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Climate Risk Spillovers and Sovereign Financing Conditions

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Abstract

Climate change strains public finances through direct local economic effects, yet interconnected economies also face indirect climate exposure via global value chains. These spillovers can amplify fiscal costs but are widely ignored. We examine whether climate affects sovereign financing conditions, the extent of foreign risk transmission, and the relative magnitude of local versus global channels. Our primary contribution lies in mapping and quantifying climate spillovers through a novel measure that systematically tracks international value added linkages from Inter-Country Input-Output tables. We exploit exogenous variation in daily temperature, precipitation, and drought data weighted by gridded economic activity to attribute changes in financing conditions, measured by sovereign credit ratings, to domestic and foreign climate. Using standard and quantile regressions for 75 countries (2000-2022), we estimate average and heterogeneous effects and disentangle domestic versus spillover impacts. Results are threefold. First, local temperature anomalies and drought conditions exhibit significant negative and heterogeneous effects on sovereign ratings, with a one-unit increase implying an average 0.2 notch downgrade. Second, incorporating spillovers from foreign climate exposure increases estimated effects by 36% compared to local-only baselines, with countries in arid climate zones experiencing the largest impacts of up to one full notch. Third, for over 40% of countries, spillovers even exceed local impacts. For some small, highly globalized economies, mainly in Europe, spillovers contribute up to 80% of total climate impacts. Thus, ignoring global spillovers leads to a systematic misestimation of climate risk, revealing a critical blind spot for investors, regulators and policymakers.

Keywords: Climate change, Climate risk propagation, International spillovers, Public finance, Sovereign credit ratings

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1 Introduction

Climate change impacts pose growing risks to fiscal sustainability worldwide. Rising temperatures, intensifying droughts, and shifting precipitation patterns can strain economic activities, eroding the tax revenues and fiscal buffers that underpin public finances and creditworthiness (Barrage, 2025; Akyapı et al., 2025). As climate change accelerates, understanding and addressing its implications for sovereign financing conditions has become critical for investors, financial regulators, and policymakers. For example, BlackRock, the world's largest asset manager, launched a sovereign bond ETF with holdings weighted by countries' level of climate risk to account for these changing dynamics (Financial Times, 2020), and a recent survey of 59 Ministries of Finance conducted by the Coalition of Finance Ministers for Climate Action (2025) highlights that the consequences of physical climate risk on public finances are a major concern. Given this relevance, a growing body of research investigates the relationship between climate and public financing conditions, demonstrating that climate has material implications for sovereign creditworthiness and borrowing costs. Forward-looking simulations and empirical evidence show that rising temperatures and acute physical impacts are associated with sovereign credit rating downgrades, particularly for highly exposed countries (Klusak et al., 2023; Cappiello et al., 2025). Studies also find that climate vulnerability is priced into sovereign bond markets through higher yields, especially for longer maturities, and that increases in borrowing costs are persistent over time (Bingler, 2022; Capelle-Blancard et al., 2019; Cevik and Jalles, 2022; Beirne et al., 2021; Boehm, 2022). In line, climate-augmented sovereign default models propose that climate damages negatively affect sovereign's cost and availability of financing and that adaptation stabilizes conditions (Barnett and Yannelis, 2024; Mallucci, 2022; Duffy, 2025).

However, the current literature shares a critical blind spot. It focuses almost exclusively on local climate, implicitly treating economies as if they operate in isolation from global climate conditions. This overlooks a fundamental reality. In a world characterized by deep global economic integration, climate shocks in one country can indirectly impact macro-financial outcomes in other countries by propagating through international production and cross-border trade networks. For countries deeply embedded in global value chains, these foreign climate exposures - what we term climate risk spillovers - may considerably add to (or potentially diversify) the impacts of domestic climate change. Thus, by ignoring climate spillovers, the current static local perspective is prone to misestimation of total risk. This was also recently acknowledged by the UK Office for Budget Responsibility (2025) which emphasized that transnational spillovers could significantly increase climate-related fiscal costs, and in a study published by the European Central Bank which suggests that trade-related climate risk amplification could lead to GDP losses in the Euro Area up to 30 times higher than direct impacts alone (Fahr et al., 2024). Further evidence underscores the importance of considering external climate conditions, estimating that global temperature shocks have economic effects an order of magnitude larger than local shocks (Bilal and Känzig, 2026), with projected global GDP damages increasing from 11% to 40% (under SSP5–8.5) when including external weather (Neal et al., 2025). Zappalà (2025) shows that even sectors not experiencing direct heat shocks still bear economic losses from trade linkages with climate-exposed foreign sectors. Yet, despite its clear relevance, to our knowledge, no study has systematically investigated whether and how climate spillovers affect sovereign financing conditions. Accordingly, existing policies, fiscal frameworks, and sovereign risk assessments may not fully internalize these risks.

This paper addresses this gap by investigating three core questions: First, do local climate impacts affect sovereign financing conditions, and which climate variables are key determinants? Second, to what degree do physical climate impacts in foreign countries transmit to domestic financing conditions? Third, what is the relative magnitude of local versus spillover channels, and how does this vary across countries? We make two key contributions. First, we move beyond crude climate vulnerability indices and the sole temperature focus in prior research by examining a wide set of realized climate impacts, including temperature, precipitation and drought metrics, that are currently under-explored. In doing so, we deploy state-of-the-art climate data based on daily observations weighted by gridded economic activity. This approach captures temporal and spatial granularity that is crucial for identifying heterogeneous climate impacts but has been widely neglected in similar studies. Second, we construct a novel climate spillover measure that links foreign climate impacts to domestic financing conditions through structural economic dependencies. This spillover metric is based on Inter-Country Input-Output tables that systematically track the flow of goods and services between economies, providing detailed information on countries' value-added origin. This approach not only allows us to attribute changes in financing conditions to both domestic and foreign climate exposure, but also provides a more accurate representation of structural economic dependencies than conventional surface level trade flow statistics. By implementing these data and methodological innovations, we aim to make climate impact assessments more comprehensive, economically sound, and policy-relevant.

Sovereign financing conditions are measured using sovereign credit ratings from Moody's, S&P, and Fitch, as they represent governments' capacity to service its debt, directly shape borrowing costs of sovereign debt as the world's largest asset class, and serve as a benchmark across financial markets. Our analysis covers a panel dataset of 75 countries (35 advanced and 40 emerging economies) from 2000 to 2022, corresponding to roughly 130,000 unique observations. Deploying both standard and quantile two-way fixed-effects panel regressions, we exploit exogenous variation in climate to estimate average and heterogeneous local effects across the distribution. We then disentangle domestic and foreign climate risk components to quantify climate spillovers through global value chains.

Results are threefold. First, local temperature anomalies and drought conditions exhibit significant negative relationships with sovereign ratings, with a one-unit increase associated with a 0.19 notch downgrade, while precipitation measures show no effect. Quantile analysis reveals pronounced heterogeneity, with effects about 10 times larger for countries at the 10th percentile of the rating distribution than at the 90th, revealing climate risks disproportionately burden lower-rated sovereigns. Second, incorporating spillovers from foreign climate exposure increases the aggregate total impact to -0.28. This implies that ignoring climate spillovers underestimates total climate risk by 36% on average, compared to the local-only baseline. Countries in arid and temperate climate zones experience the largest impacts of up to a full notch downgrade. Third, for more than 40% of countries, spillovers even dominate domestic impacts. In some smaller, highly globalized, and often European economies such as Hungary, Ireland, or Switzerland, spillovers contribute up to 80% of total climate impacts. For such economies, climate-induced stress in key trade partners seems to present a far greater risk than local physical exposures, highlighting how spillovers transform the scale and geography of climate risk.

Findings reveal a critical blind spot and come with important implications. For financial authorities and investors aiming to comprehensively integrate climate risk into regulation and investment decisions, they underline the need to expand analytical frameworks beyond national boundaries to capture climate risk interactions. For policymakers, effective climate risk assessments and mitigation strategies require not only domestic adaptation and resilience building, but also targeted trade diversification, strategic supply chain flexibility, and global adaptation efforts to weather-proof public finances against local and global climate shocks.

The remainder of this paper proceeds as follows. Section 2 situates our contribution in the relevant literature in more detail. Section 3 describes data sources and key variables. Section 4 outlines the empirical strategy for estimating local impacts and global spillover effects. Section 5 presents results. Section 6 concludes with policy implications and directions for future research.

2 Contribution to the literature

Our work draws on three strands of research in climate economics and macro finance. First, constituting the contextual foundation, we build on climate damage research that documents substantial and oftentimes heterogeneous economic losses from climate change. Kahn et al. (2021) and Burke et al. (2015) project damages from changes in global temperatures to exceed 7% and 20% of world GDP by 2100, respectively. Building on this, more recent evidence by Bilal and Känzig (2026) accounting for global temperature suggests that each 1°C of warming lowers world income by 12%. Fillon et al. (2025) and Nath et al. (2024) provide evidence that future projected damages are 25% larger when accounting for heterogeneous intra-annual temperature patterns over space, and three to five times larger when considering persistent growth effects. These central damage estimates, though consistently negative, have wide confidence intervals with uncertainty skewed toward severe negative outcomes (Tol, 2024). Integrating such tail risks, Dietz et al. (2021) show that accounting for climate tipping points increases the social cost of carbon by 25%. These macroeconomic damages translate directly into fiscal pressures. Barrage (2020) demonstrates that accounting for climate's fiscal consequences, such as increased costs for government services and adaptation, raises welfare gains (i.e., forgone damages) of efficient climate policy by 30%. Similarly, Seghini (2026) estimates that without deep emission cuts, climate-induced reductions in economic growth and capital depreciation will shrink fiscal limits, implying severe challenges to fiscal health. However, financial adaptation, for example via disaster insurance or issuance of catastrophe bonds, can partially offset such negative impacts (Phan and Schwartzman, 2024).

Because the question how these impacts translate into changes in the cost and availability of public financing remains underexplored, secondly, our work links to literature on climate risk and sovereign financing conditions. Klusak et al. (2023) simulate climate-induced sovereign credit rating downgrades as early as 2030, rising to 81 sovereigns facing an average downgrade of 2.18 notches by 2100 under higher emissions scenarios. This translates to increases in annual interest payments on sovereign debt ranging from US$45–$67 billion under RCP 2.6 to US$135–$203 billion under RCP 8.5. Likewise, Cappiello et al. (2025) find higher temperature anomalies and acute physical impacts are linked to credit downgrades, particularly for high-exposure countries after the Paris Agreement. However, Bernhofen et al. (2024) argue that these rating estimates likely understate true risks, as they tend to ignore the materialization of acute extreme events. From a more practical perspective, S&P Global Ratings (2014) acknowledged over a decade ago that climate change is a mega-trend likely to pressure sovereign creditworthiness downward. Today, all three leading credit rating agencies (S&P, Moody's, Fitch) claim to accommodate climate in their assessments, yet, their methodologies lack clear quantitative frameworks and remain neither harmonized nor externally transparent. Angelova et al. (2021) highlights that climate is assessed qualitatively based on analyst judgment rather than systematically integrated into core rating processes. While this is a first step, such a "soft" approach opens space for blind spots and inconsistencies: Which time horizon is relevant? Which climate risk sources should be considered? How to judge uncertainty and materiality of climate risks? Even for well-informed analysts it is challenging to find consistent and economically meaningful answers to such questions. So, even though climate is on the agenda of credit rating agencies, its factual relationship with financing conditions from an empirical point is less clear. This raises the broader question of how climate risks are priced in sovereign bond markets. Studies of climate vulnerability and sovereign bonds confirm similar patterns, concluding that climate risk raises bond yields and spreads, particularly for lower-rated countries and longer-term maturities (Bingler, 2022; Capelle-Blancard et al., 2019; Cevik and Jalles, 2022). Moreover, Beirne et al. (2021) suggest that these climate-induced increases in public debt cost remain permanent, with Kling et al. (2018) quantifying the average increase at 1.2%. Boehm (2022) directly analyzes temperature changes, confirming a negative relationship with sovereign bond performance. Evidence from US municipal bonds indicates that country-level insights also apply to local governments' finances (Acharya et al., 2022; Auh et al., 2022; Goldsmith-Pinkham et al., 2022; Jeon et al., 2025; Painter, 2020). Agarwala et al. (2021) provide a taxonomy for tracing climate impacts through to sovereign risk, with climate-extended sovereign default models confirming that expected climate damages negatively affect sovereign's cost and availability of financing, so that carbon abatement now, even when financed through additional borrowing, effectively lowers future capital costs to governments (Barnett and Yannelis, 2024; Mallucci, 2022; Duffy, 2025)[1]. However, these studies show two major limitations. First, they tend to rely on crude proxies of climate impacts, such as broad exposure and vulnerability indices rather than actual climate observations. Even the few studies

[1] While not the focus of this paper, there is an equally rich literature on climate transition risk and sovereign finances, e.g., Battiston and Monasterolo (2020) or De Angelis et al. (2024)

using climate data typically restrict analysis to temperature anomaly, leaving other impact signals such as precipitation patterns or drought conditions unexplored. Second, they utilize aggregate country-year-level data, neglecting spatial and temporal granularity crucial for understanding heterogeneity of climate risks.

Further, presenting the third strand of literature and key research gap, existing studies suffer from a critical blind spot regarding climate spillovers[2]: They focus almost exclusively on isolated local climate impacts, implicitly assuming that domestic economies are practically unaffected by climate shocks in foreign countries (Dingel and Meng, 2026; Fahr et al., 2024). However, this assumption is demonstrably false. External local climate shocks are known to oftentimes propagate through international production networks and cross-border trade linkages. For instance, the severe floods in Thailand in 2011, a key hard drive manufacturing base, not only severely damaged local capital but also disrupted supply chains so that car and electronics manufacturers abroad had to curtail production (Reuters, 2011). Obviously, this can affect sales, sectoral GDP and tax revenues, and thereby fiscal and financing conditions. By ignoring these climate spillovers, existing literature systematically under-represents the global scale of climate change and its economic ramifications. This recognition has spurred a growing body of empirical work aimed at quantifying climate's cross-border transmission channels into macro-financial performance. A recent report by Ranger et al. (2025) identifies significant risks to UK resilience from transnational climate impacts transmitted via infrastructure and supply chains. Jones and Olken (2010) show that temperature increases in poor countries negatively impact export growth, which also implies an effect on the importing country. Feng and Li (2021) find that exposure to foreign climate risk in key trade partners lowers the aggregate stock market valuation in the home country. Similarly, exposure to external temperature shocks are found to result in damages similar to the direct effect of local temperature (Bilal and Känzig, 2026), with the inclusion of external (i.e., global) weather conditions increasing damage to world GDP in 2100 from 11% to 40% under SSP5-8.5 (Neal et al., 2025). So, for countries with low direct climate change exposure and high adaptive capacity, spillovers can present a substantial risk beyond local climate costs. For example, in the US, trade-related spillovers are estimated to be responsible for 16% of the total costs of climate change (Schenker, 2013). However, we argue that the spillover proxies deployed are prone to measurement errors. Most studies, for instance Feng and Li (2021) and Dingel and Meng (2026), use trade shares or geographical distance as a spillover proxy. However, these metrics fail to capture deeper structural economic dependencies. Country A may not trade much with Country B directly but may rely on B's (intermediate) inputs via Country C. Climate shocks in B would effectively shape economic outcomes in A, yet remain invisible in bilateral trade balance between A and C. Put differently, trade data represents surface-level economic flows, but not necessarily structural dependencies within the integrated global economy. For example, while 4.0% of Germany's 2022 gross imports came from Ireland, it was 2.7% of foreign value added in final demand. And while 8.3% of German imports came from the United States, it was 10.7% of foreign value added.[3] So, using standard trade met-

[2]Also coined "transnational", "borderless", or "cascading" climate impacts

[3]Source: OECD TiVA database (2025 edition)

rics at face value would overestimate economic connectedness to Ireland by 48% and underestimate reliance on the United States by 22%. On sectoral level, these disparities can be even more pronounced. Similar to our study, Fahr et al. (2024) use input-output linkages to investigate the underlying spillover dynamics, suggesting that trade can amplify climate-related losses to levels up to 30 times higher than local impacts alone would suggest, with the average loss from spillovers exceeding 11% of GDP in the Euro Area. In a similar vein, Zappalà (2025) provides further evidence that sectors not experiencing direct heat shocks still bear economic losses through trade linkages with affected foreign industries. Yet, to our knowledge, no study has systematically integrated spillovers into analysis of climate impacts on sovereign financing conditions.

To address these limitations, this study implements the following steps. First, we deploy state-of-the-art climate data on actually realized observations of physical climate change rather than proxy indices. Second, we capture a higher degree of spatial and temporal granularity by accounting for gridded economic activity and utilizing daily climate input data. Third, we use data from Inter-Country Input-Output tables that systematically track flows of goods and services between economies, more accurately capturing underlying structural economic linkages between domestic and foreign countries. Leveraging information on countries' value added origin and share, we construct a novel climate spillover metric that serves as a foreign climate risk attribution factor[4]. By implementing these data and methodological innovations, we aim to make impact assessments of climate change on sovereign finances more comprehensive, economically sound, and policy-relevant.

3 Data

Sovereign financing data: As a measure of sovereign financing conditions, we use the annual average of foreign currency long-term sovereign credit ratings by Moody's, S&P, and Fitch Ratings, from Kose et al. (2022). To consolidate data, ratings were converted into a numerical scale from 1 to 21, where high (low) values indicate high (low) ratings.[5] Sovereign credit ratings are particularly well-suited for our analysis for several reasons. Credit ratings represent governments' forward-looking structural conditions and long-term debt service capacity, not just short-term market sentiment or volatility. They directly shape borrowing costs of sovereign debt as the world's largest asset class and play a central role in measuring fiscal stability and guiding investment decisions by signaling the level of risk associated with a given country (e.g., investment-grade thresholds). Further, they serve as a benchmark for other asset classes, frequently imposing a ceiling effect across capital markets. For example, municipalities or private companies are rarely rated higher than the issuer's country. Importantly, they are available for countries without deep or liquid bond markets and have substantial power to explain bond yield spreads (Cantor and Packer, 1996).

[4]While conceptually there are several other foreign climate impact transmission channels (e.g., migration), this article focuses on trade as a key mechanism, as it is most directly observable and linked to standard indicators of global economic activity

[5]The converting scheme for sovereign credit ratings is presented in Appendix A.1

Climate data: We leverage climate data at the GADM0 spatial boundary from Gortan et al. (2024). This includes daily temperature (measured in Celsius degrees, °C) and precipitation (in millimeters, mm) sourced from the ERA5 reanalysis of historical observations at a resolution of 0.25°×0.25°, and the monthly Standardized Precipitation Evapotranspiration Index (SPEI) at a 0.5°resolution based on CSIC v2.7.[6] SPEI is a drought, or water scarcity, index that combines the effects of precipitation and evapotranspiration on water balance, assessing both the severity and duration of drought conditions. Temperature, precipitation and SPEI are available weighted by population density, night-time light intensity, and cropland to account for gridded economic activity. Moreover, variables are provided not weighted by any spatial economic indicator, but only by the area of each grid cell. Following the latest climate impact literature, we compute several annualized metrics which have been widely motivated and tested (Waidelich et al., 2024): mean temperature, temperature anomaly, daily temperature variability, total precipitation, extreme daily precipitation, number of wet days, and standardised monthly precipitation deviations, as well as mean SPEI.[7]

Value added data: We extract data on the share and origin of countries' value added content in final demand from the OECD Trade in Value Added (TiVA) database derived from OECD's Inter-Country Input-Output tables.[8] This value added metric represents the domestic economy's relative reliance on foreign economies by showing the share of Country i's final consumption attributable to value added from Country y. The advantage of the TiVA database is that it provides a statistical infrastructure that maps flows of production, consumption, investment within countries and flows of international trade between countries, broken down by economic activity and by country, globally and for a time period that is meaningful for our analytical purpose.

Other data: In addition, we collect a variety of control data from the IMF and World Bank Group. Key varibles include GDP growth, GDP per capita, debt-to-GDP, average sovereign debt maturity, current account-to-GDP, fiscal balance, primary balance-to-GDP, inflation, unemployment, and political stability. For purpose of heterogeneity analysis, we also include a measure of countries' degree of economic globalisation from the KOF Globalisation Index (Gygli et al., 2019). Merging these data inputs yields an initial panel dataset containing 80 countries over 28 years (1995 to 2022). Five countries[9] are dropped due to missing sovereign credit rating, climate, or control data. Years prior to 2000 are dropped because of a large number of missing rating values. All economic and financial variables are winsorized at the 99% level. This results in a panel with 75 countries, of which 35 advanced and 40 emerging economies,[10] from 2000 to 2022 (with SPEI only available until 2020), corresponding to 1,725 unique observations and roughly 130,000 observations when

[6]https://spei.csic.es/database.html

[7]Formulas for calculating these climate variables are presented in Appendix A.2

[8]Indicator "FD_VA_SH: Value added origin shares" from OECD TiVA database (2025 edition)

[9]BRN, MMR, STP, HKG, TWN

[10]A list of countries and corresponding ISO3 codes can be found in Appendix A.3

considering input-output linkages (value added flows) between countries.

Table 1: Key descriptive statistics (full sample, 2000-2022)

Statistic	N	Mean	St. Dev.	Median	Min	Max
Temp. Anomaly (°C)	1,725	1.1	0.6	1.1	−1.0	3.3
Temp. Variability (average monthly SD of daily temp.)	1,725	2.0	1.0	2.0	0.3	4.5
Precip. Total (mm p.a.)	1,725	1,087.0	726.7	911.3	0.0	5,144.0
Precip. Extreme (mm p.a.)	1,725	12.7	26.3	0.0	0.0	254.7
Precip. WetDays (No. p.a.)	1,725	192.0	87.3	189	0	366
Precip. Deviation (standardized monthly)	1,725	−0.04	0.4	−0.1	−1.2	1.8
SPEI (water balance drought index)	1,575	−0.1	0.3	−0.1	−1.3	1.1
Domestic value added share (%)	1,725	71.4	9.6	72.6	38.9	91.9
Sovereign credit rating	1,635	14.4	5.0	14.3	1.3	21.0
GDP growth p.a. (%)	1,725	3.4	3.7	3.4	−9.0	13.1
GDP per cap (k$)	1,725	33.3	25.2	29.2	1.3	129.0
Debt to GDP (%)	1,715	55.4	35.3	48.0	3.0	226.1
Current account to GDP (%)	1,680	−0.2	6.3	−0.9	−25.7	26.9
Inflation (%)	1,687	4.5	6.0	2.8	−1.2	43.5
Unemployment (%)	1,531	7.4	4.6	6.4	0.6	25.0
Political stability	1,650	0.1	0.9	0.3	−2.3	1.6
KOF (economic globalisation) index	1,679	65.1	15.5	67.2	31.1	93.1

4 Methodology

4.1 Local climate

As a starting point, we revisit the latest research findings and test whether climate, beyond temperature alone, is considered in sovereign credit ratings. We use a standard Two-Way-Fixed-Effects (TWFE) model including a climate term. Importantly, aligned with standard literature, this is a local climate term representing the respective climate variable in country i. And even though as we argue, this local-only approach ignores the global dimension from trade-related spillover impacts, it is a useful baseline specification to investigate the relevance of climate for ratings in general before exploiting our novel spillover channel for a more nuanced assessment of direct (i.e., domestic) versus indirect (i.e., foreign) impacts. The model is inspired by the well-known ratings model of Cantor and Packer (1996) and includes further key explanatory variables widely used in the literature, plus the climate term:

$$\mathrm{Y}_{i,t} = \tilde{\beta}_0 + \tilde{\beta}_1 \, \mathrm{CR}_{i,t-1} + \tilde{\beta}_2 \, Z_{i,t-1} + \gamma_t + \alpha_i + \varepsilon_{i,t} \tag{1}$$

where Y is a country's sovereign credit rating and CR a climate risk metric from the set of computed climate variables covering temperature anomaly, daily temperature variability, total precipitation, extreme daily precipitation, number of wet days, standardised monthly precipitation deviations, and drought conditions (mean monthly SPEI)[11]. Fluctuations in these (short-run) climate variables provide idiosyncratic variation as they are largely driven by physical processes such as weather, ocean cycles, or radiative forcing, that are plausibly exogenous to contemporaneous country-level economic or political shocks. Further, $\beta_2 Z$ is a vector

[11] We also estimate a specification that allows for country-specific coefficients β_{1i} by interacting the climate variable with country indicators, thereby relaxing the assumption of homogeneous effects across observations to explore heterogeneous responses across countries.

of control variables including (log) GDP per capita, GDP growth, debt-to-GDP, current-account-to-GDP, inflation, unemployment, and political stability. α and γ are country and year fixed effects accounting for time-invariant factors and unobserved inter-temporal trends that are homogeneous across countries, respectively. To account for potential heteroskedasticity, robust standard errors clustered at the country level are deployed. Additionally, we estimate a quantile panel regression to capture conditional and potentially heterogeneous effects of the determinants of ratings by allowing the coefficients to vary across different points of the dependent variable's distribution. For a given quantile $\tau \in (0,1)$, the model is expressed as:

$$Q_{Y_{it}}(\tau \mid Z_{i,t-1}, \alpha_i, \gamma_t) = \tilde{\beta}_0 + \tilde{\beta}_1^{\tau}\,\mathrm{CR}_{i,t-1} + \tilde{\beta}_2^{\tau}\,Z_{i,t-1} + \gamma_t^{\tau} + \alpha_i^{\tau} + \varepsilon_{i,t}^{\tau} \tag{2}$$

where $Q_{Y_{it}}(\tau \mid Z_{i,t-1}, \alpha_i, \gamma_t)$ is the conditional τ-th quantile of sovereign credit ratings, with β_1^{τ} the coefficient of interest for the impact of the climate risk variable on rating quantile τ. β_2^{τ} are quantile-specific coefficients for the same vector of control variables Z described above, and α_i and γ_t country and time fixed effects. ε_{it} is the quantile error term. Bootstrapped standard errors are deployed as they do not impose strong parametric assumptions and account for heteroskedasticity and autocorrelation. This quantile method allows effects to vary across the distribution of Y_{it}, offering insights beyond the average impacts identified by standard TWFE models. It thus highlights asymmetric rating responses to climate impacts at lower versus upper parts of the distribution and can accommodate nonlinear relationships without imposing a strict functional form.

4.2 Global climate spillovers

4.2.1 Constructing a climate spillover metric

To account for structural global economic linkages, we construct a metric that captures the indirect climate risk a country absorbs from its counterpart countries (i.e., trade partners) due to value added reliance. We call this spillover metric the transnational climate exposure (TCE) metric. TCE construction is based on the foreign value added content in domestic final demand. Foreign value added dependency (FVAD) tells us what share of country i's final consumption is attributable to value added from country y. Hence, it signals the domestic economy's relative reliance on foreign economies, accounting for multi-stage multi-country production:

$$\mathrm{FVAD}_{i,y,t} = \frac{\mathrm{FVA}_{i,y,t}}{\sum_y \mathrm{FVA}_{i,y,t}} \times 100 \tag{3}$$

where FVA is the foreign value added embodied in domestic final demand. FVAD shows, for the total domestic demand of a country i, the share of the value added from foreign country y in domestic country i total value added consumed. So, FVAD provides a value added perspective of an economy's relative connectedness to other economies, independent of whether or not there are direct imports. Then, we construct the TCE as a FVAD-weighted exposure to foreign countries' climate risk, representing how much a country depends on climate-vulnerable external production sources:

$$\text{TCE}_{i,t} = \sum_{y} (\text{FVAD}_{i,y,t} \cdot \text{CR}_{y,t}) \tag{4}$$

where CR is the foreign climate risk metric. Similarly to the TCE, we define national climate exposure (NCE) as the climate risk in country i weighted by the economy's domestically generated value added content:

$$\text{NCE}_{i,t} = (1 - \sum_{y} \text{FVAD}_{i,y,t})\, \text{CR}_{i,t} \tag{5}$$

4.2.2 Estimating rating impacts with spillovers

We deploy the NCE and TCE metrics to disentangle countries' local and spillover climate impacts. This allows us to explore whether sovereigns' financing conditions change due to its own climate stress or because counterpart countries experience climate stress which propagates through global value chains. To account for different levels of vulnerability of countries to climate change, we integrate country-specific climate sensitivities[12] into the analysis. However, a key econometric challenge in estimating these country-specific parameters arises from spatial correlation in climate patterns. Highly correlated temperature anomalies in neighbouring countries can create multicollinearity when estimating individual country sensitivities, resulting in biased estimates. To address this challenge, we employ a climate zone clustering approach. We group countries into climate zones based on the Köppen-Geiger climate classification, ensuring our grouping align with established climatological patterns. This yields four primary climate clusters: arid, continental, temperate, and tropical. Next, we estimate a climate zone sensitivity parameter for each cluster. We then assign this climate zone sensitivity to all countries within the respective cluster. For instance, all countries in the arid zone are assigned the arid cluster sensitivity, reflecting their shared physical vulnerabilities from common climatic characteristics. This clustering approach mitigates spatial correlation concerns, but trades-off some country-specific granularity. To estimate the effect of domestic and foreign climate exposure on sovereign credit ratings accommodating heterogeneous sensitivities, we employ a panel regression framework that identifies cluster climate sensitivities that govern both domestic climate impacts and international spillover transmission. The estimating equation is given by:

$$Y_{i,t} = \tilde{\beta}_0 + \sum_{c=1}^{C} \tilde{\beta}_{1,c} \sum_{y \in c} E_{i,y,t-1} + \tilde{\beta}_2\, Z_{i,t-1} + \gamma_t + \alpha_i + \varepsilon_{i,t} \tag{6}$$

with

$$E_{i,y,t} = \begin{cases} NCE_{i,t} & \text{if } i = y, \\ FVAD_{i,y,t} \times CR_{y,t} & \text{if } i \neq y, \end{cases}$$

[12] We use the term climate sensitivity for the relationship between a country's climate risk and credit rating. It does not refer to climate sensitivity as defined in climate science, describing the Earth's global surface temperature increase from doubling atmospheric carbon dioxide concentration.

where $Y_{i,t}$ denotes the sovereign credit rating of country i in year t, $E_{i,y,t-1}$ country i's climate exposure originating from country y, $Z_{i,t-1}$ is the vector of control variables, γ_t captures time- and α_i country-fixed effects, and $\varepsilon_{i,t}$ is the error term.

The key innovation of our approach stems from the construction of the climate risk exposure variable, which takes two distinct forms depending on whether the climate exposure originates domestically or from foreign countries. When $y = i$, the exposure term captures domestic climate exposure through $NCE_{i,t}$, which is the product of country i's domestic value-added share and its own level of climate change, operationalized as local temperature anomalies. When $y \neq i$, the exposure term reflects foreign climate exposure through the interaction of country i's value-added dependence on country y and country y's level of climate change. This structure allows us to trace how climate shocks in other countries propagate through global value chain linkages to affect sovereign creditworthiness.

The coefficient $\tilde{\beta}_{1,c}$ represents the climate sensitivity parameter for cluster c, assigned to all countries y in the respective cluster, governing how climate in country y translates into rating impacts through climate exposure E. Crucially, the exposure parameter E plays a dual role in our framework. When country y appears as the home country ($i = y$), the term measures how country y's own rating responds to its domestic climate conditions. When country y appears as a trading partner ($i \neq y$), the same term governs how country y's climate risk spills over to its trading partners' ratings. This simultaneity is a central feature in our spillover estimation strategy, determining both countries' domestic vulnerability and their capacity to transmit climate risk internationally. The approach implies that climate sensitivity reflects fundamental cluster characteristics that are time-invariant (over the short- to medium-term) such as geographical exposure, economic structure, and adaptive capacity, that determine both how a cluster country's own rating responds to climate shocks and how consequential those shocks can be for its trading partners. By imposing this structure, we ensure internal consistency. If countries in the arid cluster are highly sensitive to climate risk domestically, our framework recognizes that climate shocks originating from these countries should also have commensurately large spillover effects on economies exposed to arid countries through trade linkages.

Operationally, we implement the sensitivities by estimating total climate impact on country i's rating, decomposed into domestic and foreign components. The domestic climate impact is calculated as $\hat{\beta}_{1,c} \times NCE_{i,t-1}$, reflecting how country i's own climate conditions affect its rating. The foreign climate impact is computed as $\sum_{y \neq i} \hat{\beta}_{1,c} \times \text{FVAD}_{i,y,t-1} \times CR_{y,t-1}$, aggregating the spillover effects from all trading partners weighted by their respective climate sensitivities and value added shares. This decomposition allows us to quantify the relative importance of domestic versus international climate transmission channels in determining sovereign credit risk. However, this also comes with restrictions that merit acknowledgment. First, we apply climate sensitivities that are homogeneous within climate zones but heterogeneous across zones. While this is more flexible than assuming global homogeneity, it does not allow for country-specific sensitivities within zones. We justify this restriction with the spatial granularity vs. correlation trade-off, and that climate zones capture the primary dimensions along which climate vulnerability varies. Second, implicitly we assume that the transmission mechanism, how climate risk in country

y affects ratings, operates identically whether y is experiencing the shock domestically or transmitting it as a trading partner. In reality, domestic and spillover channels may differ in magnitude or timing, though both should be governed by the underlying climate vulnerability of country y. Third, for simplification, we assume climate sensitivity remains constant over our sample period. While this is reasonable as structural factors like adaptive capacity or climate resilience usually evolve slow-moving over long-term horizons, it does not allow for the possibility that countries undergo rapid transformation within a short time period.

Our identification strategy exploits both cross-sectional and temporal variation in climate exposure, leveraging three key sources of exogeneity. First, our measure of climate risk, temperature anomalies, is plausibly exogenous to short- and medium-term economic and political developments. While countries may impose long-term climate trajectories through emissions, year-to-year temperature deviations are determined by climate system dynamics that cannot be influenced. Second, we lag all independent variables, ensuring that they temporally precede the rating outcomes. This lag structure reflects the transmission mechanism through which climate conditions affect economic fundamentals before manifesting in credit rating adjustments. This provides additional protection against reverse causality, as current ratings cannot cause past climate conditions. Third, the inclusion of country and time fixed effects addresses several potential confounders. Country fixed effects absorb all time-invariant factors, such as socio-economic characteristics, political environments, or geographical characteristics. Time fixed effects control for unobserved global trends that are homogeneous across countries. Despite these mitigation steps, certain identification challenges remain. While temperature anomalies are plausibly exogenous, value added linkages through which climate risk propagates are potentially endogenous, as countries may adjust their trade relations in response to economic conditions correlated with creditworthiness. We address this concern by using lagged value added shares, though we acknowledge that slow-moving changes in trade patterns could still reflect anticipatory climate responses. Additionally, our macroeconomic controls are assumed to adequately capture the main confounding pathways. This is justified by deploying explanatory variables widely used in well-established rating models. Nevertheless, unobserved time-varying factors such as changes in monetary policy regimes could introduce omitted variable bias if correlated with both climate exposure and ratings.

5 Results

5.1 Local climate impacts

Baseline results examining whether climate affects sovereign credit ratings are presented in Table 2. Findings provide clear evidence that climate conditions matter for sovereign credit ratings. Temperature anomaly shows a negative relationship with ratings, indicating that countries experiencing higher deviations from historical temperature means receive systematically lower sovereign ratings. A one-degree Celsius increase in temperature anomaly is associated with a rating downgrade of approximately 0.19 notches, holding other factors constant. This corresponds to a one standard deviation increase in temperature anomaly implying a 0.09 notch downgrade, suggesting that rating agencies recognize climate change as a material risk factor for sovereign creditworthiness. Temperature variability shows a marginally significant positive coefficient, which appears counterintuitive, and may indicate that this standard deviation metric captures aspects that operate through non-linear channels not fully captured in this specification. The SPEI demonstrates a positive relationship with ratings, consistent with conceptual logic: higher SPEI values indicate positive water balance (less drought stress), which supports higher creditworthiness. This aligns with the expectation that water availability is important for economic resilience. Notably, precipitation measures (total precipitation, extreme precipitation, wet days, precipitation deviation) do not exhibit statistically significant relationships with sovereign ratings. Among all climate variables tested, temperature anomaly stands out as the most clearly identified and economically meaningful climate-related driver of sovereign ratings. This suggests that rating agencies are particularly attentive to, or that economies are particularly vulnerable to warming rather than other dimensions of climate change. Of course, the prominence of temperature as a key metric in global climate policy, and climate-economy modeling may play a role here. The coefficients of control variables are aligned with theoretical expectations and validate the soundness of our data and model specification. GDP per capita (log) is strongly positively associated with ratings, reflecting the importance of income levels for fiscal capacity. While one could expect the same for GDP growth, we find a positive but not significant relationship. This could be explained by the fact that many emerging economies tend to grow faster than advanced economies, but this growth comes with other economic trade-offs and institutional constraints that put pressure on ratings. Debt-to-GDP ratios, inflation, and unemployment have a negative impact on ratings, highlighting that higher indebtedness, monetary and price instability, and labor market weakness raises default risk. Political stability emerges as an important institutional factor that elevates ratings.

Because temperature anomaly is found to be the climate variable with the highest predictive power of ratings, we now provide a more in-depth quantile analysis to explore whether the temperature impact varies across levels of creditworthiness (Figure 1). Findings describe the impact of temperature anomaly on ratings at different points of the dependent variable's distribution, ranging from the 10th percentile to the 90th percentile. This yields conditional estimates and a richer heterogeneous understanding that goes beyond standard regression models' average effects and allows us to test whether climate affects highly-rated and poorly-rated sovereigns differently, a question with important implications for risk assessments and international (climate) finance. The pattern of coefficients reveals two main findings. First, confirming aggregate results, estimates across all parts of the distribution are consistently negative, implying that temperature increases are detrimental to ratings independent of countries' level of creditworthiness. Second, there is relevant heterogeneity across quantiles, with the effect being 9.8 times larger at the 10th percentile (-0.157) compared to the 90th percentile (-0.016). Temperature anomalies exhibit strong negative impacts on ratings at the lower end of the distribution (Q10 to Q50), with coefficients ranging from -0.163 to -0.131 (all $p<0.05$). This indicates

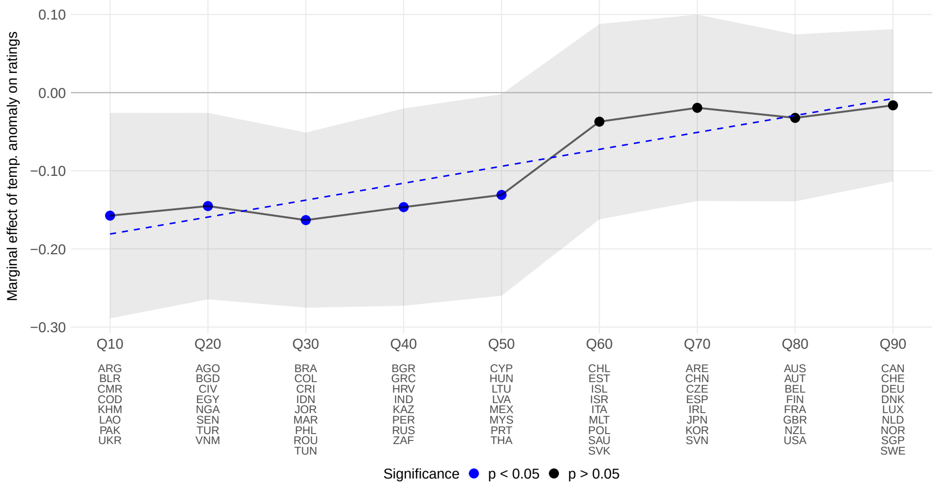
Table 2: Aggregate regression results - Local climate

	Dependent variable: Sovereign credit rating						
T Anom.$_{t-1}$	−0.185***						
	(0.070)						
T Variability$_{t-1}$		0.343*					
		(0.179)					
P Total$_{t-1}$			0.000				
			(0.000)				
P Extreme$_{t-1}$				−0.001			
				(0.001)			
P WetDays$_{t-1}$					0.000		
					(0.002)		
P Dev.$_{t-1}$						0.046	
						(0.099)	
SPEI$_{t-1}$							0.205*
							(0.106)
log GDP percap$_{t-1}$	2.889***	2.870***	2.897***	2.896***	2.895***	2.896***	3.003***
	(0.682)	(0.684)	(0.681)	(0.681)	(0.681)	(0.681)	(0.702)
GDP growth$_{t-1}$	0.019	0.022	0.019	0.019	0.019	0.019	0.023
	(0.026)	(0.027)	(0.026)	(0.026)	(0.026)	(0.026)	(0.027)
Debt/GDP$_{t-1}$	−0.045***	−0.045***	−0.045***	−0.045***	−0.045***	−0.045***	−0.047***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.006)
Curr.acc./GDP$_{t-1}$	−0.014	−0.013	−0.014	−0.014	−0.014	−0.014	−0.013
	(0.015)	(0.016)	(0.015)	(0.015)	(0.015)	(0.015)	(0.016)
CPI$_{t-1}$	−0.034**	−0.035**	−0.034**	−0.034**	−0.034**	−0.033**	−0.036**
	(0.017)	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)
Unemployment$_{t-1}$	−0.184***	−0.182***	−0.181***	−0.181***	−0.181***	−0.181***	−0.181***
	(0.040)	(0.040)	(0.040)	(0.040)	(0.040)	(0.040)	(0.041)
Political stability$_{t-1}$	1.071***	1.073***	1.083***	1.089***	1.085***	1.083***	1.030***
	(0.336)	(0.334)	(0.337)	(0.339)	(0.338)	(0.338)	(0.347)
FE (time)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
FE (country)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1340	1340	1340	1340	1340	1340	1275
R^2	0.57	0.57	0.57	0.57	0.57	0.57	0.58

Notes: Averages with country-clustered standard errors in parentheses. All explanatory variables are lagged by one year. Significance levels: * p<0.1; ** p<0.05; *** p<0.01

that countries with lower credit ratings experience economically meaningful rating downgrades in response to rising temperatures. The magnitude of the effect is relatively stable across these lower quantiles, suggesting a persistent climate penalty for public financing of less creditworthy sovereigns. In contrast, the effect becomes statistically insignificant at higher quantiles (Q60 to Q90), with coefficients between -0.037 and -0.016. This finding suggests that higher-rated sovereigns, predominantly advanced economies with healthy investment grade status, appear largely insulated from temperature-related local impacts. This differential picture likely reflects several underlying mechanisms. Lower-rated countries often have economies more dependent on climate-sensitive sectors like agriculture, weaker institutional capacity to manage climate shocks, tighter fiscal space to fund climate adaptation measures, and less diversified economic structures. These structural vulnerabilities make their creditworthiness more susceptible to climate deterioration. Conversely, higher-rated sovereigns tend to possess stronger adaptive capacity, more diversified economies, more resilient infrastructure, and greater financial resources to buffer climate impacts. In addition, this pattern could reflect that rating agencies may be more responsive to climate signals when evaluating already vulnerable economies, while giving less weight to climate concerns for countries with strong fundamentals. This distinction between actual economic resilience and rating agency perception merits further investigation. Overall, results show that climate change poses heterogeneous downward pressure on ratings across the sovereign landscape, underlining the importance of obtaining conditional estimates[13].

Figure 1: Quantile regression coefficients - Local climate



Notes: Relationship between temperature anomaly and sovereign credit rating for the 10th to 90th percentile of the rating distribution. Country codes show each countries' "typical decile" based on where its observations fall in the overall rating decile distribution, using the mean of its observation-level deciles. Countries are then ranked by this typical decile position and split into nine equally sized groups, indicating which countries are more typically associated with lower versus higher parts of the rating distribution. Dashed line represents smoothed trend line. Shaded area shows the 95% confidence interval with bootstrapped standard errors.

5.2 Global climate spillovers

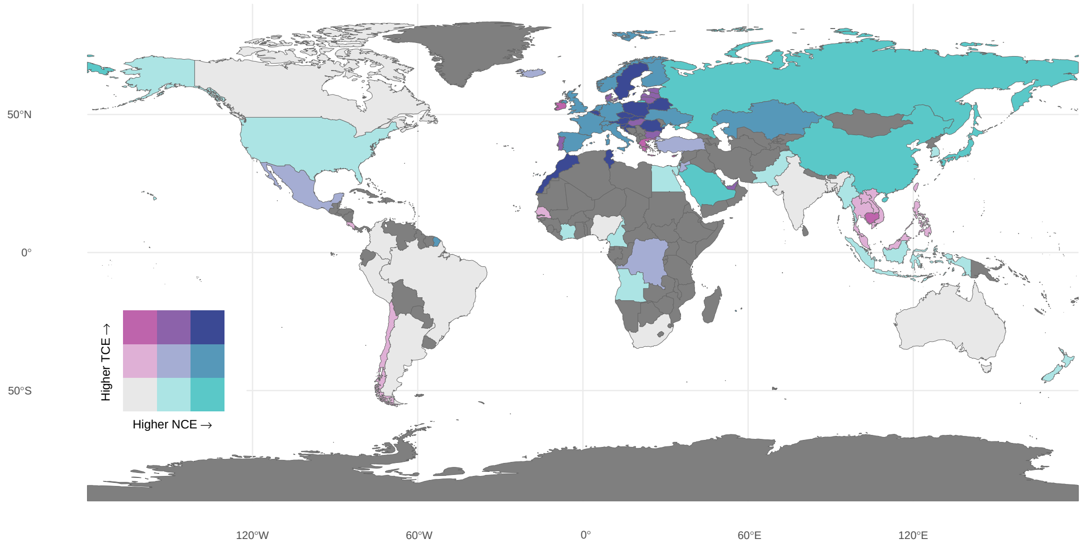
5.2.1 Climate risk exposures

To provide an intuitive and stylised descriptive overview, Figure 2 displays countries' climate exposure profiles, simultaneously capturing impacts from local (NCE) and global (TCE) sources. The color gradient indicates the joint distribution of these exposures, with darker shades representing higher exposure across both dimensions. The spatial pattern reveals heterogeneity in profiles across countries, distinguishing regions where domestic climate impacts constitute the primary source of risk from those where foreign spillovers play a dominant role. Several regions exhibit elevated local climate risk, particularly in sub-Saharan Africa and parts of South- and East Asia, consistent with observed climate patterns in these latitudes. At the same time, the geographical distribution illustrates that in addition to local impacts most countries are also exposed to transnational climate risks. For example, highly integrated economies in Europe face considerable exposure to global climate

[13]See Appendix B.1 for full quantile regression results table

spillovers (TCE) through global value chain relationships. This simple descriptive representation highlights that focusing exclusively on domestic climate conditions provides an incomplete picture. Transnational climate exposures can constitute a significant and often underappreciated risk channel, underscoring the relevance of formally incorporating spillovers in climate-related economic analyses.

Figure 2: Country classification across national and transnational climate exposure (2022)



5.2.2 Rating impacts with international climate spillovers

While the spatial patterns presented in Figure 2 suggest that foreign climate spillovers may be an important and unevenly distributed source of risk, they do not yet quantify how such exposures translate into sovereign financing outcomes. Therefore, this section econometrically analyses the relevance of these climate exposure profiles.

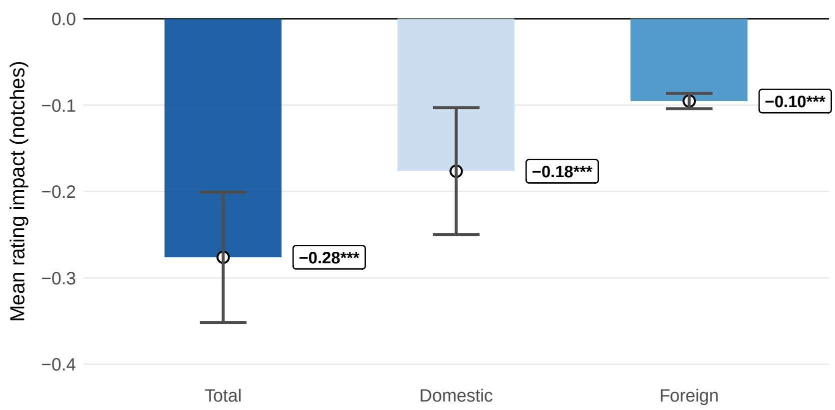
Table 3: Climate cluster sensitivities

Climate zone	Coefficient
Arid	-0.691*
	(0.408)
Continental	-0.053
	(0.137)
Temperate	-0.489**
	(0.197)
Tropical	0.421
	(0.360)
Controls	Yes
Country FE	Yes
Year FE	Yes
Observations	1,339
R^2	0.956

Notes: Averages with country-clustered standard errors in parentheses. Significance levels: * p<0.1; ** p<0.05; *** p<0.01

Figure 3 shows the aggregate total impact of temperature anomalies on sovereign credit ratings, derived from combining countries' temperature exposure and climate cluster sensitivities (Table 3). Temperature anomalies exert a statistically significant negative effect on sovereign credit ratings. A one-unit increase in temperature exposure reduces ratings by an average of 0.28 notches. This confirms that climate risk presents a relevant determinant of sovereign creditworthiness, with implications for borrowing costs and long-term fiscal stability. Domestic climate risk, capturing temperature increases within a country's borders, reduces sovereign ratings by 0.18 notches on average. Foreign climate risk transmitted through global value chain linkages yields an additional downgrade of 0.10 notches. While smaller in magnitude than the domestic channel, the foreign spillover component represents a sizeable and economically meaningful mechanism through which climate impacts propagate across borders, accounting for approximately 35% of the total climate impact. Put differently, ignoring spillovers and focusing on local impacts alone implies an underestimation of total climate impacts by over one third. Critically, the domestic and spillover impacts are statistically different from one another, indicating that they operate as distinct risk mechanisms rather than mere manifestations of a common climate factor. The larger magnitude of domestic impacts aligns with intuition. Countries face more severe consequences from climate change within their own territories, where the major share of economic value-added is generated and physical climate stress directly affects economic output and fiscal conditions. Nevertheless, the non-negligible spillover effects demonstrate that climate transcends national boundaries, creating international propagation along trade and production networks that amplify vulnerabilities beyond what domestic conditions alone would predict. For robustness, we run an alternative data-driven approach to clustering climate zones for deriving sensitivity parameters where the number and composition of clusters is based on minimized within-cluster variance of temperature anomalies. While the magnitude of individual impacts varies slightly, overall direction and significance of results holds. Further, we run a specification excluding the heterogeneity in climate sensitivities, which closely aligns with the estimated total impact.[14]

Figure 3: Aggregate temperature impact on ratings



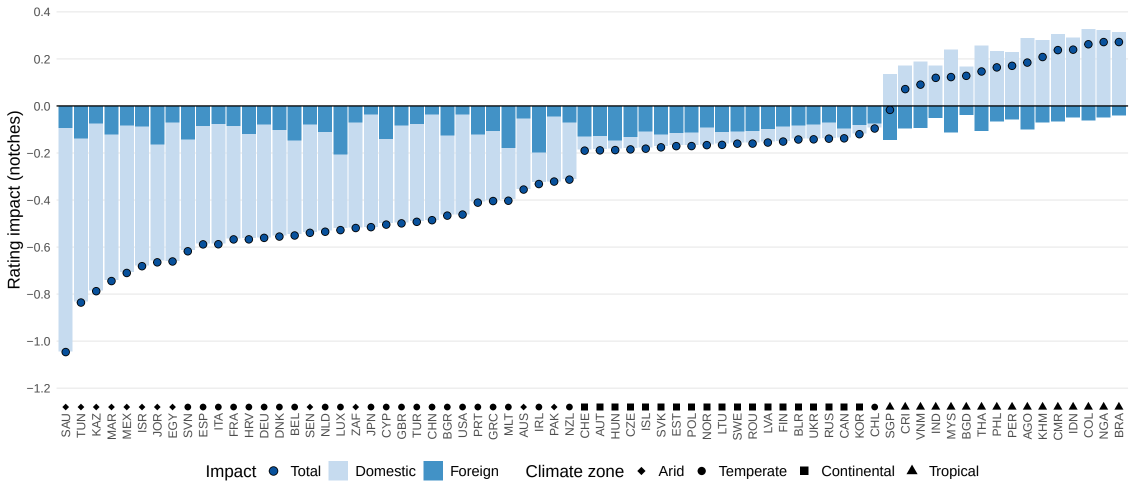
Notes: Mean effect of a one-unit increase in temperature anomaly on sovereign credit ratings for the full sample. Error bars show 95% confidence intervals and point estimates with significance levels * p<0.1; ** p<0.05; *** p<0.01

Providing a more granular perspective, we move beyond pooled averages to reveal cross-country heterogeneity. At the country level, climate impacts on sovereign creditworthiness exhibit substantial heterogeneity in both magnitude and compositional

[14]See Appendix B.4 for details

structure (Figure 4). Total climate-induced rating effects range from downgrades exceeding one full notch to modest upgrades, reflecting cross-country variation in physical climate exposure and vulnerabilities, economic structures, and network positions within global value chains. For the large majority of countries, climate change exposure reduces creditworthiness, with total impacts concentrated between -0.15 and -0.60 notches. Countries exhibiting the largest absolute impacts, predominantly located in arid and temperate climate zones, experience downgrades driven primarily by domestic exposure. For example, Mexico and Tunisia face domestic channel losses of about -0.65 notches, with foreign channels contributing "only" an additional 0.10 notch downgrade. So, the most severe consequences tend to materialize locally in countries that are hotter and drier to begin with, suggesting that a marginal temperature rise represents a relatively larger burden in arid regions.

Figure 4: Decomposition of country-level impacts by domestic and spillover channels



Notes: Impact of a one-unit increase in temperature anomaly on sovereign credit ratings by country, disentangled by domestic and foregn (spillover) impact channels.

Disentangling domestic and foreign channels reveals systematic patterns through which climate risk transmits to sovereign financing conditions. The foreign exposure share provides a perspective on sovereign vulnerability to transnational climate risk. The relative contribution of spillovers varies markedly across countries, accounting for less than 10% for countries such as Japan or Saudi Arabia, while more than 70% for countries like Hungary or Switzerland. This demonstrates differences in economic diversification, trade openness, and structural dependency on and integration with climate-vulnerable counterparts. Countries in the highest quartile of foreign share are predominantly small, highly open, and often European, economies. For example, Ireland and Luxembourg experience spillover impacts of around -0.2 notches, accounting for a large share of total impacts, reflecting their strong reliance on global production and financial networks, as well as concentrated bilateral linkages to other major EU economies such as Germany or France. For these economies, climate-induced stress in key trade partners presents greater risks than local physical exposures, highlighting how spillovers transform the scale and geography of climate risk. A subset of emerging economies with tropical climate exhibit moderate positive total impacts. These regions tend to experience high levels and variability of humidity and rainfall from distinct wet and dry seasons, which might make them less vulnerable to temperature rises and more resilient to incremental changes in climate patterns.

Overall, findings highlight that ignoring climate risk spillovers by focusing on local impacts alone can lead to a systemic underestimation of total risk exposure, particularly for highly globalized economies. This implies that for such countries, diversification away from climate-sensitive trade partners and supply chain resilience building can be an important risk mitigation option. It also suggests that climate adaptation requires coordinated international action. Individual countries strengthening domestic resilience will achieve limited protection if partner countries remain vulnerable. Put differently, the existence of economically relevant spillover impacts turns adaptation from a local into a global challenge. Thus, sovereign risk assessments must incorporate global spillover effects alongside traditional country-level indicators, and policymakers seeking to preserve creditworthiness in a warming world must consider both strengthening resilience to domestic impacts and managing exposures to climate-vulnerable external economies.

6 Conclusion

This paper contributes to the literature on climate risk and public finance by investigating how physical climate impacts, both from domestic and foreign sources, affect sovereign financing conditions. While previous research has established that local (i.e., domestic) climate vulnerability poses material risks to public finances, evidence on the cross-border transmission of climate impacts and their implications for sovereign risk remains extremely scarce. We address this gap by empirically investigating an expanded set of climate indicators and by conceptualizing, constructing, and quantifying climate spillovers transmitted through global economic linkages.

Our analysis yields three key results. First, local temperature anomalies and drought conditions exhibit significant negative and heterogeneous relationships with sovereign credit ratings, with a one-unit increase associated with a 0.2 notch downgrade. Precipitation shows no effect, suggesting that sovereign risk assessments mainly consider economic vulnerabilities from warming and water scarcity. Second, incorporating spillovers from foreign climate exposure increases the aggregate total impact to -0.28. Put differently, ignoring climate spillovers underestimates total climate risk by 36% on average, compared to the local-only baseline. Countries in arid and temperate climate zones experience the largest impacts of up to a full notch downgrade. Third, for more than 40% of countries, spillovers even exceed domestic impacts. In some smaller, highly globalized, and often European economies such as Hungary, Ireland, or Switzerland, spillovers contribute up to 80% of total climate impacts. These results demonstrate that ignoring international climate risk propagation may lead to systematic underestimation of climate risk, with consequences for optimal policy responses, fiscal planning, and asset valuation.

Findings carry important implications. For financial authorities and investors seeking to integrate climate risk into regulatory frameworks and investment decisions, our results underscore the necessity of expanding analytical tools beyond local mechanisms. For policymakers, effective climate risk mitigation strategies require a dual approach: strengthening domestic adaptation and resilience while simultaneously enhancing strategic trade diversification, supply chain flexibility, and coordinated global adaptation efforts to weather-proof public finances against both local and global climate shocks. Several avenues merit further investigation, such as extending the analysis to additional transmission mechanisms, examining temporal dynamics and non-linearity of spillovers, and modeling fiscal costs and benefits of adaptation investments.

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Appendix

A. Data

A.1 Credit rating conversion scheme

Table 4: Ratings converting scheme

S&P	Moody's	Fitch	Value
AAA	Aaa	AAA	21
AA+	Aa1	AA+	20
AA	Aa2	AA	19
AA-	Aa3	AA-	18
A+	A1	A+	17
A	A2	A	16
A-	A3	A-	15
BBB+	Baa1	BBB+	14
BBB	Baa2	BBB	13
BBB-	Baa3	BBB-	12
BB+	Ba1	BB+	11
BB	Ba2	BB	10
BB-	Ba3	BB-	9
B+	B1	B+	8
B	B2	B	7
B-	B3	B-	6
CCC+	Caa1	CCC+	5
CCC	Caa2	CCC	4
CCC-	Caa3	CCC-	3
CC C CI	Ca	CC C	2
R SD D	C	D	1
NR		NR	–

A.2 Climate variable construction

Mean temperature:

$$TM_{x,y} = \frac{1}{D_y} \sum_{d=1}^{D_y} T_{x,d,y} \tag{7}$$

Temperature anomaly:

$$TA_{x,y} = T_{x,y} - \frac{1}{N_{1951:1980}} \sum_{y'=1951}^{1980} TM_{x,y} \tag{8}$$

Daily temperature variability:

$$TV_{x,y} = \frac{1}{12} \sum_{m=1}^{12} \sqrt{\frac{1}{D_m} \sum_{d=1}^{D_m} \left(T_{x,d,m,y} - \bar{T}_{x,m,y}\right)^2} \tag{9}$$

Total precipitation:

$$PT_{x,y} = \sum_{d=1}^{D_y} P_{x,d,y} \tag{10}$$

Extreme daily precipitation:

$$\text{Pext}_{x,y} = \sum_{d=1}^{D_y} H(P_{x,d} - P99.9_x) \times P_{x,d} \tag{11}$$

Number of wet days (P > 1mm):

$$\text{Pwd}_{x,y} = \sum_{d=1}^{D_y} H(P_{x,d} - 1\text{mm}) \tag{12}$$

Standardised monthly precipitation deviations:

$$\text{RM}_{x,y} = \sum_{m=1}^{12} \frac{R_{x,m,y} - \bar{R}_{x,m}}{\sigma_{x,m}} \frac{\bar{R}_{x,m}}{\text{RA}_r} \tag{13}$$

Mean SPEI:

$$SPEI_{x,y} = \frac{1}{D_y} \sum_{d=1}^{D_y} SPEI_{x,d,y} \tag{14}$$

A.3 Sample countries and climate zone clusters

Table 5: Sample countries (based on IMF classification)

Advanced economies		Emerging economies	
Australia (AUS)	Japan (JPN)	Angola (AGO)	Malaysia (MYS)
Austria (AUT)	Korea (KOR)	Argentina (ARG)	Mexico (MEX)
Belgium (BEL)	Latvia (LVA)	Bangladesh (BGD)	Morocco (MAR)
Canada (CAN)	Lithuania (LTU)	Belarus (BLR)	Nigeria (NGA)
Croatia (HRV)	Luxembourg (LUX)	Brazil (BRA)	Pakistan (PAK)
Cyprus (CYP)	Malta (MLT)	Bulgaria (BGR)	Peru (PER)
Czechia (CZE)	Netherlands (NLD)	Cambodia (KHM)	Philippines (PHL)
Denmark (DNK)	New Zealand (NZL)	Cameroon (CMR)	Poland (POL)
Estonia (EST)	Norway (NOR)	Chile (CHL)	Romania (ROU)
Finland (FIN)	Portugal (PRT)	China (CHN)	Russia (RUS)
France (FRA)	Singapore (SGP)	Colombia (COL)	Saudi Arabia (SAU)
Germany (DEU)	Slovak Republic (SVK)	Costa Rica (CRI)	Senegal (SEN)
Greece (GRC)	Slovenia (SVN)	Côte d'Ivoire (CIV)	South Africa (ZAF)
Iceland (ISL)	Spain (ESP)	Dem. Rep. of Congo (COD)	Thailand (THA)
Ireland (IRL)	Sweden (SWE)	Egypt (EGY)	Tunisia (TUN)
Israel (ISR)	Switzerland (CHE)	Hungary (HUN)	Türkiye (TUR)
Italy (ITA)	United Kingdom (GBR)	India (IND)	Ukraine (UKR)
	United States (USA)	Indonesia (IDN)	United Arab Emirates (ARE)
		Jordan (JOR)	Vietnam (VNM)
		Kazakhstan (KAZ)	
		Laos (LAO)	

Table 6: Country classification by Köppen-Geiger climate zones (main class codes)

Tropical (A codes)	Arid (B codes)	Temperate (C codes)	Continental (D codes)
Angola (AGO)	Australia (AUS)	Argentina (ARG)	Austria (AUT)
Bangladesh (BGD)	Egypt (EGY)	Belgium (BEL)	Belarus (BLR)
Brazil (BRA)	Israel (ISR)	Bulgaria (BGR)	Canada (CAN)
Cambodia (KHM)	Jordan (JOR)	Chile (CHL)	Czechia (CZE)
Cameroon (CMR)	Kazakhstan (KAZ)	China (CHN)	Estonia (EST)
Colombia (COL)	Morocco (MAR)	Croatia (HRV)	Finland (FIN)
Costa Rica (CRI)	Mexico (MEX)	Cyprus (CYP)	Hungary (HUN)
Côte d'Ivoire (CIV)	Pakistan (PAK)	Denmark (DNK)	Iceland (ISL)
Dem. Rep. of Congo (COD)	Saudi Arabia (SAU)	France (FRA)	Korea (KOR)
Indonesia (IDN)	Senegal (SEN)	Germany (DEU)	Latvia (LVA)
India (IND)	South Africa (ZAF)	Greece (GRC)	Lithuania (LTU)
Laos (LAO)	Tunisia (TUN)	Ireland (IRL)	Norway (NOR)
Malaysia (MYS)	United Arab Emirates (ARE)	Italy (ITA)	Poland (POL)
Nigeria (NGA)		Japan (JPN)	Romania (ROU)
Peru (PER)		Luxembourg (LUX)	Russia (RUS)
Philippines (PHL)		Malta (MLT)	Slovak Republic (SVK)
Singapore (SGP)		Netherlands (NLD)	Sweden (SWE)
Thailand (THA)		New Zealand (NZL)	Switzerland (CHE)
Vietnam (VNM)		Portugal (PRT)	Ukraine (UKR)
		Slovenia (SVN)	
		Spain (ESP)	
		Türkiye (TUR)	
		United Kingdom (GBR)	
		United States (USA)	

B. Additional heterogeneity and robustness results

B.1 Quantile analysis

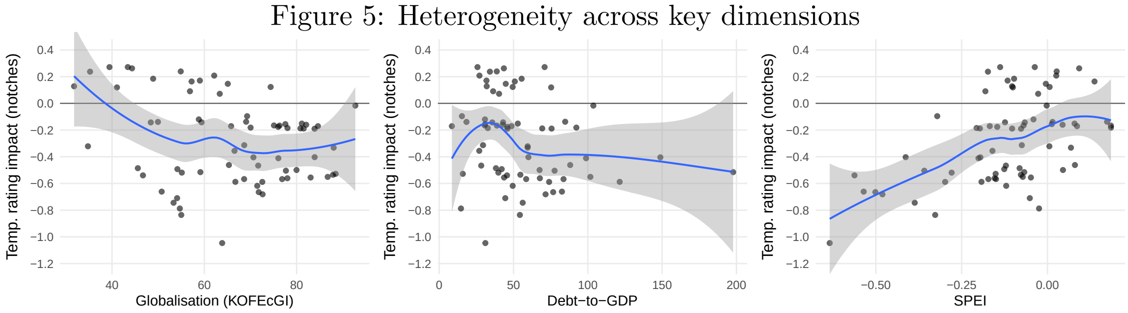
Table 7: Quantile regression results - Local climate

	Dependent variable: Sovereign credit rating								
	Q10	Q20	Q30	Q40	Q50	Q60	Q70	Q80	Q90
T Anom.$_{t-1}$	−0.157**	−0.145**	−0.163***	−0.147**	−0.131**	−0.037	−0.019	−0.032	−0.016
	(0.064)	(0.059)	(0.059)	(0.062)	(0.066)	(0.067)	(0.058)	(0.057)	(0.052)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
FE (time)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
FE (country)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1340	1340	1340	1340	1340	1340	1340	1340	1340
R^2	0.84	0.83	0.83	0.83	0.82	0.83	0.83	0.83	0.81

Notes: Averages by quantiles with country-clustered bootstrapped standard errors in parentheses. Significance levels: * p<0.1; ** p<0.05; *** p<0.01

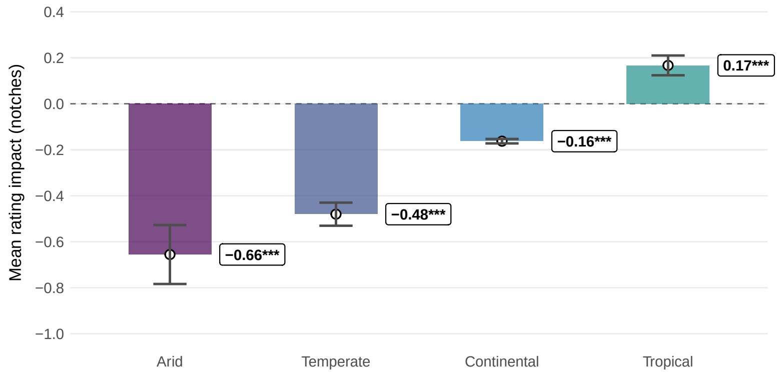
B.2 Total impact relationship with key dimensions

Figure 5: Heterogeneity across key dimensions



B.3 Total impact heterogeneity across climate zones

Figure 6: Temperature impact on ratings by climate zones



Notes: Mean effect of a one-unit increase in temperature anomaly on sovereign credit ratings by climate zone cluster. Error bars show 95% confidence intervals and point estimates with significance levels * p<0.1; ** p<0.05; *** p<0.01

B.4 Global specification excluding heterogeneous climate sensitivities

As a robustness test to the main model which assigns climate sensitivities to countries based on climate cluster-level estimation, we run an alternative specification without the sensitivity parameter:

$$Y_{i,t} = \tilde{\beta}_0 + \tilde{\beta}_1 \left(\mathrm{NCE}_{i,t-1} + \mathrm{TCE}_{i,t-1} \right) + \tilde{\beta}_3 \, Z_{i,t-1} + \gamma_t + \alpha_i + \varepsilon_{i,t} \tag{15}$$

Results (Table 8) show that the coefficient for total temperature impact (sum of NCE and TCE) is -0.26 and significant. This aligns with the total impact (-0.28) estimated in the main findings in Section 5.2.2, confirming the identified relationship between temperature deviations and ratings also with sensitivity parameter exclusion.

Table 8: Total impact without climate sensitivity parameter

	Rating impact
Total T Anom.$_{t-1}$ (NCE + TCE)	−0.260***
	(0.089)
log GDP percap$_{t-1}$	2.892***
	(0.681)
GDP growth$_{t-1}$	0.019
	(0.026)
Debt/GDP$_{t-1}$	−0.046***
	(0.005)
Curr.acc./GDP$_{t-1}$	−0.015
	(0.015)
CPI$_{t-1}$	−0.033**
	(0.017)
Unemployment$_{t-1}$	−0.184***
	(0.040)
Political stability$_{t-1}$	1.070***
	(0.335)
FE (time)	Yes
FE (country)	Yes
Observations	1340
R^2	0.57

Notes: Averages with country-clustered SE in parentheses. Total T Anom. is total temperature exposure weighted by value added dependency (NCE + TCE). Explanatory variables are lagged by one year. Significance levels: * p<0.1; ** p<0.05; *** p<0.01