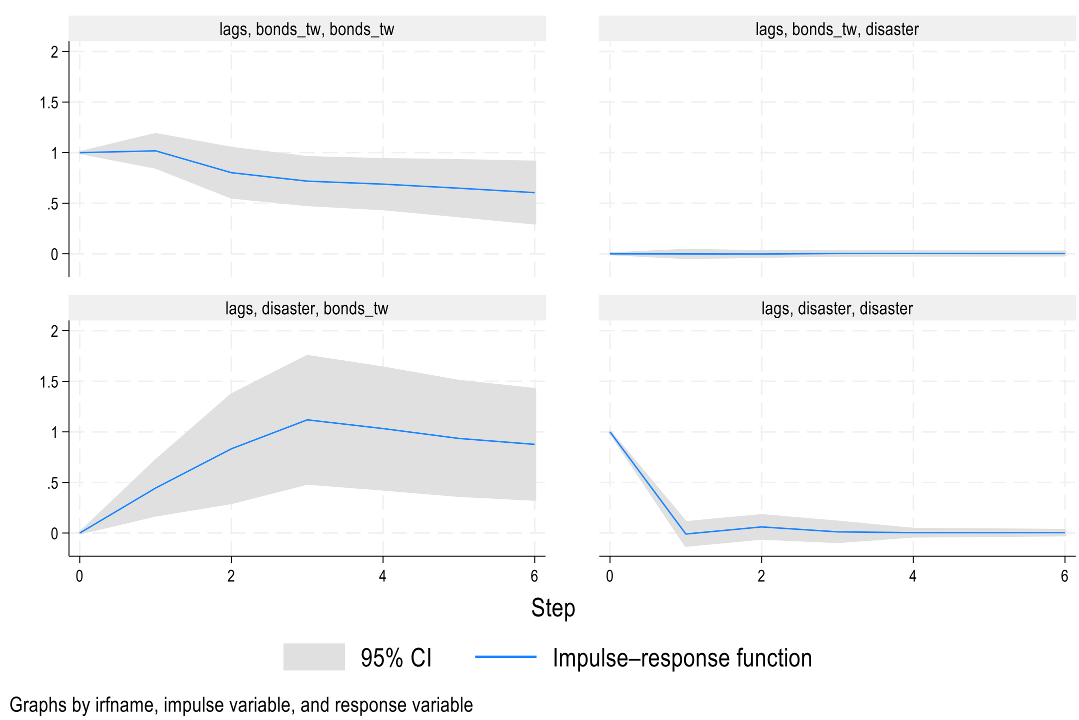

Fig. E1. Panel LP - impact of change in vulnerability on bond yields.
Authors' calculations. The shock is the occurrence of a large natural disaster. 95% confidence intervals in gray. 'lags' is the name of the impulse response dataset.

Appendix F. LP with macroeconomic controls

We address endogeneity concerns in several complementary ways. First, by dating the shock at $t-1$, the horizon-0 response is a placebo, and it is statistically nil. Second, we include forward shocks to capture anticipation effects; these leads are jointly insignificant at short horizons, indicating no pre-trend in yields in Figs. F1 to F4. Third, in a panel with country and time fixed effects and macro controls, bond yields neither predict nor Granger-cause changes in vulnerability.

We formally test, in Table F1, the following equation:

$$\Delta V_{i,t} = \alpha_i + \tau_t + \beta_1 y_{i,t-1} + \beta_2 y_{i,t-2} + \boldsymbol{\gamma}' \mathbf{X}_{i,t-1:t-2} + \varepsilon_{i,t},$$

where $\Delta V_{i,t}$ is the change in ND-GAIN vulnerability for country i in year t; $y_{i,t-\ell}$ are government bond yields at lags $\ell = 1,2$; $X_{i,t-1:t-2}$ stacks the macro controls at lags 1–2 (current account balance, CPI inflation, government net lending/borrowing, and the Laeven-Valencia crisis dummies); α_i and τ_t are country and time fixed effects; and $\varepsilon_{i,t}$ is the error term. Inference uses standard errors clustered by country. The Granger-non-causality restriction is tested via $H_0 : \beta_1 = \beta_2 = 0$ which in our data is not rejected $(F(2,100) = 0.53\,, p = 0.59)$.

Finally, inference remains stable across clustered, bootstrapped, and state-dependent specifications. Taken together, these results strongly support the predeterminedness of the shock and make reverse causality, anticipation, or omitted-variable bias unlikely to explain our findings.

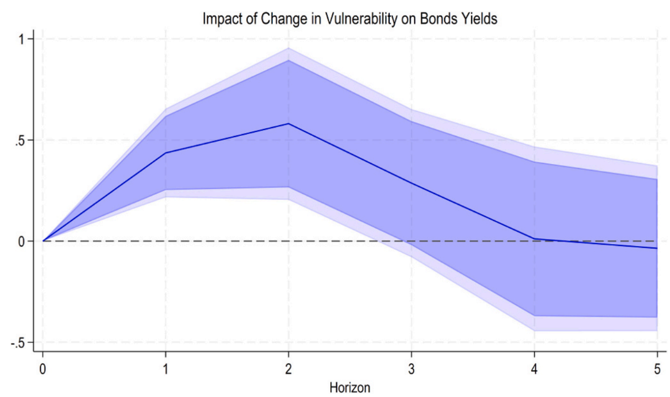

Fig. F1. Panel LP - impact of change in vulnerability on bond yields (Robustness).
Authors' calculations. The shock is a unit-shock on the change in vulnerability variable. Country- and time-fixed effects are included, and standard errors are clustered at the country level. 90 and 95% confidence Intervals in dark and light blue, respectively. We include the future climate risk shocks up to 2 years (5 years in baseline; 2 years in robustness to conserve degrees of freedom), following Teulings and Zubanov (2014), and controls. Similar results are obtained with bootstrapped standard errors were 999 replications are used.

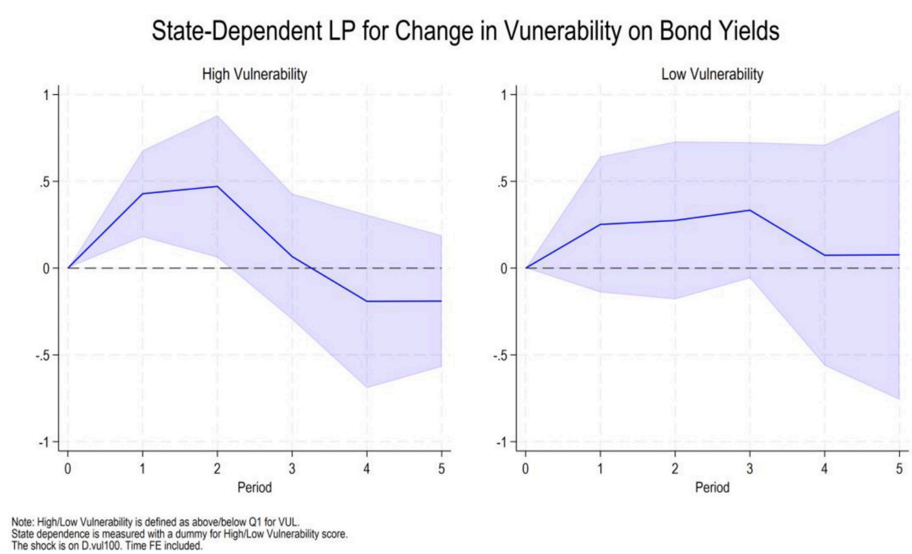

Fig. F2. Impact of change in vulnerability on bond yields (Climate vulnerability - Robustness).
Authors' calculations. The shock is a unit-shock on the change in vulnerability variable. Country- and time-fixed effects are included, and standard errors are clustered at the country level. 95% confidence Intervals in light blue. We include the future climate risk shocks up to 2 years (5 years in baseline; 2 years in robustness to conserve degrees of freedom), following Teulings and Zubanov (2014), and controls.

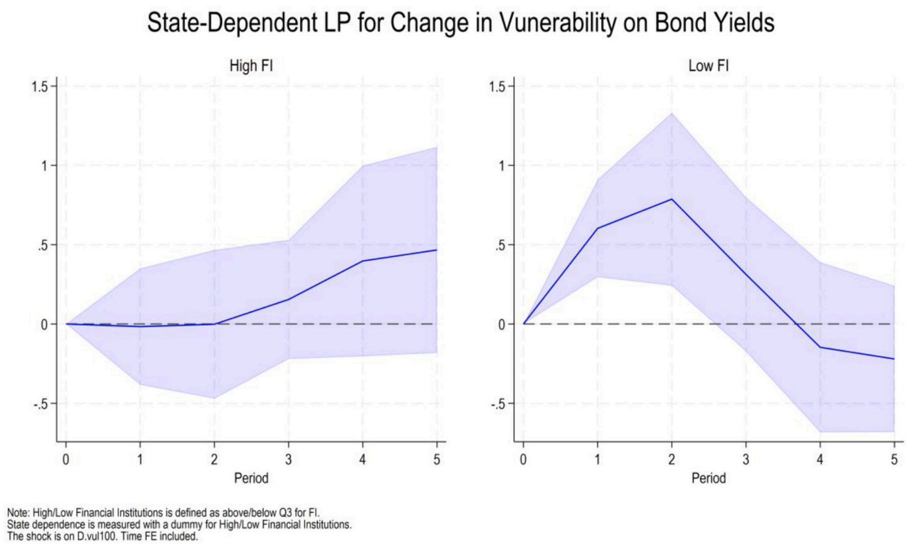

Fig. F3. Panel LP - impact of change in vulnerability on bond yields (Financial Institutions - Robustness).
Authors' calculations. The shock is a unit-shock on the vulnerability change. Country- and time-fixed effects are included, and standard errors are clustered at the country level. 95% confidence Intervals in light blue. We include the future climate risk shocks up to 2 years, following Teulings and Zubanov (2014), and controls.

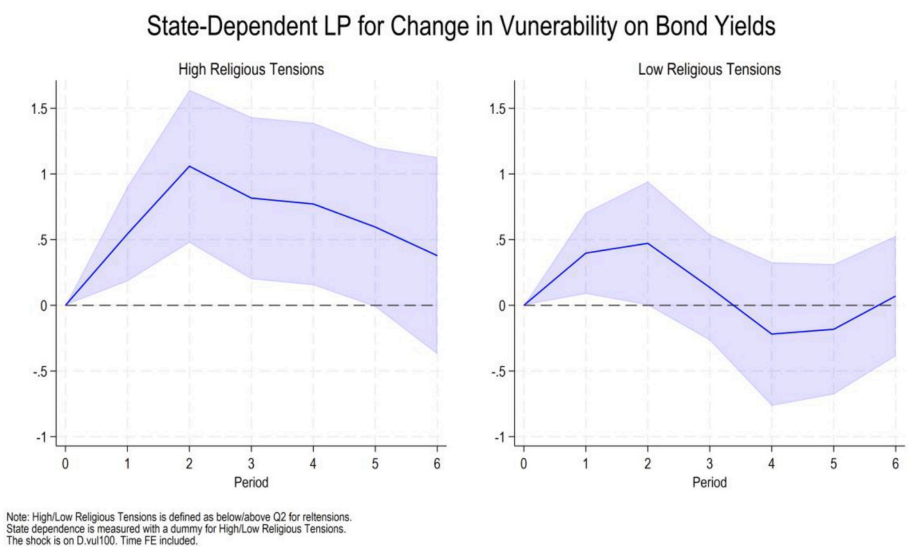

Fig. F4. Panel LP - impact of change in vulnerability on bond yields (Religious Tensions - Robustness).
Authors' calculations. The shock is a unit-shock on the vulnerability change. Fixed effects are included, and standard errors are clustered at the country level. 95% confidence Intervals in light blue. We include the future climate risk shocks up to 5 years, following Teulings and Zubanov (2014), and no controls. A Wald test indicates that the IRFs in the high and low religious tension states are statistically different at the 95% level.

Table F1. Predictability of change in ND-GAIN overall vulnerability.

	(1)	(2)
	Change in ND-GAIN overall vulnerability	Change in ND-GAIN overall vulnerability
Government Bonds Yields $_{t-1}$	0.0071	0.0002
	(0.0081)	(0.0056)
Government Bonds Yields $_{t-2}$	−0.0075	−0.0035
	(0.0077)	(0.0054)
Current Account Balance $_{t-1}$	−0.0028	
	(0.0021)	
Current Account Balance $_{t-2}$	−0.0004	
	(0.0024)	
CPI Inflation $_{t-1}$	−0.0272	
	(0.0306)	
CPI Inflation $_{t-2}$	0.0299	
	(0.0252)	
Gov. Net Lending/Borrowing $_{t-1}$	−0.0033	
	(0.0035)	

(*continued on next page*)

(*continued*)

	(1)	(2)
	Change in ND-GAIN overall vulnerability	Change in ND-GAIN overall vulnerability
Gov. Net Lending/Borrowing $_{t-2}$	0.0008	
	(0.0025)	
Laeven-Valencia's Dummy: Banking Crisis $_{t-1}$	0.0953**	
	(0.0430)	
Laeven-Valencia's Dummy: Banking Crisis $_{t-2}$	0.0260	
	(0.0576)	
Laeven-Valencia's Dummy: Currency Crisis $_{t-1}$	0.0697	
	(0.0594)	
Laeven-Valencia's Dummy: Currency Crisis $_{t-2}$	−0.1123	
	(0.0902)	
Laeven-Valencia's Dummy: Debt Crisis $_{t-1}$	−0.2077	
	(0.1272)	
Laeven-Valencia's Dummy: Debt Crisis $_{t-2}$	0.2258*	
	(0.1296)	
R-squared	0.13	0.09
Observations	1512.00	2005.00
F-stat	2.55	0.49

The few significant coefficients on the crisis dummies should not be interpreted as evidence of endogeneity. They indicate that exceptional financial crises (such as banking or debt crises) can temporarily worsen measured vulnerability by weakening adaptive capacity or economic resilience, which is economically consistent with the index's construction. What matters for identification is that lagged bond yields and standard macroeconomic variables do **not** systematically predict changes in vulnerability, as confirmed by the joint test on bond lags $F(2,100) = 0.53, p = 0.59$ and the modest explanatory power of the model $(R^2 = 0.13)$. These results confirm that the variation used in our local projections stems from the time-varying, largely exogenous component of climate vulnerability rather than from predictable macro-financial dynamics.

Appendix G. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eneco.2026.109180.

References

Acemoglu, D., Johnson, S., Robinson, J.A., 2001. The colonial origins of comparative development: an empirical investigation. Am. Econ. Rev. 91 (5), 1369–1401.

Ager, P., Ciccone, A., 2018. Agricultural risk and the spread of religious communities. J. Eur. Econ. Assoc. 16 (4), 1021–1068.

Aizenman, J., Chinn, M.D., Ito, H., 2013. The “impossible trinity” hypothesis in an era of global imbalances: measurement and testing. Rev. Int. Econ. 21 (3), 447–458.

Aizenman, J., Park, D., Qureshi, I.A., Saadaoui, J., Uddin, G.S., 2024. The performance of emerging markets during the fed’s easing and tightening cycles: a cross-country resilience analysis. J. Int. Money Financ. 148, 103169.

Bansal, R., Kiku, D., Ochoa, M., 2016. Price of Long-Run Temperature Shifts in Capital Markets (vol. No. w22529). National Bureau of Economic Research.

Beirne, J., Renzhi, N., Volz, U., 2021. Feeling the heat: climate risks and the cost of sovereign borrowing. International Review of Economics & Finance 76, 920–936.

Besley, T., Persson, T., 2009. The origins of state capacity: property rights, taxation, and politics. American Economic Review 99 (4), 1218–1244.

Boitan, I.A., Marchewka-Bartkowiak, K., 2022. Climate change and the pricing of sovereign debt: insights from European markets. Res. Int. Bus. Financ. 62, 101685.

Bolton, P., Kacperczyk, M., 2021. Do investors care about carbon risk? J. Financ. Econ. 142 (2), 517–549.

Burke, M., Hsiang, S.M., Miguel, E., 2015. Global non-linear effect of temperature on economic production. Nature 527 (7577), 235–239.

Caballero, R.J., Krishnamurthy, A., 2004. Fiscal policy and financial depth. NBER Working Paper 10532.

Carattini, S., Heutel, G., Melkadze, G., 2023. Climate policy, financial frictions, and transition risk. Rev. Econ. Dyn. 51, 778–794.

Cavallo, Eduardo, Noy, Ilan, 2011. Natural disasters and the economy – a survey. Int. Rev. Environ. Resour. Econ. 5 (1), 63–102.

Cevik, S., Jalles, J.T., 2022. This changes everything: climate shocks and sovereign bonds. Energy Econ. 107, 105856.

Cevik, S., Jalles, J.T., 2023. For whom the bell tolls: climate change and income inequality. Energy Policy 174, 113475.

Chen, C., Noble, I., Hellmann, J., Coffee, J., Murillo, M., Chawla, N., 2015. University of Notre Dame Global Adaptation Index. Country Index Technical Report. University of Notre Dame, Notre Dame, IN.

Chinn, M.D., Ito, H., 2006. What matters for financial development? Capital controls, institutions, and interactions. J. Dev. Econ. 81 (1), 163–192.

Dasgupta, S., Emmerling, J., Shayegh, S., 2023. Inequality and growth impacts of climate change—insights from South Africa. Environ. Res. Lett. 18 (12), 124005.

Dell, M., Jones, B., Olken, B., 2012. Temperature shocks and economic growth: evidence from the last half century. Am. Econ. J. Macroecon. 4 (3), 66–95.

Diffenbaugh, N.S., Burke, M., 2019. Global warming has increased global economic inequality. Proc. Natl. Acad. Sci. 116 (20), 9808–9813.

Dissart, J., 2003. Regional economic diversity and regional economic stability: research results and agenda. Int. Reg. Sci. Rev. 36 (4), 423–446.

Giglio, S., Maggiori, M., Stroebel, J., 2015. Very long-run discount rates. Q. J. Econ. 130 (1), 1–53.

Hsiang, S.M., Jina, A.S., 2014. The Causal Effect of Environmental Catastrophe on Long-Run Economic Growth: Evidence from 6,700 Cyclones (vol. No. w20352). National Bureau of Economic Research.

Jordà, Ò., 2005. Estimation and inference of impulse responses by local projections. American Economic Review 95 (1), 161–182.

Kahn, M.E., 2005. The death toll from natural disasters: the role of income, geography, and institutions. Rev. Econ. Stat. 87 (2), 271–284.

Keefer, P., Neumayer, E., Plümper, T., 2011. Earthquake propensity and the politics of mortality prevention. World Dev. 39 (9), 1530–1541.

Kling, G., Volz, U., Murinde, V., Ayas, S., 2021. The impact of climate vulnerability on firms’ cost of capital and access to finance. World Dev. 137, 105131.

Klomp, J., 2014. Financial fragility and natural disasters: an empirical analysis. J. Financ. Stab. 13, 180–192.

Klomp, J., 2015. Sovereign risk and natural disasters in emerging markets. Emerg. Mark. Financ. Trade 51 (6), 1326–1341.

Kose, M.A., Kurlat, S., Ohnsorge, F., Sugawara, N., 2022. A cross-country database of fiscal space. Journal of International Money and Finance 128, 102682.

Laeven, L., Valencia, F., 2020. Systemic banking crises database II. IMF Econ. Rev. 68, 307–361.

Levine, R., 2005. Finance and growth: theory and evidence. Handbook of Economic Growth 1, 865–934.

Mendelsohn, R., Dinar, A., Williams, L., 2006. The distributional impact of climate change on rich and poor countries. Environ. Dev. Econ. 11, 159–178.

Noy, I., 2009. The macroeconomic consequences of disasters. Journal of Development Economics 88 (2), 221–231.

Jordà, Ò., Taylor, A.M., 2025. Local projections. J. Econ. Literature 63 (1), 59–110.

Oppenheimer, M., Campos, M. & Warren, R. (2014). Emergent Risks and Key Vulnerabilities. Cambridge University Press, pg. 1039-1099.

Paglialunga, E., Coveri, A., Zanfei, A., 2022. Climate change and within-country inequality: new evidence from a global perspective. World Dev. 159, 106030.

Painter, M., 2020. An inconvenient cost: the effects of climate change on municipal bonds. J. Financ. Econ. 135 (2), 468–482.

Pike, A., Dawley, S., Tomaney, J., 2010. Resilience, adaptation and adaptability. Camb. J. Reg. Econ. Soc. 3 (1), 59–70.

Ramey, V.A., Zubairy, S., 2018. Government spending multipliers in good times and in bad: evidence from US historical data. J. Polit. Econ. 126 (2), 850–901.

Sharma, S., Ang, J.B., Fredriksson, P.G., 2021. Religiosity and climate change policies. Energy Econ. 101, 105414.

Svirydzenka, K., 2016. Introducing a New Broad-Based Index of Financial Development. International Monetary Fund.

Teulings, C.N., Zubanov, N., 2014. Is economic recovery a myth? Robust estimation of impulse responses. J. Appl. Economet. 29 (3), 497–514.

Tol, R., Downing, T., Kuik, O., Smith, J., 2003. Distributional aspects of climate change impacts. Glob. Environ. Chang. 14 (3), 259–272.

Yang, R., Caporin, M., Jiménez-Martin, J.A., 2024. Measuring climate transition risk spillovers. Review of Finance 28 (2), 447–481.

You, W.H., Zhu, H.M., Yu, K., Peng, C., 2015. Democracy, financial openness, and global carbon dioxide emissions: heterogeneity across existing emission levels. World Dev. 66, 189–207.

Zenios, S.A., 2022. The risks from climate change to sovereign debt. Clim. Change 172 (3–4), 30.