Migrant Remittances and Sovereign Credit Risk: Insuring Consumption Against Disasters*

Harrison Hong
Columbia University and NBER

Jose Scheinkman
Columbia University and NBER

Jiangmin Xu
Peking University

April 2026

Abstract

Migrant remittances, an annual trillion-dollar flow, reduce the sensitivity of sovereign credit risk to disasters in vulnerable countries. We find that while weather disasters significantly lower credit ratings and raise sovereign yields, consumption remains stable and governments do not increase borrowing. Remittances are *anticipatory*: they increase with disasters, especially when perceived disaster risk is high. A sovereign-default model with disaster risk and remittances rationalizes this: remittances, by smoothing consumption, lower optimal debt issuance and mute disaster-driven increases in yields. Consistent with the model, sovereign yields respond far less to disasters when perceived risk is high. A calibration suggests that yields would be meaningfully higher following disasters absent anticipatory remittances.

*We thank seminar participants at Peking University Guanghua Conference and COP30 Advisory Council. Hong acknowledges financial support from a Guggenheim Fellowship.

1 Introduction

Sovereign debt stability is increasingly threatened by the rising frequency and intensity of weather disasters. These shocks destroy infrastructure, depress output, and strain public finances (Dell et al., 2012; Hsiang and Jina, 2014). As they become more frequent and severe due to climate change (National Academies of Sciences, Engineering, and Medicine, 2016), investors demand higher yields on sovereign bonds and credit-rating agencies downgrade exposed sovereigns, amplifying fiscal stress precisely when governments most need financing for recovery (Barrage, 2024). These vulnerabilities are most acute in developing economies with limited tax capacity, large informal sectors, and rising debt burdens. A central challenge in understanding sovereign vulnerability to these large, negative shocks is identifying the private channels that offset their financial effects.

Migrant remittances, which globally reached near $905 billion annually in 2024, are a natural candidate, yet their macro-financial implications for sovereign credit risk remain poorly understood. For economies vulnerable to disasters, remittances constitute a significant and counter-cyclical source of foreign exchange, averaging over five percent of GDP in our sample. This paper provides the first systematic evidence that these private transfers attenuate the adverse impact of weather disasters on sovereign credit risk, and that this attenuation operates through anticipatory remittance responses to perceived disaster risk.

To ground this analysis, we assemble a global panel combining data on tropical cyclones (58 countries) and heatwaves (113 countries) from 1980 to 2019 with sovereign credit indicators, remittance flows, and macroeconomic variables. We document three sets of empirical findings.

First, we find, as in the literature, that weather disasters raise sovereign credit risk. Panel event studies show that cyclones increase government bond yields by 56 basis points within one year and trigger credit-score downgrades of 0.6 notches on impact. Heatwaves produce comparable effects: yields rise by 62 basis points and credit scores fall by 0.6 notches. These are economically meaningful deteriorations in sovereign creditworthiness.

Second, remittances provide a private consumption-smoothing margin. Despite these clear fiscal pressures, consumption growth shows no significant response to either disaster type, and governments do not systematically increase borrowing. Instead, real remittances surge: remittance growth increases by approximately 5 percentage points one year after a cyclone and after a heatwave. The fact that consumption is fully insured despite no additional public borrowing implies that private transfers are doing substantial work in smoothing household welfare.

Third, and most importantly, the remittance response to disasters is *anticipatory*: it is

larger when perceived disaster risk is high. Using the Poisson mixture intensity (PI) model of Hong et al. (2025) to measure time-varying disaster arrival rates, we regress real remittance growth on the disaster indicator interacted with perceived risk, controlling for country and year fixed effects. The elasticity of the remittance response with respect to perceived risk is positive and significant for both cyclones (+0.104, $t = 2.1$) and heatwaves (+0.087, $t = 4.1$). Migrant networks that have experienced elevated disaster risk maintain stronger and more responsive transfer channels, providing a larger consumption cushion when disasters strike.

To rationalize these facts, we introduce private transfers and disaster risk into the canonical sovereign default model for a small open economy (Eaton and Gersovitz, 1981; Arellano, 2008). Remittances flow only when a disaster strikes, but the size of the transfer depends on the perceived arrival rate: migrants send more when risk is high, reflecting the preparedness of diaspora networks. The model yields a sharp prediction: if the remittance response scales with perceived risk, the disaster-induced resource gap between disaster and non-disaster states shrinks when risk is elevated, reducing the marginal-utility spike that drives sovereign borrowing and default risk. Consequently, both government borrowing and sovereign yields should respond *less* to disasters when the perceived arrival rate is high. This prediction holds even if remittances arrive with a lag, because bond prices are forward-looking: lenders price in the expected future remittance inflow at the time of the disaster.

We test this prediction by interacting the disaster indicator with perceived risk in regressions of sovereign credit variables. The results confirm the model across all outcomes and both disaster types: the disaster-induced increase in debt growth, bond yields, and credit downgrades is significantly attenuated when perceived risk is high. The attenuation is large and precisely estimated—for example, cyclone-driven yield increases are reduced by more than half at elevated risk levels. Crucially, the model shows that this attenuation arises *if and only if* remittances are anticipatory—connecting the remittance response documented in our stylized facts directly to the sovereign credit attenuation.

A calibrated counterfactual quantifies the magnitude of the attenuation. Using the cyclone-event-weighted mean remittance ratio of 5.3% of GDP, we find that anticipatory remittances reduce the disaster premium on sovereign spreads by approximately 2%. Adjusting for informal remittances and using the remittance ratios of the high-risk countries that drive the identification (Haiti 10%, Indonesia 10%, Panama 12%), the attenuation rises to 16%, or 63 basis points. We view this as a conservative lower bound, since remittances are only one of several private adaptation channels.

Contributions and related literature. Our first contribution is to the literature on how climate and disaster risk shape sovereign credit risk (see Hong et al., 2020; Giglio et al.,

2021, for reviews). A growing body of work documents that climate damages are priced in sovereign debt: reduced-form panel studies find higher borrowing costs for climate-vulnerable sovereigns (Cevik and Jalles, 2022; Beirne et al., 2021), structural models imply large long-run effects (Barnett and Yannelis, 2024), and Klusak et al. (2023) projects one- to two-notch downgrades under unmitigated warming. Parallel findings for U.S. municipal bonds show that physical climate risks are capitalized into yields (Painter, 2020; Goldsmith-Pinkham et al., 2023). A closely related strand builds sovereign-default models with disasters: Mallucci (2022) introduces disaster risk into an Eaton–Gersovitz framework, Phan and Schwartzman (2024) analyzes catastrophe bonds and financial adaptation, and Duffy (2025) documents an "adaptation trap." Our paper differs by showing that the magnitude of the sovereign credit response depends crucially on a private-sector channel—migrant remittances—that the prior literature has not examined.

Second, we contribute to the literature on international risk sharing and the macro-financial role of remittances. Previous research shows that migrant remittances are stable and counter-cyclical, mitigating income and consumption shocks (Bettin et al., 2025), and that disasters prompt persistent migration responses that build diaspora networks (Mahajan and Yang, 2020; Missirian and Schlenker, 2017; Cattaneo and Peri, 2016). At the household level, Morten (2019) shows that temporary migration substitutes for informal risk sharing in rural India. We build on this work by showing that remittances also provide macro-financial insurance at the *sovereign* level: when remittances are anticipatory, they attenuate sovereign borrowing costs and credit deterioration following climate disasters.

Third, we connect these insights to the economics of climate adaptation and endogenous disaster risk. The idea that agents learn and adapt to repeated disasters is central to recent work (Hong et al., 2023a,b). A parallel literature emphasizes migration as a major adaptation margin: quantitative spatial models show that mobility reallocates population as climates shift (Cruz and Rossi-Hansberg, 2024; Desmet and Rossi-Hansberg, 2024; Bilal and Rossi-Hansberg, 2023), while reduced-form studies document that disasters trigger migration (Cattaneo and Peri, 2016; Hoffmann et al., 2024; Jessoe et al., 2017). By exploiting the non-i.i.d. Poisson nature of disaster arrivals following Hong et al. (2025), we show that as climate-disaster risk intensifies, remittance inflows respond more strongly to new events while sovereign credit risk becomes less sensitive—evidence that remittances finance effective private adaptation. Our framework thus integrates fiscal fragility, migration, and adaptation into a unified macro-financial perspective on climate resilience.

Policy implications. Our results have several implications for financial and fiscal policy. First, migration and remittances—central to this private insurance mechanism—are under

policy pressure, from anti-immigration initiatives to proposals to tax remittances. Our estimates suggest that the anticipatory remittance channel substantially attenuates the sovereign yield response to climate shocks. Policies that restrict migration or raise transfer costs may unintentionally weaken one of the most effective buffers available to vulnerable economies. Second, sovereign risk assessments should account for diaspora connections. Countries with strong remittance channels are more resilient to climate disasters, and this resilience should be reflected in credit ratings and debt sustainability analyses. Third, new financial instruments such as debt-for-climate swaps should consider the existing private insurance channel. Countries with large diaspora networks may need less debt relief, since anticipatory remittances already partially cushion the fiscal impact of disasters.

2 Data

We assemble a country-level annual panel spanning 1980–2019 that combines data on extreme-weather events, migrant remittances, sovereign credit risk, and standard macroeconomic indicators. This section describes each data source, discusses the construction of key variables, documents secular trends that motivate our empirical framework, and reports summary statistics.

2.1 Extreme Weather

We consider two widely-studied extreme-weather events: tropical cyclones and abnormal summer temperatures. The two types of disasters differ in geographic reach, frequency, and the economic channels through which they operate, providing complementary tests of our hypotheses.

Tropical cyclones. Cyclone data come from the International Best Track Archive for Climate Stewardship (IBTrACS), the most comprehensive global database for tropical cyclone observations. Following Hsiang and Jina (2014), the sample is restricted to countries with geographic exposure to tropical cyclones—that is, countries that have experienced at least one landfall of tropical-storm strength or higher in the IBTrACS record. This geographic restriction is important: it ensures that the "control" periods within each country are years in which a cyclone *could have* struck but did not, rather than years in a country that never faces cyclone risk. For geographically large countries such as the United States, China, and Canada, we further restrict to eastern regions most prone to cyclone landfall to avoid diluting the treatment effect with large areas that are unaffected by cyclones.

Our cyclone sample covers 58 countries from 1980 to 2019 with 2,320 country-year observations. We define $\text{Landfall}_{i,t}$ as an indicator equal to one if country i experienced at least one tropical-storm-strength or higher landfall in year t. The unconditional arrival rate is 0.30 per annum—a typical country in the sample is struck roughly once every 3.4 years. Because cyclone exposure requires a coastline in the tropics or subtropics, this sample is considerably smaller than the heatwave sample described below and excludes landlocked and high-latitude countries entirely.

Heatwaves. Temperature data come from Willmott and Matsuura (2018), providing 0.5-degree gridded monthly averages for all land areas over 1900–2017, supplemented by Berkeley Earth data for 2018–2019. Following Burke et al. (2015), we aggregate grid-cell temperatures to the country-month level using year-2000 population weights from the Gridded Population of the World, then compute country-year averages. A heatwave is defined as a year in which mean summer temperature exceeds historical summer norms by more than 1°C.

Because nearly every country can experience an anomalously hot summer, the heatwave sample is substantially broader than the cyclone sample, covering 113 countries from 1980 to 2019 with 4,520 country-year observations. Of these, 48 countries overlap with the cyclone sample; the remaining 65 are primarily landlocked, interior, or non-tropical countries (e.g., in Europe, Central Africa, and South America) that face heat risk but not cyclone risk. The unconditional heatwave arrival rate is 0.25 per annum, meaning a typical country experiences a heatwave roughly once every four years.

The two disaster types thus provide variation along different margins. Cyclones are acute, localized events with immediate physical destruction; heatwaves are diffuse, affecting agriculture, labor productivity, and health over broader areas and longer durations. Their distinct geographic footprints allow us to test whether the remittance-insurance mechanism operates across qualitatively different climate shocks.

Figure 1 plots the annual share of bond-yield countries affected by each disaster type. Because our sovereign-credit identification operates on this subsample, we restrict the figure to countries with both bond-yield data and disaster exposure. Heatwave incidence in this intersection rises sharply from near zero in the early 1980s to roughly 40% by the late 2010s, consistent with the climate-science consensus on intensifying heat extremes (National Academies of Sciences, Engineering, and Medicine, 2016). Cyclone incidence is higher and flatter, hovering at 35–40% per annum—consistent with evidence that cyclone *counts* have not trended even as individual storm intensity has risen (Knutson et al., 2020). The divergence implies that heatwaves contribute a growing share of the climate-disaster burden over our sample period, especially for the financially integrated economies whose sovereign credit

we analyze.

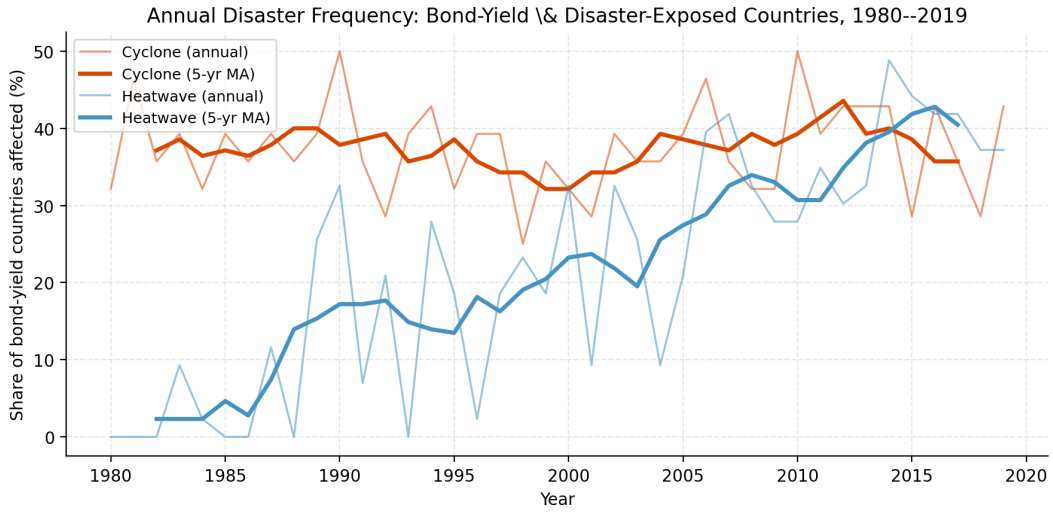


Figure 1: Annual Disaster Frequency: Bond-Yield & Disaster-Exposed Countries

Notes: Share of countries in the intersection of the bond-yield subsample and the cyclone or heatwave samples experiencing at least one cyclone landfall (orange) or a heatwave (blue) in each year. Heavy lines show 5-year centered moving averages.

2.2 Migrant Remittances and Macroeconomic Variables

Country-level annual data on migrant remittances, GDP, consumption, government debt, inflation, unemployment, current account balances, and population growth come from the World Bank Development Indicators. Long-term government bond yields are sourced from LSEG Datastream. Sovereign credit ratings from S&P Global are converted to a numerical score from 0 (D) to 20 (AAA).

Several variables require construction or transformation. Remittances-to-GDP is the ratio of personal remittance receipts to nominal GDP, expressed in percentage points. Real remittance growth is computed as the log change in remittances deflated to constant 2015 USD. Real debt growth is computed analogously for central government debt. Consumption growth is the log change in real household final consumption expenditure per capita. Inflation is winsorized at the 5th and 95th percentiles to limit the influence of hyperinflationary episodes. All growth rates and first-differenced variables are winsorized at the 1st and 99th percentiles unless otherwise noted.

2.3 Summary Statistics

Table 1 reports summary statistics. We organize the table into two panels: Panel A covers the full sample of 113 countries for which we observe both disaster arrivals and remittance data, while Panel B focuses on the subset of countries with sovereign credit risk data. The main analysis focuses on tropical cyclones (58 countries), the canonical climate disaster in the sovereign credit literature; we present heatwave results (113 countries) as a robustness check in the Appendix.

Panel A: Full sample. The heatwave arrival indicator has a mean of 0.25, confirming that roughly one quarter of country-years in the sample experience an abnormally hot summer. The cyclone arrival rate, computed over the 58-country cyclone subsample, is slightly higher at 0.30.

Turning to remittances, the mean remittances-to-GDP ratio is 5.1% with a standard deviation of 9.2%, reflecting substantial cross-country heterogeneity. The median of 2.2% is well below the mean, indicating a right-skewed distribution: a small number of highly remittance-dependent economies (such as Tonga, Haiti, and Nepal, where remittances can exceed 20% of GDP) pull the mean upward. The 10th percentile is just 0.27%, capturing countries with modest diaspora populations, while the 90th percentile reaches 11.5%. Real remittance growth averages 5.9% per annum (standard deviation 8.8%), with a median of 5.7% and a relatively tight interquartile range, indicating steady growth in remittance flows across most countries.

Consumption-to-GDP averages 66.9%, with considerable spread (standard deviation 16.3%) reflecting differences in savings rates and government spending shares across developing and developed economies. Consumption growth averages 3.3% per annum, with a standard deviation of 7.7% that reflects the volatility of household spending in developing economies.

Mean GDP per capita is \$11,700 in constant 2015 USD, but the distribution is highly skewed: the 10th percentile is just \$540 (reflecting the poorest countries in Sub-Saharan Africa and South Asia) while the 90th percentile is \$36,300 (capturing high-income OECD economies). This enormous heterogeneity—a 67-fold ratio between the 10th and 90th percentiles—underscores the importance of country fixed effects in our empirical specifications. GDP growth averages 3.2% with a standard deviation of 6.0%. Inflation averages 9.2% (after winsorization) with a standard deviation of 10.4%, and a median of 5.5% that is well below the mean, again reflecting a right-skewed distribution driven by emerging-market economies with historically higher price growth. Unemployment averages 7.9%, though this variable is available for only 2,474 of the 4,520 country-years, reflecting limited labor-market data in many developing economies. The current account-to-GDP ratio averages -2.7%, consis-

tent with the predominantly developing-country composition of the sample running modest external deficits. Population growth averages 1.8% with relatively low dispersion (standard deviation 1.7%).

Panel B: Sovereign credit risk subsample. Panel B reports variables that are available for progressively smaller subsets of countries. The mean credit score of 11.0 (roughly BBB−) with a standard deviation of 5.8 reflects the emerging-market composition of the sovereign-rated sample; 77 countries have S&P ratings, but coverage is unbalanced, with most emerging-market sovereigns first rated in the 2000s. The median of 11.0 confirms that the typical rated country in our sample sits at the lower end of investment grade.

Mean debt-to-GDP is 64.9% (standard deviation 55.7%), available for 65 countries. The wide dispersion—with a 10th percentile of 17.4% and a 90th percentile of 130.1%—reflects the coexistence of lightly indebted commodity exporters and heavily indebted small island states and post-crisis economies. Real debt growth averages 3.6% per annum with a standard deviation of 4.3%.

The mean government bond yield is 6.3% (standard deviation 5.1%), available for 43 countries with 1,114 observations. This is the most restrictive subsample, as long-term sovereign bond markets exist primarily in middle- and high-income countries. The 10th percentile yield of 0.14% captures advanced economies in the post-2008 low-rate environment, while the 90th percentile of 12.6% reflects emerging-market risk premia. The observation counts in Panel B—1,727 for credit scores, 1,221 for debt-to-GDP, 1,114 for bond yields—illustrate the trade-off between sample breadth and the availability of financial-market data that is central to our analysis.

Figure 2 plots the distribution of S&P long-term foreign-currency ratings across country-years in the intersection of the bond-yield subsample and the disaster-exposed sample. The distribution is bimodal, with mass at both ends of the rating scale: a cluster of advanced economies at AA and AAA (the upper tail includes Germany, France, Netherlands, Italy), and a cluster of emerging markets and speculative-grade sovereigns at B and BB. Observations below BBB− (speculative grade, shaded orange) account for roughly a quarter of the sample, confirming that our evidence on disaster-induced credit deterioration is drawn substantially from sovereigns whose ratings are genuinely at risk of material downgrades—not just countries with ratings too high to be affected by any realistic shock.

2.4 Sample Composition

Figure 3 summarizes the geographic and cross-country structure of the bond-yield subsample—the countries over which our sovereign-credit identification is executed. Panel (a) is a world

Table 1: Summary Statistics

	Mean	S.D.	Median	P10	P90	N
Panel A: Full sample (113 countries, 1980–2019)						
Heatwave arrival	0.250	0.433				4,520
Cyclone arrival (58 countries)	0.295	0.456				2,320
Remittances/GDP (%)	5.10	9.16	2.17	0.27	11.53	3,924
Remittances growth (%)	5.94	8.82	5.66	−0.38	11.84	3,813
Consumption/GDP (%)	66.91	16.26	65.84	47.14	87.52	4,108
Consumption growth (%)	3.34	7.71	3.22	−3.54	10.16	3,991
GDP per capita (thousands, 2015 USD)	11.69	17.51	3.60	0.54	36.26	4,485
GDP growth (%)	3.17	6.01	3.42	−1.46	7.99	4,461
Inflation (%)	9.23	10.41	5.47	0.07	28.18	4,460
Unemployment (%)	7.88	5.30	6.75	2.58	14.59	2,474
Current account/GDP (%)	−2.65	9.42	−2.70	−10.48	5.53	3,913
Population growth (%)	1.84	1.65	1.85	0.20	3.40	4,519
Panel B: Sovereign credit risk subsample						
Credit score (0–20, 77 countries)	10.98	5.83	11.00	2.00	19.00	1,727
Debt/GDP (%, 65 countries)	64.94	55.68	50.45	17.41	130.14	1,221
Debt growth (%, 65 countries)	3.63	4.29	3.80	−1.22	8.41	1,156
Bond yield (%, 43 countries)	6.31	5.11	5.53	0.14	12.64	1,114

Notes: The heatwave sample covers 113 countries observed annually from 1980 to 2019; the cyclone subsample covers 58 countries. Panel A reports statistics for the full sample. Remittances growth and debt growth are log changes in real (constant 2015 USD) values. Inflation is winsorized at the 5th and 95th percentiles. Panel B reports sovereign credit risk variables available for smaller subsets. Credit score maps S&P long-term foreign currency ratings to 0 (D)–20 (AAA). Bond yield is the long-term government bond yield from LSEG Datastream.

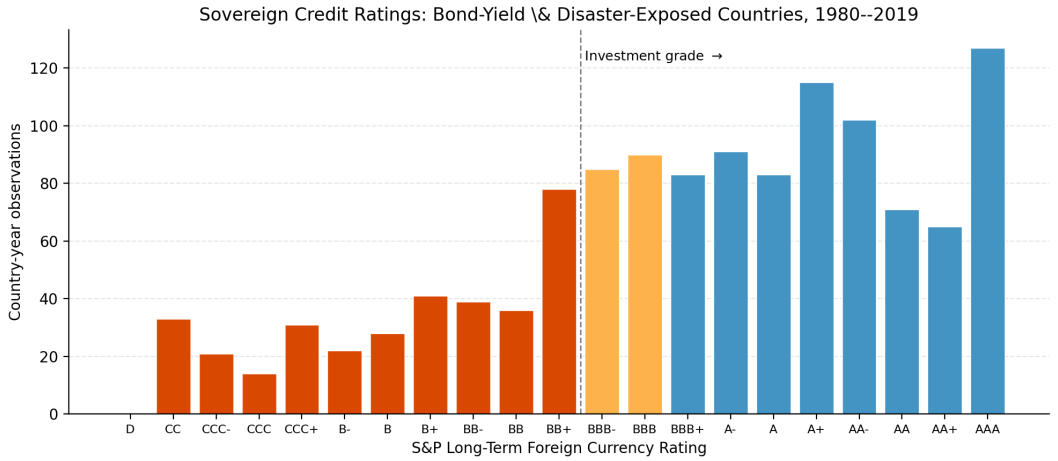


Figure 2: Sovereign Credit Ratings in the Bond-Yield & Disaster-Exposed Subsample

Notes: Country-year observations by S&P long-term foreign currency rating, mapped to a 0–20 numerical scale, restricted to countries in the intersection of the bond-yield subsample and the disaster-exposed (cyclone or heatwave) sample. Speculative-grade observations (below BBB−) are shaded orange; investment-grade observations are blue. The dashed line marks the investment-grade threshold.

map restricted to this subsample, classified by disaster exposure: roughly 21 countries in the bond-yield subsample are exposed to both cyclones and heatwaves (concentrated in South and Southeast Asia, the Americas, and parts of Sub-Saharan Africa), about 22 to heatwaves only (primarily European and interior economies), and about 7 to cyclones only (coastal East Asia and Oceania). Countries shaded grey are outside the bond-yield subsample. The map makes visible that the sovereign-credit identification draws on a geographically balanced but restricted set of countries with active long-term sovereign-debt markets.

Panel (b) ranks the top 25 countries in the *bond-yield subsample* by median remittances-to-GDP over 1980–2019. Restricting to the bond-yield subsample is informative because this is the set of countries over which our sovereign-credit identification is executed; it is useful for the reader to see where remittance heterogeneity comes from within that set. Jordan tops the list at roughly 31%, followed by Russia, Bangladesh, Indonesia, and Botswana. At the other end of the top 25 are advanced European economies (Spain, Italy, Lithuania) with median remittance ratios of 2–3%, and East Asian economies (China, Israel) near the bottom. For the high-dependence end of the distribution, remittances are comparable in magnitude to sizeable fiscal line items. The dispersion across bond-yield countries—from 2% to 30%—motivates our empirical strategy: the interaction effect of disasters with remittances will be identified primarily from the high-remittance tail of this distribution.

Panel (c) plots median remittances-to-GDP against the maximum disaster arrival rate (the higher of cyclone and heatwave) for each country in the bond-yield subsample, color-

coded by cyclone exposure. The scatter reveals a broadly positive association: countries with higher disaster arrival rates tend to have higher remittance inflows. Notably, the high-remittance, high-exposure quadrant contains several of the countries that drive our IV identification: Bangladesh, India, Indonesia, Philippines on the cyclone side, and Jordan, Russia, Botswana on the heatwave side. This cross-sectional correlation is consistent with a long-run equilibrium in which repeated disaster exposure builds diaspora networks and sustains remittance flows (Mahajan and Yang, 2020). It also foreshadows our identification strategy in Section 5: we use time-varying disaster risk as an instrument for remittances to isolate the component of remittance flows driven by disaster exposure.

2.5 Secular Trends

Figure 4 documents three secular trends that frame our analysis. Each panel plots time series separately for higher-income (average GDP per capita exceeding $15,000) and lower-income countries where relevant.

Rising sovereign debt (Panel a). Debt-to-GDP ratios have risen markedly since 1990, with a pronounced divergence between income groups. Lower-income countries saw median debt-to-GDP climb from below 40% in the early 1990s to above 50% by 2019, driven by a combination of commodity-price volatility, fiscal deficits, and—importantly for our analysis—the cumulative fiscal burden of repeated natural disasters. Higher-income countries experienced an even steeper rise in the aftermath of the 2008–2009 global financial crisis, with median ratios climbing from roughly 40% to above 60%. The secular upward trend in public debt implies that governments' fiscal capacity to absorb disaster shocks has been eroding over time, increasing the importance of alternative insurance channels.

Growing remittance flows (Panel b). Remittances-to-GDP have grown steadily over the four-decade sample, especially for lower-income countries, where the median roughly tripled from around 1% of GDP in the early 1980s to over 3.5% by 2019. For higher-income countries, remittance ratios remain low and flat (below 1% of GDP), reflecting smaller diaspora populations relative to domestic output. The divergent trajectories imply that remittances have become an increasingly important source of external financing precisely for the countries that are most fiscally constrained. This secular expansion reflects both growth in migrant stocks (driven by economic migration, conflict, and disaster-induced displacement) and reductions in the cost of cross-border transfers due to financial technology and regulatory reforms.

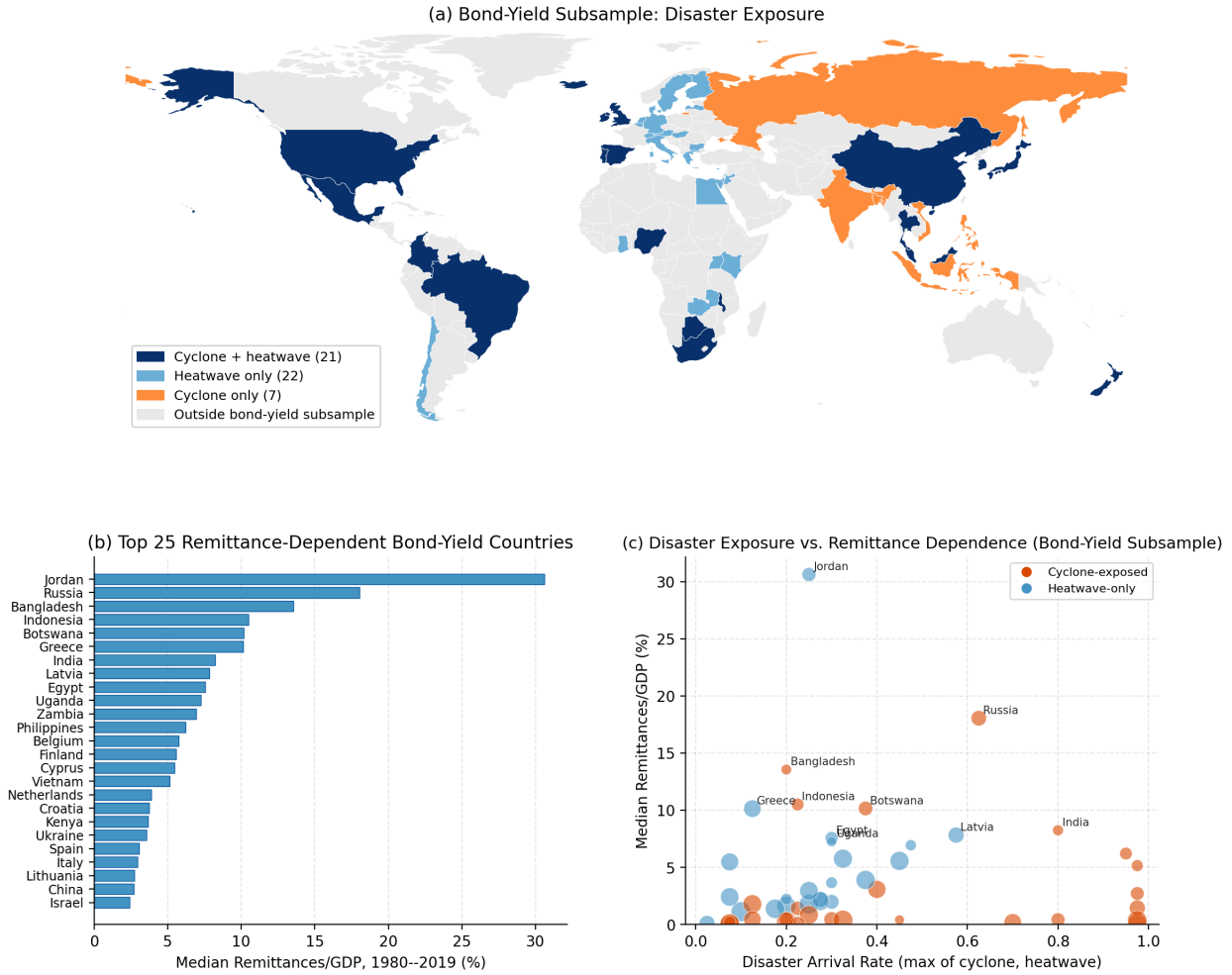


Figure 3: Sample Composition: Geographic Coverage, Remittance Dependence, and Disaster Exposure

Notes: All three panels are restricted to the bond-yield subsample—countries with long-term government bond yields available in LSEG Datastream. Panel (a) classifies each bond-yield country by disaster exposure: in both cyclone and heatwave samples (dark blue), heatwave only (medium blue), or cyclone only (orange). Countries outside the bond-yield subsample are shaded grey. Panel (b) ranks the top 25 bond-yield countries by median remittances-to-GDP over 1980–2019; Belize is excluded due to implausible reported values (more than 100% of GDP in later years). Panel (c) scatters country-level median remittances-to-GDP against the higher of cyclone and heatwave arrival rates for bond-yield countries, with labels for the most remittance-dependent observations.

Increasing disaster frequency (Panel c). The fraction of countries experiencing a heatwave in any given year rose from roughly 10% in the 1980s to over 40% by the late 2010s, a fourfold increase. This trend is consistent with the well-documented intensification of extreme heat events due to anthropogenic climate change (National Academies of Sciences, Engineering, and Medicine, 2016). The 5-year moving average in the figure smooths year-to-year variability and reveals a clear upward trend that accelerated after 2000. Cyclone frequency has not exhibited the same secular increase, consistent with the climate science literature that finds a less clear trend in cyclone counts even as individual storms have grown more intense.

Implications. These three trends are mutually reinforcing from a fiscal perspective. Rising disaster frequency strains public finances precisely as debt burdens grow, creating a fiscal "scissors" that limits governments' ability to borrow for adaptation and recovery. At the same time, the expansion of remittance flows provides a potential private insurance margin that grows in parallel with the fiscal need. Our empirical framework exploits the within-country time-series variation generated by these dynamics to identify the causal links between disaster arrivals, remittance responses, and sovereign credit outcomes.

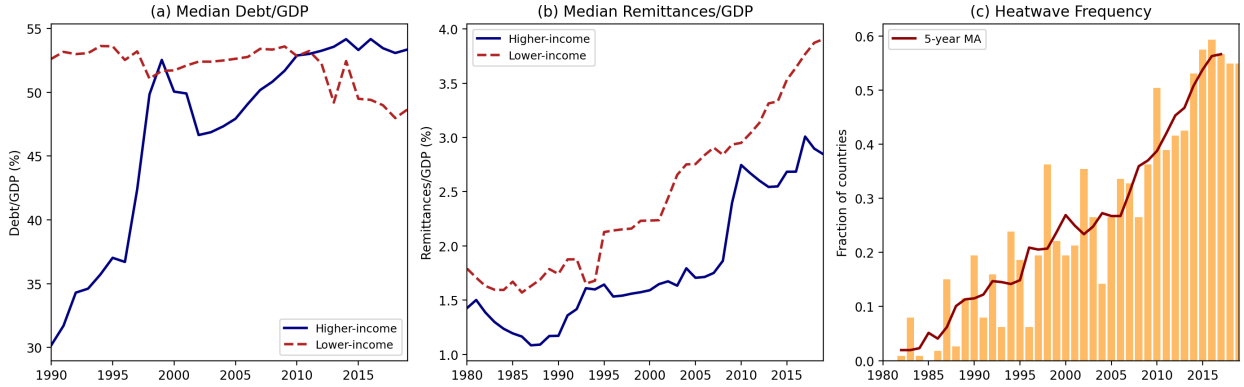


Figure 4: Secular Trends in Debt, Remittances, and Heatwave Frequency

Notes: Panel (a) plots median debt-to-GDP ratios for higher-income (average GDP per capita > $15,000) and lower-income countries in the heatwave sample, 1990–2019. Panel (b) plots median remittances-to-GDP ratios, 1980–2019. Panel (c) plots the fraction of sample countries experiencing a heatwave in each year, with a 5-year moving average. A heatwave is defined as mean summer temperature exceeding historical norms by more than 1°C.

Figure 5 provides a panel-level view of data availability. Each row is a country, each column a year, and the shading indicates which outcomes are observed. Coverage is most complete for weather and remittance variables (available for nearly all country-years from 1980 onward) and most restricted for bond yields and credit scores, which begin in the 1990s for most emerging markets. The visual makes clear that our sovereign-credit identification

exploits the subset of country-years in which financial-market data are available, while our event-study and risk-intensity analyses leverage the broader panel.

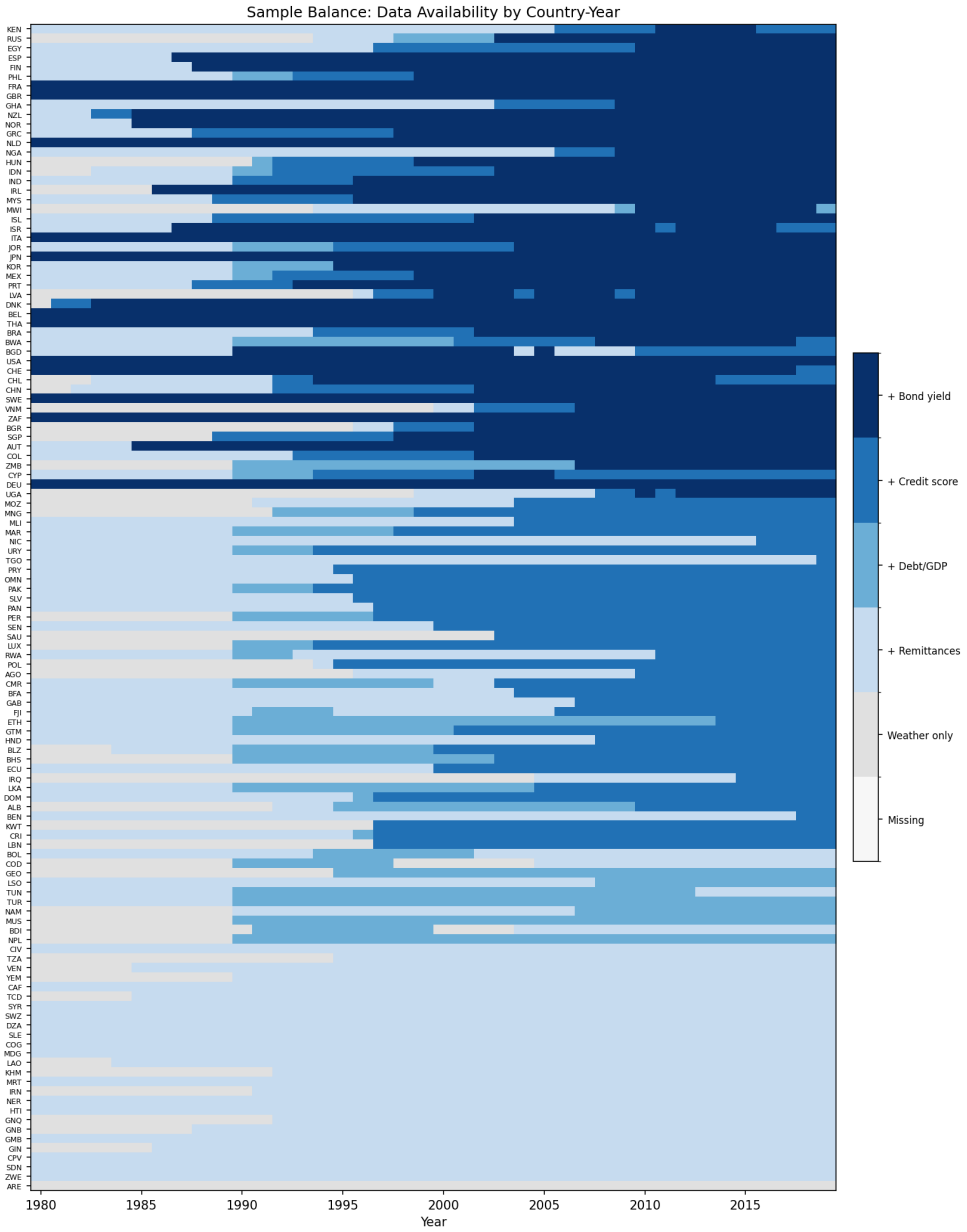


Figure 5: Sample Balance: Data Availability by Country and Year

Notes: Each row is a country in the sample (heatwave or cyclone), sorted by the deepest outcome available; each column is a year. Shading indicates the deepest variable observed: weather only, plus remittances, plus debt-to-GDP, plus credit score, plus bond yield.

3 Stylized Facts

3.1 Event Study of Climate Disasters on Macro-Financial Outcomes

We begin by documenting the dynamic macro-financial effects of climate disasters—tropical cyclones and heatwaves—on sovereign credit risk, consumption, government borrowing, and remittance inflows. Our goal is to establish three empirical regularities: (1) disasters increase sovereign credit risk; (2) consumption does not fall and governments do not increase borrowing; (3) remittances surge following disasters. Together, these facts motivate the theoretical mechanism developed in Section 4: remittances function as decentralized disaster insurance that stabilizes household consumption and reduces the fiscal burden on sovereign balance sheets.

To estimate these dynamic effects, we employ panel event studies. The specification takes the form:

$$\Delta Y_{it} = \sum_{k=-4,\, k\neq -1}^{3} \phi_k D_{it}^k + u_i + v_t + \epsilon_{it}, \tag{1}$$

where ΔY_{it} denotes the outcome of interest for country i in year t, and D_{it}^k is an indicator equal to one if t is k years from a disaster ($k = 0$ is the event year). We include country fixed effects u_i and year fixed effects v_t. The base period is $k = -1$. Standard errors are clustered by year.

Disasters increase sovereign credit risk. Figure 6 presents the dynamic response of sovereign credit indicators to both cyclone (blue) and heatwave (red) arrivals.

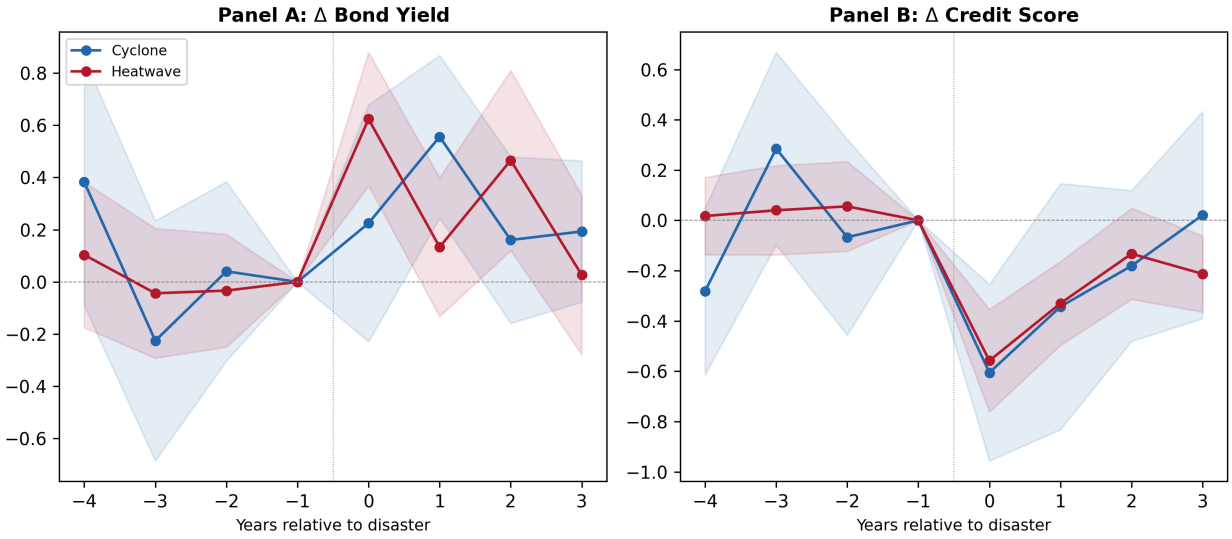
Bond yields (Panel A). Bond yields increase following both disaster types. For cyclones, the response peaks at $k = 1$ (+0.56 pp, $t = 3.5$), consistent with markets gradually incorporating the fiscal consequences of the storm. For heatwaves, yields rise sharply at $k = 0$ (+0.62 pp, $t = 4.8$) and again at $k = 2$ (+0.47 pp, $t = 2.7$). The faster heatwave response may reflect the more predictable nature of heat events relative to the acute onset of cyclones.

Credit scores (Panel B). Credit ratings decline following both disaster types. Cyclone-driven downgrades peak at $k = 0$ (-0.61 notches, $t = -3.4$) and persist at $k = 1$ (-0.34, $t = -1.4$). Heatwave-driven downgrades are also large and persistent: -0.56 at $k = 0$ ($t = -5.4$) and -0.33 at $k = 1$ ($t = -3.9$).

Consumption is insured; remittances surge. Figure 7 reports the corresponding responses for consumption growth, real government debt growth, and real remittance growth.

Figure 6: Dynamic Event Study: Changes in Sovereign Credit Risk

This figure plots estimates of ϕ_k from Equation (1). Blue: cyclone arrivals (58 countries). Red: heatwave arrivals (113 countries). The base period is $k = -1$. Shaded areas denote 95% confidence intervals based on clustered standard errors.



Consumption growth (Panel A). Despite the clear deterioration in sovereign credit conditions, consumption growth shows no significant response to either cyclones or heatwaves. Point estimates are centered around zero at all horizons. The absence of a consumption response is striking given the magnitude of the credit deterioration, and is consistent with a private insurance channel that transfers resources directly to households.

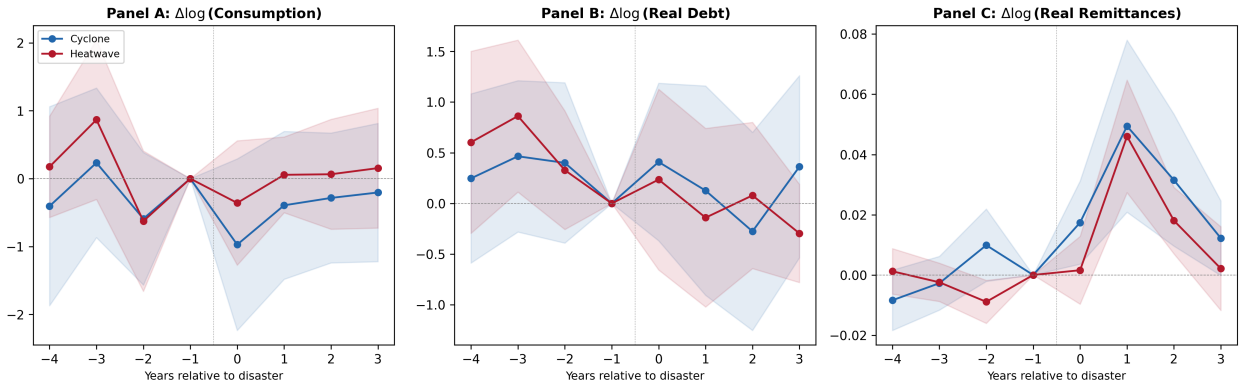
Real debt growth (Panel B). Debt growth shows no systematic post-event increase for either disaster type. Governments are *not* actively increasing borrowing after disasters, possibly because higher borrowing costs make new issuance prohibitively expensive.

Real remittance growth (Panel C). The key finding: real remittance growth increases sharply at $k = 1$ for both disaster types. For cyclones, remittances grow by 4.9 percentage points ($t = 3.4$); for heatwaves, by 4.6 percentage points ($t = 4.8$). The response persists at $k = 2$ for both disaster types (cyclone: +3.2%, $t = 2.8$; heatwave: +1.8%, $t = 3.2$). The one-year lag is consistent with the time required for diaspora networks to mobilize transfers.

Interpretation. The joint dynamics across Figures 6 and 7 reveal an important risk-sharing equilibrium between public and private sectors. When climate disasters strike, sovereign borrowing costs rise and creditworthiness declines, yet consumption remains stable and governments do not increase borrowing. The missing piece is remittances: private

Figure 7: Dynamic Event Study: Consumption, Debt Growth, and Remittances

This figure plots estimates of ϕ_k from Equation (1). Blue: cyclone arrivals. Red: heatwave arrivals. The base period is $k = -1$. Shaded areas denote 95% confidence intervals based on clustered standard errors.



transfers from migrant networks surge following disasters, supplying liquidity directly to households and reducing the need for public borrowing. This pattern holds for both cyclones and heatwaves, across 58 and 113 countries respectively, suggesting a robust and general mechanism.

3.2 Anticipatory Remittances: Time-Varying Risk and the Insurance Channel

The event studies document that remittances surge after both cyclones and heatwaves, peaking at $k = 1$. We now ask whether remittances are *anticipatory*—that is, whether the remittance response to disasters is larger when perceived risk is high. This is the key empirical input to the model developed in Section 4.

Measuring time-varying disaster risk. To capture the dynamic component of disaster risk, we estimate time-varying arrival intensities at the country level using the Poisson mixture intensity (PI) model of Hong et al. (2025). The PI model posits two climate states—a "bad" state with high disaster arrival rate λ_B and a "good" state with low arrival rate λ_G—with agents forming posterior beliefs about which state prevails. Using the history of disaster arrivals in each country, the parameters $(\lambda_B, \lambda_G, \pi_0)$ are estimated by simulated method of moments (Duffie and Singleton, 1993). The model generates a time-varying expected arrival rate:

$$\lambda_{it} = \pi_{it}\lambda_B + (1 - \pi_{it})\lambda_G, \tag{2}$$

where π_{it} is the posterior probability of the bad climate state. Disaster arrivals sharply raise π_{it} (and hence λ_{it}); quiet periods lead to a gradual decline. The resulting λ_{it} is persistent, bounded between λ_G and λ_B, and stationary—properties that align naturally with the quantitative model in Section 6, where λ_t is discretized as a stationary Markov chain.

Estimating equation. To test whether the remittance response to disasters varies with perceived risk, we estimate:

$$\Delta \log R_{it} = \beta_1 D_{it} + \beta_2 (\lambda_{it} - \lambda_{i0}) D_{it} + u_i + v_t + \varepsilon_{it}. \tag{3}$$

Here, β_1 captures the baseline remittance response to a disaster when perceived risk equals its initial level, and β_2 captures how this response changes as perceived risk deviates from the initial level. A positive β_2 means remittances respond more to disasters when perceived risk is elevated—consistent with more prepared diaspora networks responding more aggressively. We use Δ log real remittances as the dependent variable to avoid the mechanical denominator effect from scaling by GDP.

The parsimonious specification omits the standalone $(\lambda_{it} - \lambda_{i0})$ term because, with country and year fixed effects absorbing cross-sectional and common time variation, the slow-moving λ provides limited additional identifying variation. Adding the standalone term splits the anticipatory effect into a level component (β_λ) and an interaction component ($\beta_{D\lambda}$); both are positive but individually weaker due to collinearity. The total anticipatory effect—captured by β_2 in the parsimonious specification—is unchanged.[1]

All specifications include country and year fixed effects. Standard errors are clustered by year. We use contemporaneous D_{it} for both disaster types; the event studies show that the remittance response peaks at $k = 1$, so the contemporaneous coefficient captures the onset of the response rather than the peak. This is conservative: using lagged $D_{i,t-1}$ yields larger estimates (see footnote below).

Results. Table 2 presents estimates for both disaster types.

Cyclones (Panel A, 58 countries). The interaction $\beta_2 = +0.104$ ($t = 2.1$) is significant at the 5% level: remittances respond significantly more to cyclones when perceived risk is elevated. The estimate strengthens with macroeconomic controls ($\beta_2 = +0.111$, $t = 2.2$). A unit increase in perceived risk raises the remittance response to cyclones by approximately 10 percentage points of real growth. The reactive coefficient β_1 is small and insignificant,

[1] With the standalone λ included, cyclone results are: $\beta_\lambda = +0.078$ ($t = 2.3$), $\beta_{D\lambda} = +0.079$ ($t = 1.7$). For heatwaves: $\beta_\lambda = +0.101$ ($t = 2.5$), $\beta_{D\lambda} = +0.096$ ($t = 2.6$). The sum $\beta_\lambda + \beta_{D\lambda}$ is similar to β_2 in the parsimonious specification.

consistent with the event study showing the cyclone remittance response peaking at $k = 1$ rather than $k = 0$.

Heatwaves (Panel B, 113 countries). Both channels are highly significant. The reactive effect $\beta_1 = +0.016$ ($t = 4.1$) confirms the remittance response to heatwaves. The interaction $\beta_2 = +0.087$ ($t = 4.1$) is significant: the remittance response to heatwaves is amplified when perceived risk is high. The estimate is stable with controls ($\beta_2 = +0.076$, $t = 3.4$).[2]

Table 2: Anticipatory Remittances: Responses to Disaster Risk (PI Model)

This table reports estimates of $\Delta \log R_{it} = \beta_1 D_{it} + \beta_2(\lambda_{it} - \lambda_{i0})D_{it} + u_i + v_t + \varepsilon_{it}$, where D_{it} is the disaster indicator and λ_{it} is the perceived arrival rate from the PI model of Hong et al. (2025). The coefficient β_2 captures the anticipatory remittance response: remittances respond more to disasters when perceived risk is elevated. Controls include lagged GDP growth, inflation, unemployment, CA/GDP, and population growth. t-statistics (clustered by year) in parentheses.

Panel A: Cyclone (58 countries)		
	Δ log(Real Remittances)	
	(1)	(2)
β_1 (Cyclone)	0.0073	0.0048
	(0.69)	(0.43)
β_2 ($D \times \lambda$)	0.1036**	0.1108**
	(2.13)	(2.20)
Controls	No	Yes
Country FE	Yes	Yes
Year FE	Yes	Yes
Panel B: Heatwave (113 countries)		
	Δ log(Real Remittances)	
	(1)	(2)
β_1 (Heatwave)	0.0162***	0.0188***
	(4.06)	(4.47)
β_2 ($D \times \lambda$)	0.0866***	0.0763***
	(4.10)	(3.42)
Controls	No	Yes
Country FE	Yes	Yes
Year FE	Yes	Yes

Summary. The evidence in Table 2 establishes the key empirical input to the model: the remittance response to disasters is increasing in perceived risk, for both cyclones and heatwaves. Migrant networks that have experienced elevated disaster risk respond more aggressively when disasters strike, consistent with more prepared transfer channels. By Proposition 1 in Section 4, this anticipatory remittance response implies that sovereign yields

[2]Using lagged $D_{i,t-1}$ for heatwaves yields larger estimates: $\beta_1 = +0.041$ ($t = 5.7$) and $\beta_2 = +0.178$ ($t = 4.5$), consistent with the event study showing the peak remittance response at $k = 1$.

and borrowing should respond less to disasters when perceived risk is high—regardless of whether the remittance flow arrives contemporaneously or with a lag, because bond prices are forward-looking. We test this prediction in Section 5.

4 Sovereign Default Model with Disasters and Remittances

We develop a minimal Eaton–Gersovitz style model in which migrant remittances attenuate the effect of climate disasters on sovereign credit risk. The model is intentionally parsimonious and serves to organize the stylized facts documented in Section 3 and to generate a testable prediction that links the remittance response to the sovereign credit response.

4.1 Environment and Timing

The perceived disaster arrival rate λ_t follows a persistent process. In the empirical analysis of Section 3.2, λ_t is estimated from the Poisson mixture intensity (PI) model, which generates Bayesian updating of beliefs about a latent two-state climate regime. The resulting λ_t is bounded between λ_G and λ_B, persistent, and stationary. In the quantitative model of Section 6, this process is discretized as a stationary Markov chain. The within-period timing is as follows:

1. *State.* The sovereign enters period t with debt $B_t \geq 0$ and the current arrival rate λ_t.

2. *Disaster draw.* Nature draws the disaster indicator $D_t \in \{0, 1\}$ with probability λ_t, and the productivity shock ε_t. Output is realized:

$$Y_t = \bar{Y}(1 - \chi D_t) \exp(\varepsilon_t), \tag{4}$$

   where $\chi \in (0, 1)$ is the fractional output loss.

3. *Remittances.* Migrant remittances arrive:

$$R_t = (\mu_1 + \mu_2 \lambda_t) D_t. \tag{5}$$

   Remittances flow only when a disaster strikes ($D_t = 1$), but the size of the transfer depends on perceived risk λ_t. The parameter $\mu_1 > 0$ captures the *baseline* remittance response to a disaster. The parameter $\mu_2 > 0$ captures *anticipatory* remittances: the disaster-contingent transfer is larger when perceived risk is high, because diaspora

networks that have experienced elevated risk maintain stronger and more responsive transfer channels. The empirical evidence in Section 3.2 establishes that $\mu_2 > 0$: the remittance response to disasters is significantly increasing in perceived risk for both cyclones and heatwaves.

4. *Default decision.* The sovereign observes the disaster realization D_t, output Y_t, and remittances R_t, and decides whether to repay or default. The decision depends on λ_t because the arrival rate governs the probability of future disasters, which enters the continuation value and bond pricing.

5. *Borrowing.* If the sovereign repays, it issues new bonds B_{t+1} at price $q(B_{t+1}, Y_t, \lambda_t)$.

6. *Transition.* The arrival rate transitions to λ_{t+1} via a persistent process that depends on D_t. In the PI model, a disaster ($D_t = 1$) raises the posterior on the bad climate state, increasing λ_{t+1}; a quiet period ($D_t = 0$) lowers it. We write $P(\lambda'|\lambda, D)$ for this transition.

The state variables for the sovereign's decision problem are (B_t, Y_t, λ_t), where Y_t is pre-disaster output $\bar{Y}\exp(\varepsilon_t)$ and λ_t is the arrival rate governing the current disaster draw. The sovereign chooses default and borrowing *after* observing D_t but within the same period, using λ_t and D_t to evaluate future disaster risk in the continuation value.

4.2 Debt and Default

If the sovereign repays, it retires B_t and issues new one-period bonds $B_{t+1} \geq 0$ at the endogenous price $q_t(B_{t+1}, Y_t, \lambda_t)$. Consumption under repayment is

$$C_t^R = Y_t + R_t - B_t + q_t(B_{t+1}, Y_t, \lambda_t)\, B_{t+1}. \tag{6}$$

If the sovereign defaults, it is excluded from financial markets and suffers an asymmetric output cost following Arellano (2008). While the original Eaton and Gersovitz (1981) framework assumes permanent exclusion, we follow the quantitative literature and allow stochastic re-entry: each period in default, the sovereign regains market access with probability ϕ and re-enters with zero debt. Default-state consumption is:

$$C_t^D = \min\{\theta\bar{Y}, Y_t\} + R_t, \tag{7}$$

where $\theta \in (0, 1)$ caps output in default. This formulation penalizes default more heavily in good times, generating the realistic feature that default occurs predominantly during bad times.

Preferences are standard: $\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t u(C_t)$, with $u(C) = C^{1-\gamma}/(1-\gamma)$ and $\gamma > 1$.

4.3 Value Functions and Optimal Borrowing

The structure follows Arellano (2008) and Mallucci (2022), with two value functions V^R (repayment) and V^D (default) defined over the state (B_t, Y_t, λ_t). Because the sovereign observes D_t before making its decision, both current consumption and the continuation value depend on the disaster realization.

The value of repayment is

$$V^R(B_t, Y_t, \lambda_t; D_t) = \max_{B_{t+1} \geq 0} \left\{ u(C_t^R) + \beta \mathbb{E}_t \big[W(B_{t+1}, Y_{t+1}, \lambda_{t+1}) \,\big|\, D_t \big] \right\}, \tag{8}$$

where consumption under repayment depends on the disaster realization:

$$C_t^R = \begin{cases} Y_t - B_t + q_t B_{t+1} & \text{if } D_t = 0, \\ Y_t(1-\chi) + \mu_1 + \mu_2 \lambda_t - B_t + q_t B_{t+1} & \text{if } D_t = 1. \end{cases} \tag{9}$$

Remittances $\mu_1 + \mu_2 \lambda_t$ appear only in the disaster state. Because the sovereign observes D_t before choosing B_{t+1}, the optimal borrowing policy implicitly conditions on the disaster state.

The value of default is

$$V^D(Y_t, \lambda_t; D_t) = u(C_t^D) + \beta \mathbb{E}_t \big[\phi\, W(0, Y_{t+1}, \lambda_{t+1}) + (1-\phi)\, V^D(Y_{t+1}, \lambda_{t+1}) \,\big|\, D_t \big], \tag{10}$$

where ϕ is the probability of re-entering financial markets at zero debt, and default-state consumption is:

$$C_t^D = \begin{cases} \min\{\theta \bar{Y}, Y_t\} & \text{if } D_t = 0, \\ \min\{\theta \bar{Y}, Y_t(1-\chi)\} + \mu_1 + \mu_2 \lambda_t & \text{if } D_t = 1. \end{cases} \tag{11}$$

The sovereign's continuation value is $W(B_t, Y_t, \lambda_t) = \max\{V^R, V^D\}$. The conditional expectation $\mathbb{E}_t[\cdot|D_t]$ integrates over future states (Y_{t+1}, λ_{t+1}) and the next-period disaster draw D_{t+1}:

$$\mathbb{E}_t \big[W \,\big|\, D_t \big] = \sum_{Y', \lambda'} P(Y'|Y_t)\, P(\lambda'|\lambda_t, D_t) \left[(1-\lambda') W(B_{t+1}, Y', \lambda') + \lambda'\, W(B_{t+1}, Y'_d, \lambda') \right], \tag{12}$$

where $Y'_d = Y'(1-\chi)$ is disaster-hit income. The continuation depends on D_t through

the transition $P(\lambda'|\lambda_t, D_t)$: in the PI model, a disaster ($D_t = 1$) raises λ_{t+1} (worsening the outlook), while a quiet period ($D_t = 0$) lowers it. When $\mu_2 > 0$, higher future λ implies larger disaster-contingent remittances, which partially offset the worse outlook by cushioning future disaster-state consumption.

International lenders are risk-neutral and competitive. Because bonds are issued after D_t is observed, the bond price conditions on the current disaster state:

$$q(B_{t+1}, Y_t, \lambda_t, D_t) = \frac{1}{1+r^*} \sum_{Y',\lambda'} P(Y'|Y_t)\, P(\lambda'|\lambda_t, D_t) \left[(1-\lambda')\mathbf{1}_R(B_{t+1}, Y', \lambda') + \lambda'\, \mathbf{1}_R(B_{t+1}, Y'_d, \lambda')\right], \tag{13}$$

where $\mathbf{1}_R(B, Y, \lambda) = \mathbf{1}\{V^R(B, Y, \lambda) \geq V^D(Y, \lambda)\}$ is the repayment indicator, and r^* is the world risk-free rate. The bond price depends on D_t through the λ transition: after a disaster, λ shifts upward, raising future default probability and lowering the bond price. The sovereign may default in the disaster state (Y'_d) but repay in the no-disaster state (Y'), or vice versa; the bond price integrates over both possibilities.

4.4 Central Prediction: Anticipatory Remittances and Yield Sensitivity

We now derive the model's central prediction, which links the remittance response documented in Section 3.2 to the sovereign credit response tested in Section 5.

When a disaster strikes ($D_t = 1$) at perceived arrival rate λ_t, the net shock to household resources relative to the no-disaster state is

$$\Delta\mathcal{W}(\lambda_t) = \underbrace{-\chi \bar{Y} \exp(\varepsilon_t)}_{\text{output loss}} + \underbrace{\mu_1 + \mu_2 \lambda_t}_{\text{remittance offset}}. \tag{14}$$

The output loss χ is independent of λ_t, but the remittance offset is increasing in λ_t when $\mu_2 > 0$:

$$\frac{\partial(\Delta\mathcal{W})}{\partial \lambda_t} = \mu_2 > 0. \tag{15}$$

When perceived risk is high, the disaster-contingent remittance offset is larger, directly reducing the resource gap between disaster and no-disaster states. By the concavity of $u(\cdot)$, a smaller resource gap generates a smaller marginal-utility difference across states, reducing the sovereign's incentive to adjust borrowing.

Proposition 1. *If remittances are anticipatory ($\mu_2 > 0$), then:*

(i) The disaster-induced increase in government borrowing is decreasing in the perceived

arrival rate:

$$\frac{\partial}{\partial \lambda_t}|B_1^\star - B_0^\star| < 0. \tag{16}$$

(ii) The disaster-induced increase in sovereign yield is decreasing in the perceived arrival rate:

$$\frac{\partial}{\partial \lambda_t}\left|\frac{\partial y_t}{\partial D_t}\right| < 0. \tag{17}$$

Conversely, if $\mu_2 = 0$, both sensitivities are independent of λ_t.

Proof. The sovereign observes D_t before choosing B_{t+1}, yielding optimal policies B_0^* (no disaster) and B_1^* (disaster). The disaster-induced borrowing response is $|B_1^* - B_0^*|$.

Current-period channel. The resource gap $|C_0 - C_1| = \chi \bar{Y} \exp(\varepsilon_t) - \mu_1 - \mu_2 \lambda_t$ is directly decreasing in λ_t when $\mu_2 > 0$. A smaller resource gap produces a smaller marginal-utility difference and hence a smaller borrowing differential. This is the central mechanism: anticipatory remittances cushion the disaster state, and the cushion grows with perceived risk.

Continuation channel. In the PI model, a disaster shifts λ upward, worsening the continuation. Higher λ_t implies higher future λ on average (by persistence), which raises future disaster-contingent remittances $\mu_1 + \mu_2 \lambda'$, partially offsetting the worse outlook.

Both channels imply that $|B_1^* - B_0^*|$ is decreasing in λ_t when $\mu_2 > 0$, establishing part (i).

For part (ii), a smaller $|B_1^* - B_0^*|$ implies a smaller difference in default probability across disaster states (since the default region is monotone in B) and hence a smaller yield response:

$$\left|\frac{\partial y_t}{\partial D_t}\right| = \underbrace{\frac{\partial y_t}{\partial \lambda_t^{def}}}_{>0} \cdot \underbrace{\frac{\partial \lambda_t^{def}}{\partial B_{t+1}}}_{>0} \cdot |B_1^* - B_0^*|. \tag{18}$$

Since each term is positive, the yield response inherits the comparative static from part (i).

If $\mu_2 = 0$, the remittance offset μ_1 is independent of λ_t, so the resource gap does not vary with perceived risk and neither the borrowing response nor the yield response varies with λ_t. □

Proposition 1 provides the link between the two sets of empirical results. Section 3.2 establishes that $\mu_2 > 0$: the remittance response to disasters is increasing in perceived risk. The proposition then predicts that both government borrowing and sovereign yields should respond *less* to disasters when the arrival rate is high—exactly the pattern we test in Section 5. Crucially, the prediction requires that remittances are anticipatory ($\mu_2 > 0$). If remittances responded to disasters at a constant rate regardless of perceived risk ($\mu_2 = 0$), the model would predict no attenuation, even if the baseline reactive response (μ_1) were large.

Robustness to the timing of remittances. The proposition holds even if remittances arrive with a lag—that is, if the reactive and interaction components respond to D_{t-1} rather than D_t. To see why, note that bond prices are forward-looking. When a disaster strikes at t, lenders price bonds using the expected probability of repayment at $t+1$. If $\mu_2 > 0$, they anticipate that next-period remittances will include the disaster-contingent offset $\mu_1 + \mu_2\lambda_t$ (triggered by $D_t = 1$), which reduces next-period default probability and supports the bond price at t. The yield attenuation therefore operates contemporaneously with the disaster even if the remittance flow itself materializes at $t+1$. This is empirically relevant: the event studies in Section 3.1 show that remittances peak at $k = 1$ for both cyclones and heatwaves, while the yield response to heatwaves is contemporaneous ($k = 0$). The forward-looking nature of bond markets reconciles these timing patterns.

5 Testing the Model: Sovereign Credit Responses to Disaster Risk

Section 3.2 establishes that remittances are anticipatory for both cyclones and heatwaves. Proposition 1 in Section 4 predicts that sovereign yields and borrowing should respond less to disasters when perceived risk λ_{it} is high. This prediction holds regardless of whether remittances arrive contemporaneously or with a lag, because bond prices are forward-looking: lenders at time t price in the expected remittance inflow, even if it materializes at $t+1$. We test this prediction using contemporaneous disaster arrivals for both disaster types.

5.1 Specification

The model's central predictions (Proposition 1) are:

(i) The disaster-induced increase in government borrowing is decreasing in perceived risk: $\beta_2 < 0$ for debt growth.

(ii) The disaster-induced increase in sovereign yield is decreasing in perceived risk: $\beta_2 < 0$ for bond yields; $\beta_2 > 0$ for credit scores.

We estimate the same interaction specification, now including the standalone $(\lambda_{it} - \lambda_{i0})$ as a control:

$$\Delta Y_{it} = \beta_1 D_{it} + \gamma(\lambda_{it} - \lambda_{i0}) + \beta_2[(\lambda_{it} - \lambda_{i0}) \cdot D_{it}] + u_i + v_t + \varepsilon_{it}. \tag{19}$$

The coefficient β_2 tests the model's prediction: whether the disaster impact on sovereign credit is attenuated when perceived risk is high. The standalone γ controls for any direct effect of risk on credit variables. We report specifications without and with macroeconomic controls.

5.2 Results

Table 3 reports estimates for both cyclones (Panel A, 58 countries) and heatwaves (Panel B, 113 countries).

Bond yields. The yield interaction is highly significant for both disaster types. For cyclones, $\beta_2 = -10.2$ ($t = -5.7$): financial markets penalize cyclones much less when perceived risk is high. For heatwaves, $\beta_2 = -4.65$ ($t = -5.4$). In both cases, the standalone risk term β_2 is insignificant or only marginally significant, confirming that the attenuation operates through the disaster-contingent interaction, not through a direct level effect of risk on yields.

Credit scores. The sign reverses as expected: $\beta_2 = +3.61$ ($t = 2.3$) for cyclones and $+2.81$ ($t = 5.7$) for heatwaves. Credit downgrades following disasters are less severe when perceived risk is high. The standalone β_2 is insignificant for both disaster types.

Debt growth. The borrowing interaction $\beta_2 = -6.11$ ($t = -1.9$) for cyclones and -9.15 ($t = -5.0$) for heatwaves. Governments borrow less after disasters when perceived risk is elevated, consistent with part (i) of the proposition.

Summary. Across all sovereign credit variables and both disaster types, the interaction β_2 has the sign predicted by Proposition 1 and is statistically significant. The standalone risk term β_2 is insignificant for yields and credit scores, confirming that the attenuation is driven by the disaster-contingent interaction. Combined with $\beta_2, \beta_2 > 0$ for remittances (Section 3.2), the full pattern matches the model's signature: anticipatory remittances build a buffer and amplify the disaster response, which attenuates the sovereign credit impact through both the consumption-level and interaction channels identified in Proposition 1. The fact that bond markets respond contemporaneously to disasters—even though remittances arrive with a lag—is consistent with forward-looking lenders who price in the expected private insurance flow.

Table 3: Sovereign Credit Response to Disaster Risk (PI Model)

This table reports estimates from $\Delta Y_{it} = \beta_1 D_{it} + \gamma(\lambda_{it} - \lambda_{i0}) + \beta_2(\lambda_{it} - \lambda_{i0})D_{it} + u_i + v_t + \varepsilon_{it}$, where γ controls for the direct effect of perceived risk on credit variables. The coefficient β_2 tests Proposition 1: whether the disaster-induced increase in borrowing and yields is attenuated when perceived risk is high. t-statistics (clustered by year) in parentheses. The standalone γ is insignificant for bond yields and credit scores in both panels.

Panel A: Cyclone						
	Debt Growth (%)		Δ Bond Yield		Δ Credit Score	
	(1)	(2)	(3)	(4)	(5)	(6)
β_1 (Cyclone)	1.063**	1.060**	0.570***	0.594***	-0.933***	-0.889***
	(2.29)	(2.34)	(2.85)	(2.81)	(-7.78)	(-7.05)
β_2 ($D \times \lambda$)	-12.884***	-12.678***	-10.172***	-11.107***	3.606**	3.336**
	(-3.01)	(-2.98)	(-5.53)	(-4.55)	(2.29)	(2.05)
Controls	No	Yes	No	Yes	No	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Panel B: Heatwave						
	Debt Growth (%)		Δ Bond Yield		Δ Credit Score	
	(1)	(2)	(3)	(4)	(5)	(6)
β_1 (Heatwave)	0.718*	0.638	0.829***	0.816***	-0.768***	-0.755***
	(1.80)	(1.60)	(6.72)	(6.69)	(-8.64)	(-8.10)
β_2 ($D \times \lambda$)	-14.240***	-14.590***	-4.650***	-4.667***	2.809***	2.758***
	(-5.15)	(-4.97)	(-5.28)	(-5.12)	(5.57)	(5.09)
Controls	No	Yes	No	Yes	No	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes

5.3 Interpretation

The joint evidence across Sections 3.2 and 5 traces the complete chain predicted by the model:

1. **Remittances are anticipatory**: $\beta_2 > 0$ for both cyclones and heatwaves, establishing $\mu_2 > 0$. The remittance response to disasters is larger when perceived risk is high.

2. **The disaster-state consumption gap shrinks with risk**: the remittance offset $\mu_1 + \mu_2 \lambda_t$ grows with λ_t, directly reducing the resource gap between disaster and non-disaster states.

3. **Sovereign credit responds less to disasters when risk is high**: $\beta_2 < 0$ for yields and debt growth, $\beta_2 > 0$ for credit scores, for both disaster types. A smaller resource gap produces a smaller marginal-utility spike, reducing the incentive to borrow and the default risk that drives spreads.

Crucially, if $\mu_2 = 0$, the remittance offset would be independent of λ_t, and the model would predict no attenuation ($\beta_2 = 0$ for credit variables), even if the baseline reactive response (μ_1) were large.

We emphasize that the credit attenuation may also reflect other adaptation channels that respond to perceived risk. The model provides one specific mechanism (anticipatory remittances), and the evidence in Section 3.2 confirms it is empirically active. The contribution of this paper is to identify remittances as a leading mechanism and to show that the joint pattern—anticipatory remittances combined with attenuated credit impacts—is consistent with the model's predictions for two distinct disaster types across a broad panel of countries.

6 Quantitative Counterfactual: How Much Do Anticipatory Remittances Matter?

The empirical evidence in Sections 3.2–5 establishes that remittances are anticipatory ($\mu_2, \mu_2 > 0$) and that sovereign credit responses to heatwaves are attenuated when perceived risk is high. Proposition 1 provides the theoretical link between these two findings. We now solve the model numerically to quantify the magnitude of this attenuation: how much higher would the disaster premium on sovereign spreads be if remittances were not anticipatory?

The counterfactual exercise compares two economies that differ only in the anticipatory parameters: one with $\mu_2, \mu_2 > 0$ (as estimated in the data) and one with $\mu_2 = \mu_2 = 0$ (where

remittances respond to disasters at a constant rate μ_1 regardless of perceived risk). All other parameters are held fixed.

6.1 Solution Method

We solve the model by value function iteration (VFI) on a discrete state space (B, Y, λ), following the computational approach developed for sovereign default models by Arellano (2008) and implemented in the open-source QuantEcon project (Sargent and Stachurski (2024)).[3]

State space discretization. The log-income process ε_t follows an AR(1) with persistence $\rho_\varepsilon = 0.945$ and innovation standard deviation $\sigma_\varepsilon = 0.025$. We discretize this into a 21-state Markov chain using the Tauchen method (Tauchen (1986)), yielding income levels $\{Y_1, \ldots, Y_{21}\}$ and transition matrix P_Y. The perceived disaster arrival rate λ_t is discretized into 5 grid points spanning $[0.10, 0.40]$—the range of heatwave arrival rates in our sample—with transitions governed by a discretized AR(1) process with persistence $\rho_\lambda = 0.85$ and innovation standard deviation $\sigma_\lambda = 0.05$. The bond grid contains 201 equally spaced points over $[0, 0.45]$, where positive values represent debt. The total state space contains $201 \times 21 \times 5 = 21{,}105$ grid points.

Implementation. Following Section 4, the algorithm maintains two value functions $V^R(B, Y, \lambda)$ and $V^D(Y, \lambda)$. Because the sovereign observes D_t before deciding, current consumption depends on the disaster realization as in Equation (9): in the no-disaster state, consumption includes the anticipatory buffer $\mu_2\lambda$; in the disaster state, it includes the reactive transfer μ_1 and the full anticipatory flow $(\mu_2 + \mu_2)\lambda$. Computationally, for each state (B, Y, λ) and each candidate B', the algorithm evaluates consumption under both $D = 0$ and $D = 1$, computes a single shared continuation value that branches over the next-period disaster draw using λ', and selects the optimal B' for each disaster state. This yields potentially different policies $B_0'^*$ and $B_1'^*$, as in Mallucci (2022).

Iteration procedure. Each iteration consists of four steps: (1) update default values under both disaster states; (2) update repayment values by searching over B', with the continuation computed once and shared; (3) update bond prices using disaster-state-specific

[3]The QuantEcon lectures provide a well-documented Python implementation of the Arellano (2008) model using value function iteration with Numba acceleration. See `https://quantecon.org/lectures/arellano.html`. Our code extends their two-dimensional (B, Y) implementation to three dimensions (B, Y, λ) and adds disaster-state branching. The code is available in the replication package.

repayment indicators; (4) check convergence ($\|V^R_{new} - V^R_{old}\|_\infty + \|V^D_{new} - V^D_{old}\|_\infty < 10^{-6}$). The algorithm is implemented in Python using Numba just-in-time compilation (Lam et al. (2015)). Each model solution converges in approximately 200 iterations and 110 seconds on a standard laptop.

6.2 Calibration

Table 4 reports the baseline parameters. The preference and income-process parameters follow the canonical calibration of Arellano (2008), which targets the Argentine economy but has been widely adopted as a benchmark for emerging-market sovereign default models (Aguiar et al. (2016)). The asymmetric default cost $\min\{\theta\bar{Y}, Y\}$ caps output in default, penalizing default more heavily in good states and generating the empirically realistic feature that sovereigns default primarily during recessions.

Table 4: Model Calibration

Parameter	**Symbol**	**Value**	**Source / Target**
Preferences and technology (Arellano 2008)			
Discount factor	β	0.953	Standard
Risk aversion	γ	2	Standard
World risk-free rate	r^*	0.017	US T-bill rate
Income persistence	ρ_ε	0.945	Argentine GDP
Income volatility	σ_ε	0.025	Argentine GDP
Default cost	θ	0.969	Arellano (2008)
Re-entry probability	ϕ	0.282	Arellano (2008)
Disaster and remittance parameters			
Disaster output loss	χ	0.08	Hsiang & Jina (2014)
Disaster arrival rate range	λ	$[0.10, 0.40]$	Cyclone data, Section 2
Arrival rate persistence	ρ_λ	0.85	Estimated, Section 3
Baseline remittance	μ_1	0.0004	Table 2, $\beta_1 \times \bar{R}/\bar{Y}$
Anticipatory remittance	μ_2	0.0055	Table 2, $\beta_2 \times \bar{R}/\bar{Y}$

The disaster parameters are chosen to match the empirical setting. The output loss $\chi = 0.08$ is at the upper end of the range estimated by Hsiang and Jina (2014) for tropical cyclones. The disaster arrival rate λ spans $[0.10, 0.40]$, matching the range of cyclone frequencies across countries in our sample (Table 1).

Mapping empirical estimates to model parameters. The empirical specification in Section 3.2 estimates $\Delta \log R_{it}$ as a function of D_{it} and $D_{it} \times \lambda_{it}$, whereas the model specifies $R_t = (\mu_1 + \mu_2\lambda_t)D_t$ in levels for tractability. The mapping is standard: the regression

coefficients β represent percentage changes in remittances, which translate to level changes after scaling by the mean remittance-to-GDP ratio $\bar{R}/\bar{Y}$. With the cyclone-event-weighted mean $\bar{R}/\bar{Y} = 5.3\%$ (Table 1), we set $\mu_j = \beta_j \times 0.053$: $\mu_1 = 0.007 \times 0.053 \approx 0.0004$ and $\mu_2 = 0.104 \times 0.053 \approx 0.0055$. At the mean arrival rate $\lambda = 0.25$, a cyclone triggers total remittances of $\mu_1 + \mu_2\lambda = 0.18\%$ of GDP.

Informal remittances. The calibration based on formal remittance data likely understates the true flow. The World Bank estimates that informal remittance channels (hand-carried cash, hawala networks, in-kind transfers) add 50–250% on top of recorded flows in many developing countries (Freund and Spatafora (2008)). Moreover, the cyclone-event-weighted mean $\bar{R}/\bar{Y} = 5.3\%$ averages over all cyclone-exposed countries, including large economies (USA, Japan, China) where remittances are negligible. For the high-remittance countries that drive the identification—such as Haiti (10%), Indonesia (10%), and Panama (12%)—the effective $\bar{R}/\bar{Y}$ is substantially higher. To bracket the effect, we report results using $\bar{R}/\bar{Y} = 16.4\%$, corresponding to the mean for countries with high λ variation (8.2%) scaled by two for informal transfers.

6.3 Results

We simulate each economy for 50,000 periods and compute moments from periods when the sovereign is not in default. Table 5 reports the main results.

The model generates realistic unconditional moments: a mean sovereign spread of approximately 740 basis points (within the range observed for emerging-market sovereigns), a default rate of about 4% (close to the 3% target in Arellano (2008)), and a disaster frequency of 25% (matching the cyclone arrival rate in our data).

The central result is the disaster premium. Without anticipatory remittances ($\mu_2 = 0$), the average spread in disaster periods is 1,032 basis points compared to 641 in non-disaster periods—a disaster premium of 391 basis points. At the upper-bound calibration, the disaster premium falls to 328 basis points, an attenuation of 63 basis points or 16%. For a sovereign with \$10 billion in outstanding debt, this attenuation corresponds to \$63 million per year in lower borrowing costs—an economically meaningful benefit from the private insurance channel.

We view this as a conservative lower bound on the total attenuation from adaptation, for two reasons. First, remittances are only one of several channels through which households and governments adapt to elevated disaster risk; precautionary savings, infrastructure hardening, crop diversification, and migration itself all contribute to reducing the fiscal impact of disasters. Second, the mapping from $\Delta \log R$ regression coefficients to model parameters

Table 5: Counterfactual: Disaster Premium on Sovereign Spreads

	$\mu_2 > 0$ (baseline) $\bar{R}/\bar{Y} = 5.3\%$	$\mu_2 > 0$ (upper bound) $\bar{R}/\bar{Y} = 16.4\%$	$\mu_2 = 0$ (no anticipation)
Mean spread (bps)	738	733	738
Mean spread, disaster periods (bps)	1027	979	1032
Mean spread, non-disaster periods (bps)	643	651	641
Disaster premium (bps)	**384**	**328**	**391**
Attenuation (bps)	**6**	**63**	–
Attenuation (%)	**2%**	**16%**	–
Default rate (%)	4.1	3.8	4.1
Disaster frequency (%)	25.1	25.2	25.1

Notes: Simulated moments from the calibrated sovereign default model described in Section 4. The disaster premium is the difference in mean sovereign spreads between periods when a cyclone occurs ($D_t = 1$) and periods when it does not ($D_t = 0$). Moments are computed from non-default periods over a 50,000-period simulation. Remittance parameters are mapped from Table 2 via $\mu_j = \beta_j \times \bar{R}/\bar{Y}$. The baseline uses $\bar{R}/\bar{Y} = 5.3\%$ (cyclone-event-weighted mean). The upper bound uses $\bar{R}/\bar{Y} = 16.4\%$ (high-λ subsample $\times$ 2 for informals). The no-anticipation column sets $\mu_2 = 0$, retaining only the baseline response μ_1.

via $\mu = \beta \times \bar{R}/\bar{Y}$ depends on the remittance ratio, which varies widely across countries: for the high-remittance economies that drive the empirical identification, the attenuation is proportionally larger.

The mechanism operates through the channel identified in Proposition 1: the disaster-contingent remittance offset ($\mu_1 + \mu_2\lambda$) grows with perceived risk, directly reducing the resource gap between disaster and non-disaster states. A smaller resource gap produces a smaller marginal-utility spike, reducing the sovereign's incentive to borrow and the default risk that drives spreads.

7 Discussion and Policy Implications

Our results show that climate disasters systematically worsen sovereign credit risk by increasing debt burdens, raising borrowing costs, and triggering rating downgrades. Yet these effects are substantially attenuated when perceived disaster risk is high—precisely because anticipatory remittances buffer the fiscal shock. This interaction between public fiscal fragility and private cross-border insurance has several implications for macro-financial stability and climate policy.

7.1 Fiscal Space and the Debt-Adaptation Trade-off

Developing countries face a fundamental constraint: adaptation investments are most needed when fiscal space is smallest. Our evidence shows that repeated disasters weaken creditworthiness, reinforcing a climate–debt feedback loop. Higher sovereign spreads constrain post-disaster borrowing, delaying recovery and increasing vulnerability to future shocks. Duffy (2025) characterizes this dynamic as an "adaptation trap": high borrowing costs restrict adaptation spending, which raises future disaster losses, which in turn raises borrowing costs. This feedback loop implies that traditional debt-financed adaptation may be self-limiting in economies with already elevated debt ratios.

Private financial inflows such as remittances can partly relax this constraint by supplying liquidity directly to households, thereby reducing the fiscal burden of relief spending. However, the aggregate stabilizing role of remittances depends on maintaining credible macroeconomic frameworks that allow these inflows to translate into domestic resilience rather than capital flight or currency volatility.

7.2 Private Insurance and International Risk Sharing

The counter-cyclical nature of remittances implies that migrant networks provide an international insurance mechanism against climate shocks. When disasters strike, remittance inflows rise automatically, smoothing consumption and stabilizing local economies without fiscal transfers or international aid. This decentralized channel of insurance is particularly valuable for countries with limited access to contingent debt instruments or climate-insurance markets.

In effect, remittances perform the same macro-financial role as a state-contingent debt instrument: their flows increase precisely when sovereigns' repayment capacity deteriorates. Recognizing this property could help integrate remittances into sovereign-risk assessments and climate-finance frameworks, where they can be treated as a stabilizing offset to fiscal fragility.

7.3 Policy Design: Leveraging Remittances for Climate Adaptation

Our results also suggest that migration and remittances can be mobilized as part of a broader climate-finance architecture. Three policy avenues follow:

Debt-for-Adaptation Swaps. Given the debt overhang associated with repeated disasters, targeted swaps can link debt relief to verified adaptation investments (Hebbale and Urpelainen, 2023). Such mechanisms convert fiscal vulnerability into an opportunity for resilience-building while preserving market discipline.[4]

Diaspora Bonds and Remittance Matching. Governments can issue climate-linked diaspora bonds that channel remittance savings into public adaptation projects. Matching schemes—where donor institutions co-finance remittance-funded community adaptation—could further amplify this effect.

Migration Policy and Climate Mobility. Restrictive migration policies in host countries can undermine this private-adaptation channel. Facilitating legal migration pathways and reducing transaction costs for remittances would enhance the efficiency of this decentralized insurance system.

7.4 Broader Implications for Financial Stability

Traditional debt-sustainability frameworks often ignore the stabilizing role of remittances and the endogenous learning dynamics of climate risk. Incorporating both could improve assessments of sovereign resilience and the pricing of climate-related credit risk.

More broadly, the evidence suggests that climate adaptation is not purely a public good: it also emerges from private networks of migration and finance. Recognizing this hybrid nature of adaptation finance is crucial for designing resilient fiscal and financial systems in an era of intensifying climate volatility.

8 Conclusion

This paper examines how private cross-border financial flows mediate the macro-financial consequences of climate disasters. We document three facts: (1) disasters elevate sovereign credit risk; (2) consumption is insured and governments do not increase borrowing—the missing channel is migrant remittances, which surge after disasters; (3) remittances are *anticipatory*—they respond more strongly to disasters when perceived arrival intensity is high. We develop a sovereign default model showing that anticipatory remittances predict

[4]Examples include the 2023 Belize and Barbados debt-for-climate swaps, which reduced debt servicing while funding marine and coastal adaptation programs, as well as more recent swaps in Cape Verde, Gabon, Kenya, and El Salvador.

attenuated borrowing and yield responses to disasters, and we confirm this prediction in the data.

From a macro-financial perspective, our results reveal that sovereign resilience to climate risk depends not only on fiscal space and debt management, but also on the strength of transnational private insurance mechanisms. The key insight is that remittances are not merely counter-cyclical—they are risk-sensitive, responding more aggressively when disaster risk is elevated. This anticipatory behavior is what drives the attenuation of sovereign credit deterioration, as the model makes precise.

Several avenues for further research arise from our analysis. Future work could examine how investors incorporate remittance-based insurance into sovereign credit spreads or default probabilities; incorporating private risk-sharing mechanisms into asset-pricing models could improve the valuation of climate-vulnerable sovereign debt. Linking household-level remittance behavior and migration decisions with macro-level sovereign outcomes would deepen understanding of how micro adaptation scales to macro resilience—an exercise that could be pursued using household surveys, bank-level transfer data, or mobile-money platforms. The buffering effect of remittances may also depend on exchange-rate regimes, banking depth, or capital controls, and future research could study how institutional and financial-market characteristics amplify or dampen this private insurance channel. Finally, how remittances interact with official climate-finance instruments—such as debt-for-adaptation swaps, catastrophe bonds, or IMF Resilience and Sustainability Trust programs—remains an open question; joint modeling of public and private adaptation flows could yield richer policy insights.

In sum, the paper underscores that climate resilience is not purely fiscal—it is financial, social, and transnational. Understanding how private flows such as remittances interact with sovereign balance sheets will be central to managing macro-financial stability in a warming world.

References

Arellano, C. (2008). Default risk and income fluctuations in emerging economies. *American economic review 98*(3), 690–712.

Arellano, C., Y. Bai, and G. Mihalache (2024). Deadly debt crises: Covid-19 in emerging markets. *Review of Economic Studies 91*(3), 1243–1290.

Barnett, M. and C. Yannelis (2024). Does climate change impact sovereign bond yields? Working paper, Arizona State University and University of Cambridge.

Barrage, L. (2024). Climate change impacts on public finances around the world. *Annual Review of Resource Economics 17*.

Barrage, L. (2025). Climate change impacts on public finances around the world. *Annual Review of Resource Economics 17*, 281–300.

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

Bettin, G., A. Jallow, and A. Zazzaro (2025). Responding to natural disasters: What do monthly remittance data tell us? *Journal of Development Economics 174*, 103413.

Bilal, A. and E. Rossi-Hansberg (2023). Anticipating climate change across the united states. Technical report, National Bureau of Economic Research.

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

Cai, R., S. Feng, M. Oppenheimer, and M. Pytlikova (2016). Climate variability and international migration: The importance of the agricultural linkage. *Journal of Environmental Economics and Management 79*, 135–151.

Carleton, T., A. Jina, M. Delgado, M. Greenstone, T. Houser, S. Hsiang, A. Hultgren, R. E. Kopp, K. E. McCusker, I. Nath, J. Rising, A. Rode, H. K. Seo, A. Viaene, J. Yuan, and A. T. Zhang (2022). Valuing the global mortality consequences of climate change accounting for adaptation costs and benefits. *The Quarterly Journal of Economics 137*(4), 2037–2105.

Cattaneo, C., M. Beine, C. J. Fröhlich, D. Kniveton, I. Martinez-Zarzoso, M. Mastrorillo, K. Millock, E. Piguet, and B. Schraven (2019). Human migration in the era of climate change. *Review of Environmental Economics and Policy 13*(2), 189–206.

Cattaneo, C. and G. Peri (2016). The migration response to increasing temperatures. *Journal of Development Economics 122*, 127–146.

Cevik, S. and J. T. Jalles (2022). This changes everything: Climate shocks and sovereign bonds. *Energy Economics 107*, 105856.

Conte, B. (2024). Climate change and migration: the case of africa. *Working Paper*.

Cruz, J.-L. and E. Rossi-Hansberg (2024). The economic geography of global warming. *The Review of Economic Studies 91*(2), 899–939.

Dell, M., B. F. Jones, and B. A. Olken (2012). Temperature shocks and economic growth: Evidence from the last half century. *American Economic Journal: Macroeconomics 4*(3), 66–95.

Desmet, K. and E. Rossi-Hansberg (2024). Climate change economics over time and space. *Annual Review of Economics 16*, 271–304.

Duffie, D. and K. J. Singleton (1993). Simulated moments estimation of markov models of asset prices. *Econometrica 61*, 929–952.

Duffy, S. (2025). Climate change, adaptation, and sovereign risk. Technical report, Job Market Paper.

Eaton, J. and M. Gersovitz (1981). Debt with potential repudiation: Theoretical and empirical analysis. *The Review of Economic Studies 48*(2), 289–309.

Giglio, S., B. Kelly, and J. Stroebel (2021). Climate finance. *Annual review of financial economics 13*(1), 15–36.

Goldsmith-Pinkham, P., M. T. Gustafson, R. C. Lewis, and M. Schwert (2023). Sea-level rise exposure and municipal bond yields. *Review of Financial Studies 36*(11), 4588–4635.

Hebbale, C. and J. Urpelainen (2023). Debt-for-adaptation swaps: A financial tool to help climate vulnerable nations. Technical report, Brookings Institution.

Hoffmann, R., G. Abel, M. Malpede, R. Muttarak, and M. Percoco (2024). Drought and aridity influence internal migration worldwide. *Nature Climate Change 14*(12), 1245–1253.

Hong, H., G. A. Karolyi, and J. A. Scheinkman (2020). Climate finance. *The Review of Financial Studies 33*(3), 1011–1023.

Hong, H., S. Ng, and J. Xu (2025). The return of adaptation in a changing climate. Technical report, National Bureau of Economic Research.

Hong, H., N. Wang, and J. Yang (2023a). Mitigating disaster risks in the age of climate change. *Econometrica 91*(5), 1763–1802.

Hong, H., N. Wang, and J. Yang (2023b). Welfare consequences of sustainable finance. *Review of Financial Studies 36*(12), 4864–4918.

Hsiang, S. M. and A. S. Jina (2014). The causal effect of environmental catastrophe on long-run economic growth: Evidence from 6,700 cyclones. Working paper, National Bureau of Economic Research.

Jessoe, K., D. T. Manning, and J. E. Taylor (2017). Climate change and labour allocation in rural mexico: Evidence from annual fluctuations in weather. *The Economic Journal 128*(608), 230–261.

Kaczan, D. and J. Orgill-Meyer (2020). The impact of climate change on migration: a synthesis of recent empirical insights. *Climatic Change 158*, 281–300.

Klusak, P., M. Agarwala, M. Burke, M. Kraemer, and K. Mohaddes (2023). Rising temperatures, falling ratings: The effect of climate change on sovereign creditworthiness. *Management Science 69*(12), 7468–7491.

Knutson, T., S. J. Camargo, J. C. Chan, K. Emanuel, C.-H. Ho, J. Kossin, M. Mohapatra, M. Satoh, M. Sugi, K. Walsh, et al. (2020). Tropical cyclones and climate change assessment: Part ii: Projected response to anthropogenic warming. *Bulletin of the American Meteorological Society 101*(3), E303–E322.

Mahajan, P. and D. Yang (2020). Taken by storm: Hurricanes, migrant networks, and us immigration. *American Economic Journal: Applied Economics 12*(2), 250–77.

Mallucci, E. (2022). Natural disasters, climate change, and sovereign risk. *Journal of International Economics 139*, 103672.

Missirian, A. and W. Schlenker (2017). Asylum applications respond to temperature fluctuations. *Science 358*(6370), 1610–1614.

Morten, M. (2019). Temporary migration and endogenous risk sharing in village india. *Journal of Political Economy 127*(1), 1–46.

Mueller, V., C. Gray, and K. Kosec (2014). Heat stress increases long-term human migration in rural pakistan. *Nature Climate Change 4*, 182–185.

National Academies of Sciences, Engineering, and Medicine (2016). *Attribution of extreme weather events in the context of climate change*. National Academies Press.

Painter, M. (2020). An inconvenient cost: The effects of climate change on municipal bonds. *Journal of Financial Economics 135*(2), 468–482.

Phan, T. and F. Schwartzman (2024). Climate defaults and financial adaptation. *European Economic Review 170*, 104866.

Pindyck, R. S. and N. Wang (2013). The economic and policy consequences of catastrophes. *American Economic Journal: Economic Policy 5*(4), 306–339.

Strömberg, D. (2007). Natural disasters, economic development, and humanitarian aid. *Journal of Economic perspectives 21*(3), 199–222.

Willmott, C. J. and K. Matsuura (2018). Terrestrial air temperature: 1900-2008 gridded monthly time series. *Center for Climatic Research, University of Delaware, Newark. http://climate.geog.udel.edu/climate*.

Aguiar, M., S. Chatterjee, H. Cole, and Z. Stangebye (2016). Quantitative models of sovereign debt crises. *Handbook of Macroeconomics 2*, 1697–1755.

Lam, S. K., A. Pitrou, and S. Seibert (2015). Numba: A LLVM-based Python JIT compiler. *Proceedings of the Second Workshop on the LLVM Compiler Infrastructure in HPC*, 1–6.

Sargent, T. J. and J. Stachurski (2024). QuantEcon Lectures. `https://quantecon.org`. Accessed April 2026.

Tauchen, G. (1986). Finite state Markov-chain approximations to univariate and vector autoregressions. *Economics Letters 20*(2), 177–181.

Freund, C. and N. Spatafora (2008). Do workers' remittances respond to compensation differentials? *Review of Economics and Statistics 90*(4), 757–768.