The Impact of Physical Climate Risks and Adaptation on Sovereign Credit Ratings

Implications for financial resilience and fiscal policy at the sovereign-bank nexus

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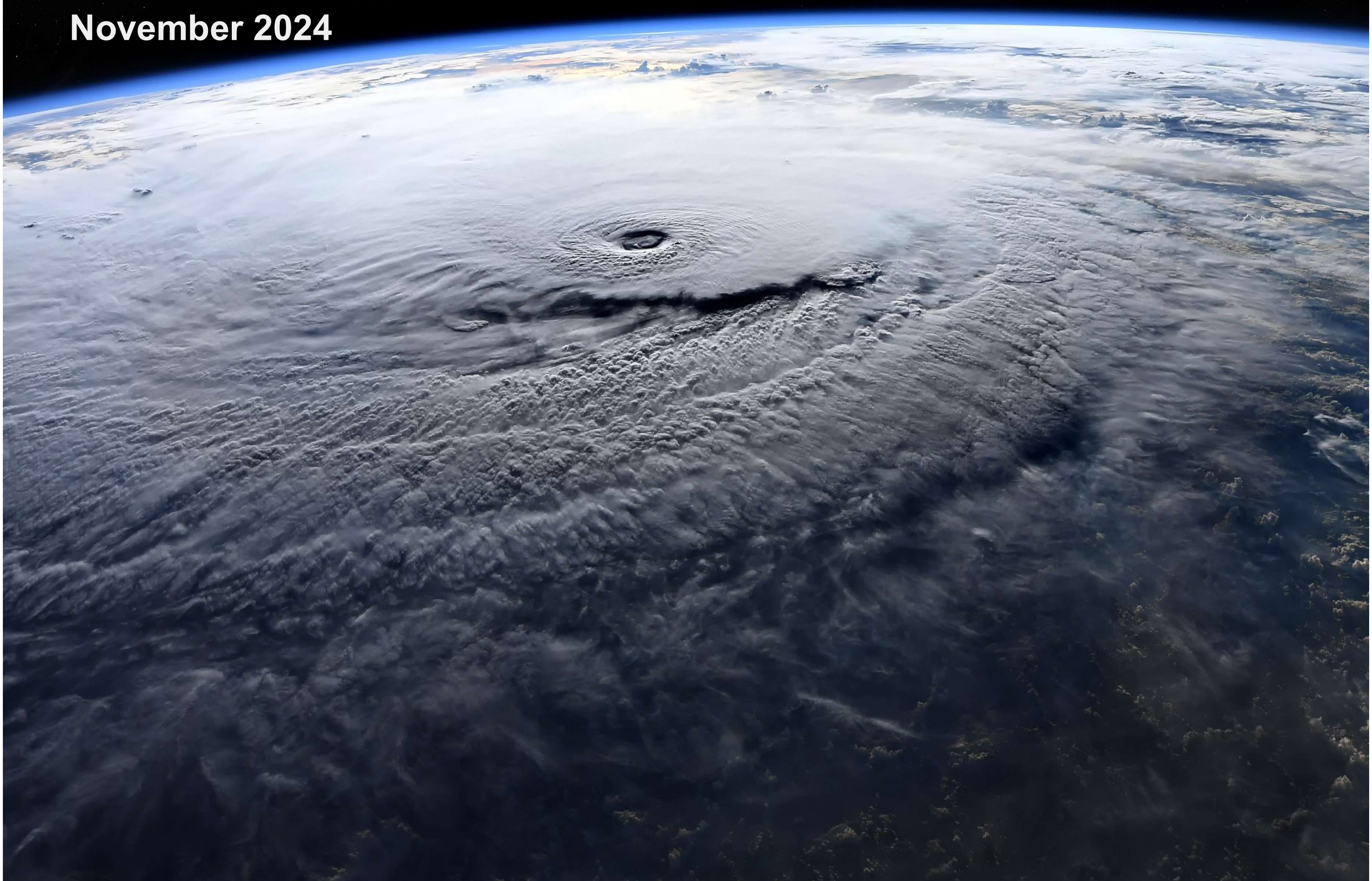

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Disclaimer

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Executive Summary

As global temperatures rise and extreme weather events become more frequent and severe, the resulting rising economic costs will put considerable strain on government (sovereign) finances, potentially increasing debt levels for climate vulnerable countries, with major implications for people and prosperity. For some vulnerable countries, this could increase the risk of default and so create a negative downward pressure on sovereign credit ratings (SCRs). SCRs rate a nation's ability to repay its debt and have a large influence on investor demand, bond pricing and borrowing costs. While sovereign credit ratings are influenced by many factors beyond climate, such as inflation and governance, previous studies have explored how the climate component of ratings may change in the future under long-term climate scenarios. Klusak et al. 2023, for example, found that climate-induced sovereign credit downgrades could materialize for nearly 60 countries by 2030 due to the macroeconomic impacts of rising temperatures. The strengthening downward influence of the *climate-credit rating* would mean lower value of bonds for the bond holder and higher borrowing costs for the issuer. Coupled with rising debt levels and the wider macroeconomic challenges faced by many vulnerable countries, previous authors have highlighted the potential for countries to be locked into a 'climate investment trap' (Ameli et al. 2021, Beirne et al. 2021).

The most climate-vulnerable developing countries will be worst affected, and we argue that this could result in an 'adaptation investment trap' of rising climate impacts and debt. In line with previous authors (Ameli et al., 2021, Beirne et al., 2021), we argue that rising borrowing costs limit the ability of countries to invest in adaptation, leading to even higher risks – an 'adaptation investment trap'.

In this discussion paper, we show how *acute* climate risk and adaptation can affect sovereign credit ratings under a range of scenarios as a 'stress test' on current and future fiscal and financial risks. **Using the more granular method proposed in this briefing, potential impacts on sovereign credit ratings are far greater than shown in previous studies. Yet, importantly, we show that these impacts can be largely offset through investment in adaptation, demonstrating the importance of adaptation for both fiscal risk and financial stability.** Previous sovereign climate risk estimates, while severe, are likely an underestimate, as they do not fully consider the materialization of extreme events (acute climate risk). In this paper, we propose a new methodology based upon insurance catastrophe risk modelling approaches that addresses this gap. In a case study in Thailand, we show that flooding could lead to sovereign downgrades of up to 4 notches, in the most extreme 1 in 1000-year future scenario. However, importantly, previous studies have also not accounted for adaptation. We show that national-scale flood adaptation investments reduce the risk significantly over time: decreasing average annual capital stock losses by up to 64% and reducing potential downgrades from the most extreme events by up to 2 notches. We show that adaptation benefits can be quantified both in terms of avoided losses and avoided increases in interest payments: providing governments with a clear economic case for large-scale adaptation investments.

In our illustrative case in Thailand, an adaptation investment of $55 billion USD reduces average annual capital stock losses by up to $9 billion and mitigates extreme scenario (1 in 1000-year) capital stock losses by up $48 billion. Additional benefits include avoiding significant downgrades, resulting in savings of $2.3 billion annually in interest payments under the extreme scenario. Our analysis demonstrates positive benefit-cost ratios across all adaptation scenarios.

We propose that sovereigns should incorporate future scenarios of physical climate risks and adaptation within current and forward-looking fiscal risk assessments as a stress test. For ratings agencies and others to provide such scenarios could be a catalyst for adaptation investment, particularly in nations that may be perceived as climate risk hotspots Quantifying what a country is (or isn't) doing to adapt to climate change and reflecting this in a future stress test of key metrics - including debt sustainability analyses (DSA) metrics and SCRs - could help incentivize more investment towards adaptation by showing the investment case for adaptation pathways over time. Indeed, not including this, and not fully representing the risks, could create a disincentive for adaptation investment. By providing countries with information on how their risks could change with climate change, and how this can be reduced through investments including adaptation, and consequently what this could mean for their debt and cost of capital, could help Ministries of Finance to chart a roadmap for investment over time to manage risks.

Our results also demonstrate that it is crucial for financial institutions to begin to incorporate risks to the value of sovereign bond assets due to climate change within stress testing and scenario analyses. Not incorporating the potential climate-related risks to sovereign bonds in financial risk analyses means that financial institutions may be mispricing the risk of world's largest asset class[2], with potential systemic implications for institutions that hold a lot of sovereign debt. The methodologies shown in this briefing to generate sovereign rating scenarios that incorporate these climate risks can be used by financial institutions in their climate stress tests.

Finally, our results reinforce that financial resilience and sovereign credit risk are linked, and both are expected to worsen in a changing climate. Indeed, the compounding impact of both can amplify physical climate financial risks. Given that many financial institutions, including banks, hold substantial amounts of sovereign debt, this devaluing of the asset can challenge financial resilience. At the same time, a higher risk to financial stability can put more pressure on government balance sheets. This is the so-called sovereign-bank nexus. This paper applies a new methodology to explore the potential strength of this sovereign-bank nexus for physical climate-related financial risks, and the potential implications for sovereign credit risk and financial stability, as well as the benefits of adaptation.

[2] According to 2020 estimates from the International Capital Markets Association, the global sovereign bond market is valued at nearly $65 trillion, with Global South countries accounting for around a quarter of this https://www.icmagroup.org/market-practice-and-regulatory-policy/secondary-markets/bond-market-size/

Introduction

Last year (2023) was the warmest year on record (NOAA, 2024). Anthropogenic emissions are causing our climate to warm at an unprecedented rate. Considering emission reduction policies currently in place, the median estimate of global warming by the end of the century is 2.7°C above pre-industrial levels; that is, 1.2°C above the 1.5°C global target set in Paris in 2015 (Climate Action Tracker, 2023). As global temperatures increase, so do the frequency and severity of extreme weather events. In 2023, weather and climate events in Asia impacted more than nine million people and resulted in over 2,000 fatalities (WMO, 2024) while global economic losses from natural catastrophes reached 280 billion USD (Banerjee et al., 2024). The influence of climate change on extreme weather events happening today is increasingly apparent. For example, the 2022 floods in Pakistan, which caused $15 billion in damages and over 1,500 deaths, were made 50% more likely due to climate change (Otto et al., 2022).

Climate change will have enormous impacts on our natural, social, and economic systems. Estimates suggest possible global financial losses in the tens of trillions by the end of the century if we follow a business-as-usual emissions path (Dietz et al., 2016). This emphasises the need to mitigate future warming by reducing our emissions. However, many climate impacts are already *baked in.* Recent estimates suggest—regardless of the emissions path—the global economy is already committed to a loss of income of 19% by 2050 (Kotz et al., 2024). This demonstrates the importance of adapting to climate impacts.

Adaptation needs to happen quickly and at scale. This was enshrined in Article 7 of the Paris Agreement[3], which defined a global goal on adaptation; and further operationalized at COP 27 through the Sharm-El-Sheikh Adaptation Agenda[4], which established 30 global adaptation targets to be met by 2030. However, a significant financing gap remains, especially in Global South countries that will bear the brunt of climate impacts. In its latest adaptation gap report, the United Nations Environment Programme Finance Initiative (UNEP FI) reported that current adaptation financing needs in Global South countries are 10-18 times larger than current finance flows (UNEP FI, 2023). Closing the adaptation financing gap will involve increasing international climate adaptation finance flows[5], mobilizing more private finance for adaptation, and increasing domestic expenditure on adaptation.

Climate change has enormous implications for the financial resilience of both governments and financial institutions (FIs). For the case of FIs, regulators are starting to take note, evidenced

[3] https://unfccc.int/sites/default/files/english_paris_agreement.pdf.
[4] https://climatechampions.unfccc.int/wp-content/uploads/2022/11/SeS-Adaptation-Agenda_Complete-Report-COP27_FINAL-1.pdf.
[5] Negotiations are currently ongoing for a new collective quantified goal on climate finance https://unfccc.int/NCQG.

by a growing number[6] of climate scenario exercises being conducted in jurisdictions such as the UK (Bank of England, 2022), the US (Federal Reserve Board, 2024), and the EU (European Central Bank, 2022). Climate financial risks are particularly acute in climate vulnerable regions such as Southeast Asia, where growing emissions coupled with more frequent and intense extreme events could lead to losses of gross domestic product (GPD) of up to 11% by the end of the century (Asian Development Bank, 2015). For example, an analysis conducted by the International Monetary Fund (IMF) and the World Bank found that the compound impact of a climate-intensified typhoon and a COVID-like pandemic could significantly strain the capital of banks in the Philippines (Hallegatte et al., 2022). These impacts may be further amplified if nature-related physical risks are taken into account (Ranger et al., 2023a), given the large financial-sector nature dependencies in the region. In Malaysia, over half of banks' lending is to sectors highly dependent on nature (World Bank and Bank Negra Malaysia, 2022). These climate financial risks have systemic implications and can propagate internationally across the financial system (Mandel et al., 2021). However, many of these risks are missing from current climate stress tests of the financial sector (Ranger et al., 2023b).

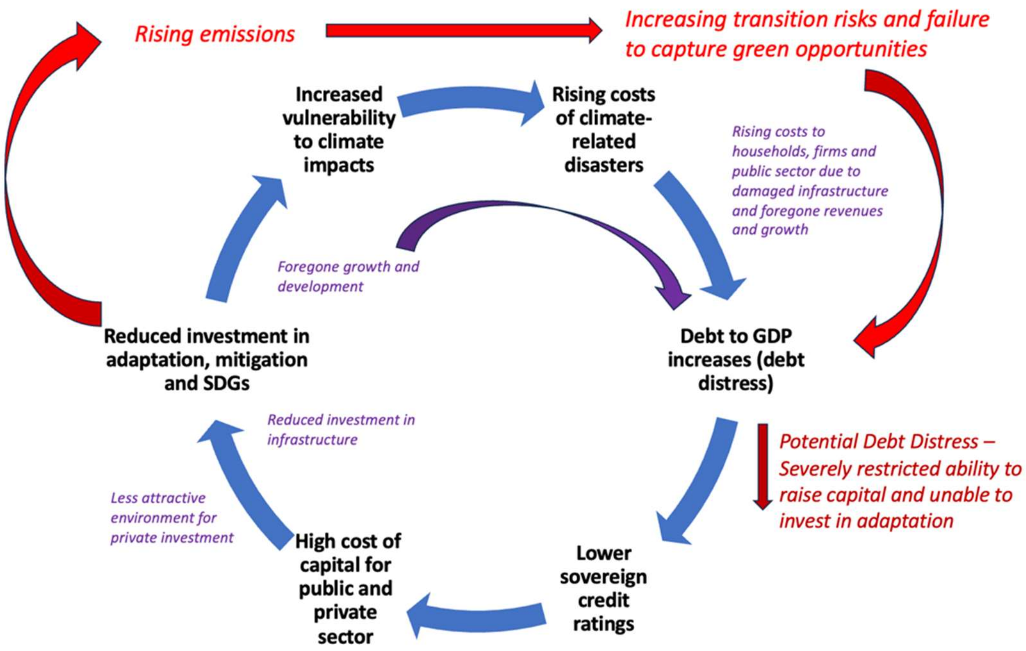
Governments also face considerable physical climate financial risk themselves with implications for fiscal resilience, sovereign debt, credit ratings and the sovereign-bank nexus. Modelled effects of climate change on the macroeconomy show long-term impacts on productivity and growth (Burke et al., 2015, Kahn et al., 2021), which will negatively affect public finances through reduced tax revenues and higher debt. Further, as extreme weather events become more frequent and intense due to climate change, they will impact sovereign finances through the economic disruption they cause and the cost of reconstruction and recovery, especially in countries with low insurance penetration where the government acts as the insurer of last resort (Volz et al., 2020). Climate impacts on the domestic financial sector also have the potential to spillover and amplify sovereign risk, and vice-versa, through the so-called sovereign-banking nexus. This nexus is particularly acute in Global South countries, where banks hold large amounts of government debt (Feyen and Zuccardi, 2019). As a result, any climate-induced stress on either the sovereign or the banking sector can trigger a feedback loop, intensifying financial instability and further constrain a governments' capacity to manage debt and finance adaptation efforts.

Governments carry significant responsibility with regards to adaptation. They develop national adaptation plans, which identify a country's long-term adaptation needs. They are also responsible for the implementation and financing of national (public) adaptation projects. To finance both adaptation and recovery efforts, governments may have to reallocate financing or increase their levels of sovereign debt. However, many of the most climate-vulnerable countries are already in debt distress and previous authors have identified that face a "climate investment trap" (Ameli et al., 2021, Beirne et al., 2021), whereby rising costs of capital reduce country ability to invest in responses,

[6] A 2022 publication by the FSB found that a total of 67 climate scenario analyses had been carried out or were in the process of being carried out across 36 jurisdictions https://www.fsb.org/wp-content/uploads/P151122.pdf

worsening impacts. We argue that countries also face a dangerous climate investment trap for adaptation (see Figure 1), whereby countries could see rising physical climate risks and debt levels which could lead to higher borrowing costs that may limit their ability to invest in the large-scale adaptation projects needed to make them resilient to future climate impacts (Ranger et al., Forthcoming), leading to a vicious cycle of growing vulnerabilities and indebtedness.

Figure 1. The climate investment trap for adaptation (from Ranger et al. (Forthcoming)), building upon analogous framework for mitigation (Ameli et al., 2021)



In this discussion paper, we explore how climate risk and adaptation analytics can be incorporated into sovereign financial risk analysis and serve as evidence for the benefits of investing in adaptation. We advance on previous work through linking credit risk modelling to a more granular, probabilistic and forward-looking assessment of climate-related risks using an insurance catastrophe risk modelling approach. A further advancement of our method is to incorporate adaptation, allowing governments and financial institutions to assess the benefits of investing in adaptation and the potential improvements in costs of capital. We focus on sovereign credit ratings as a metric for sovereign risk and show that acute climate events in Thailand can have significant negative impacts on the country's credit rating. We also demonstrate that when adaptation is incorporated into such analyses, the impacts on sovereign credit ratings are significantly reduced. The following section provides a background on sovereign credit ratings and climate change.

Background: Climate Change and Sovereign Credit Ratings

Sovereign credit ratings are an indicator of a government's ability and willingness to repay its debt. Sovereign defaults can occur due to an exhausted capacity to pay or a lack of willingness to prioritize debt repayment under economic or political constraints. Sovereign credit ratings are necessary for a country to issue bonds and play an important role in attracting foreign direct investment. They signal to investors the level of risk an investment in that country faces. They also influence a country's borrowing costs. Sovereign credit ratings are determined by ratings agencies[7] and integrate various quantitative and qualitative information around the country's economy, institutions, fiscal health, and exposure to various risks (financial, geopolitical, environmental, etc.)[8] Sovereign ratings are also a good indicator for the ratings of other asset classes. For example, they can have a ceiling effect for other asset class ratings and sovereign downgrades will often result in "spillover" downgrades for other asset classes (Sun et al., 2023).

In this study, we use sovereign credit rating as a metric for sovereign risk and conduct a forward-looking *stress test* of the potential impact of climate change on sovereign credit ratings over the long-term (by 2075) under different scenarios of climate shocks and adaptation. Our goal is to explore the extent to which investing in adaptation, and incorporating this within forward-looking *climate credit ratings,* can help to alleviate the financial impacts of climate change and 'break' the climate investment trap.

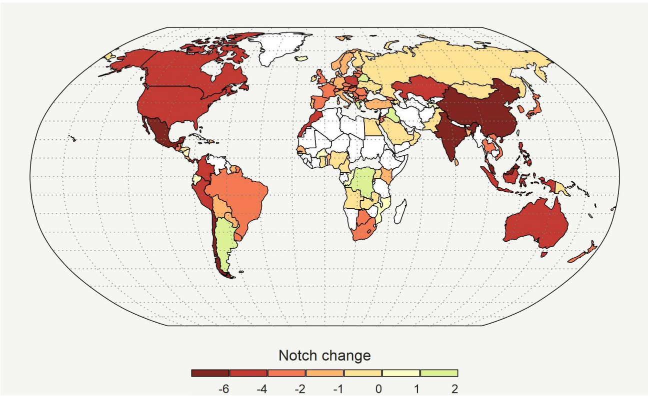
Credit ratings agencies note that climate change is already included in sovereign credit ratings today where relevant. Some credit ratings agencies are beginning to publish information on where (for a particular rating) climate change is considered material and is included. For example, *ex-ante* adjustments may be made if a country is in a hurricane-prone region, or there may be *ex-post* adjustments, for example where Fitch downgraded Pakistan's credit rating following the devastating 2022 floods[9]. Fitch Ratings has published quantitative analysis on sovereign climate risk (Fitch Ratings, 2021b) and S&P have even quantified the potential climate impact on sovereign credit ratings (Standard & Poors, 2015). However, these analyses are accompanied by disclaimers that they are exploratory and are not currently considered in ratings decisions. In some cases, climate change is not included as it is considered immaterial compared with other sovereign risks, or due to uncertainties where the risk of climate change is not yet well enough understood (Fitch Ratings, 2021a). There is also little information about how future risks are counted in assessments versus present-day risks. S&P advocates for scenario analysis to understand the impacts of climate change on creditworthiness (Birry et al., 2024) and has conducted global scenario analyses on the impacts of physical climate risk on GDP, finding 12% of GDP at risk in South Asia (Munday et al., 2023). They conclude that while

[7] The three largest ratings agencies are S&P Global Ratings, Moody's, and Fitch Ratings.
[8] See Moody's sovereign rating methodology here https://www.moodys.com/research/doc--PBC_1346995?WT.mc_id=RateSov and S&P's here https://www.spglobal.com/ratings/_division-assets/pdfs/021519_howweratesovereigns.pdf.
[9] https://www.fitchratings.com/research/sovereigns/pakistan-02-12-2022.

the scenario analysis provides useful insights, uncertainty around future government policy responses to adapt to these risks precludes the scenario analysis from forming the base case for sovereign ratings. Yet, they argue that the scenario analysis reinforces their view that physical climate risks will become more material to sovereign ratings in the future (Munday et al., 2023). The rationale for scenario analyses and stress testing is well accepted in financial risk management. We argue that while there are uncertainties, providing this information – scenario dependent – is exactly what governments require to help them make decisions over how and where to invest in adaptation, as well as for investors to take a forward-looking approach to risk management. Accordingly, in this study, we build on existing work by stress testing sovereign ratings for a range of future climate and adaptation scenarios.

A recent study published the first "climate-smart" sovereign credit ratings, which estimated ratings impacts for 109 countries until 2100 under various climate scenarios (Klusak et al., 2023). The study found that over 50 countries could experience climate-induced downgrades as early as 2030. By 2100, nearly three-quarters of the analysed countries would experience downgrades, with an average downgrade of 2.18 notches in a high-emission (RCP 8.5) scenario (see Figure 2). The climate impacts in the study are based on derived relationships between temperature variability and GDP growth (Kahn et al., 2021). These estimates capture, to an extent, the aggregate, chronic, macroeconomic impacts of climate change; however, they do not capture the effects of extreme events (such as floods or tropical cyclones). This means that these estimates of sovereign climate credit risk may be underestimating the actual risk. GDP impact estimated based on historical empirical analyses also have well known limitations, including missing the potential for tipping points and cascading and compounding risks. Further, adaptation is assumed to occur implicitly[10] in the study – and provides little actionable information to demonstrate how countries can become more resilient to climate impacts.

Figure 2. Global climate induced sovereign ratings changes (2100, RCP 8.5) from Klusak et al. (2023)



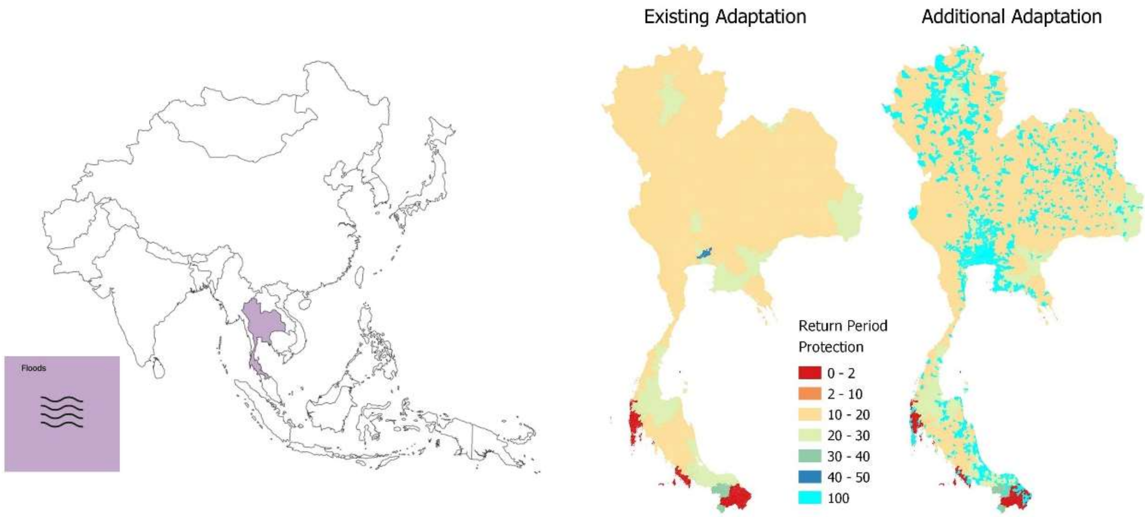
[10] Adaptation is captured implicitly in the study by altering the baseline time-window against which temperature variability is calculated. For example, smaller time-windows assume quicker adaptation while larger time-windows assume slower adaptation.

Exploring how acute physical climate risk and adaptation options may impact sovereign credit ratings would provide a more comprehensive view of sovereign climate risk than captured in existing studies, enabling both sovereigns and investors to conduct future stress tests and make more informed decisions on risk management, including adaptation investment. The increased frequency and intensity of extreme events brought about by climate change has the potential to significantly impact countries in the future. This is particularly true for small island developing states (SIDS), many of which are facing existential threats from the combined impact of sea level rise and tropical storms; as well as countries that are vulnerable to extremes, such as many Southeast Asian economies for flood and tropical cyclone or African economies for drought and flooding. Acute events can have enormous macroeconomic impacts. For example, in 2017 Hurricane Maria caused losses equivalent to 226% of Dominica's GDP (Government of Dominica, 2017). Forward looking stress tests on climate-credit ratings could reflect these potential risks in an *ex-ante* manner, helping both governments and investors to develop plans to manage risks over time. Integrating analyses of how adaptation could reduce risks could act as a signal to governments and investors on where and how adaptation investments are or could be made to manage the risks and protect credit worthiness. Accordingly, it is also crucial that ratings today incorporate adaptation where this materially impacts on losses. Moreover "adaptation-responsive" climate-credit ratings could act as a vehicle to promote further adaptation action, especially if it could lead to improved ratings.

Thailand Case Studies

Here we provide a new methodology that estimates how acute climate risk and adaptation can impact sovereign credit ratings in Thailand. Uniquely, our approach learns from insurance catastrophe risk modelling and builds upon lessons from analogous studies that use similar approaches to model physical climate financial risks, for example in the Philippines (Hallegatte et al., 2022). We use Thailand as a case study, which has a debt-to-GDP ratio of over 60%, and where over half of government bonds are held by banks, insurers, and contractual funds (Thailand Ministry of Finance, 2024). Thailand is one of the most exposed countries in the world to river flooding. In 2011, it experienced its worst ever flood event, which resulted in over $45 billion in economic damages (World Bank, 2012) and had repercussions for supply chains and manufacturing that affected industry globally. To this day, it remains the costliest flood event ever for the insurance industry (Swiss Re, 2021). Despite the enormous losses, the 2011 flood event was not a rare event from a climatological perspective. Analysis of historical rainfall and river flow records show that the estimated return period of the flood event was between 10-30 years[11] (Gale and Saunders, 2013). Climate change is expected to increase the intensity of flooding in the future for Thailand (Kiguchi et al., 2021), meaning a flood event occurring that is similar to or worse than the 2011 floods is increasingly likely in the future. As such, improving flood management is central to Thailand's national adaptation plan (Government of Thailand, 2023).

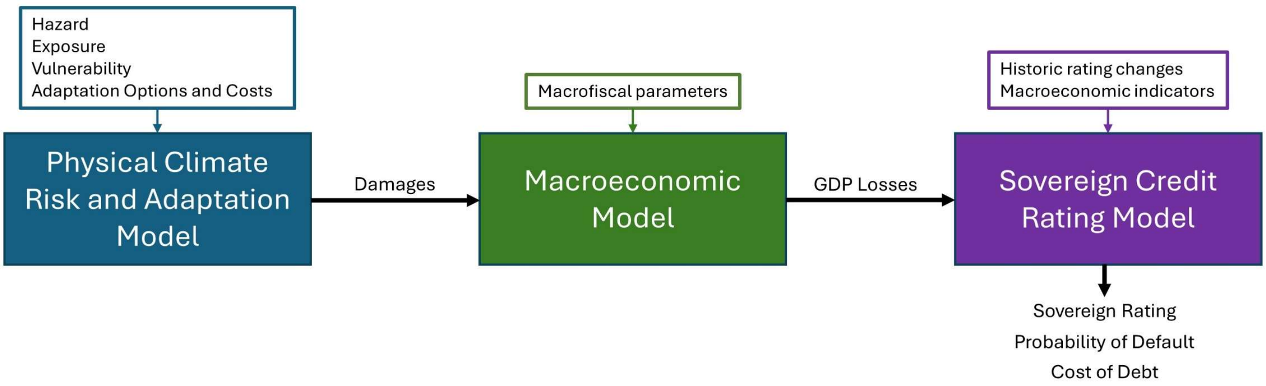
Figure 3. (left) Thailand, the focus of this study, (centre) it's existing levels of river flood adaptation, and (right) the additional adaptation scenario (where river flood protection in all urban areas is increased to protect against a 100-year return period flood)



[11] A return period is the average time you might expect between events occurring. Its inverse is the annual probability of occurrence. For example, a 10-year return period flood has an annual probability of occurrence of 0.1.

We develop a modelling framework for estimating the impact of floods on sovereign credit ratings that combines three different types of models (see Figure 4). This framework consists of (1) a flood risk and adaptation model, built using probabilistic catastrophe modelling approaches common in the insurance industry. This model simulates the capital stock damages from thousands of years of simulated flooding. These damages are then fed into (2) a macroeconomic model[12], calibrated for Thailand, which estimates the impacts of disaster years on Thailand's GDP. We finally use the GDP impacts to simulate and estimate potential changes in Thailand's sovereign credit rating, applying (3) the model described in Klusak et al. (2023). This model relies on a random forest regression to derive the relationship between macroeconomic fundamentals and the sovereign credit rating. We then adjust the economic fundamentals in line with the macroeconomic model (from step 2) to estimate the adjusted sovereign credit rating. A common concern with machine learning techniques is the danger of overfitting, however random forest algorithms are uniquely positioned to deal with this issue. We estimate 2,000 individual models, each iterated on a different subset of the original data and variable selection. We seed the model to enable replication as per Klusak et al. (2023). Our modelling chain allows us to calculate the capital stock and GDP losses as the result of different loss-probability years. As well as what this means for Thailand's sovereign credit rating, probability of default, and cost of debt. We note that this is not a full sovereign credit risk assessment in that it uses a simplified empirical model and does not capture non-climate effects that could also change significantly over the timescale; and so, results should be interpreted as illustrative.

Figure 4. Modelling framework for estimating the impact of acute climate risk and adaptation on sovereign credit ratings.



We consider 5 different combinations of climate and adaptation scenarios; focussed on acute climate shocks (see Table 1). For climate, we consider three scenarios: a baseline scenario that represents the historical distribution of flood risk, and two future (2075) scenarios – one representing a low emission (SSP126) trajectory and one representing a high emission (SSP585) trajectory. We

[12] We use the IMF's Debt-Investment-Growth and Natural Disasters (DIGNAD) model which is a general equilibrium model developed to study the effects of natural disasters on the macroeconomy of climate vulnerable countries.

also consider two adaptation scenarios. The first is an *existing adaptation* scenario, where we assume current river flood protection levels (see Figure 3). Existing flood protection levels at the province level are taken from Scussolini et al. (2016). These show an average level of return-period flood protection across the 76 Thai provinces of ~18 years, with the highest level of protection (50 years) in Bangkok Metropolitan Region. The second adaptation scenario is an *additional adaptation* scenario where we assume that all suburban areas or denser in Thailand will increase river protection levels to protect against a 100-year return period flood (see Figure 3). The cost of the *additional adaptation* scenario is calculated following the approach described in Tanoue et al. (2021), which relates the increase in return-period protection and the river length to be protected to a cost of protection. We find that our *additional adaptation* scenario would cost $55 billion. We only consider the additional adaptation scenario in combination with the future scenarios, assuming it will take several decades for these measures to be implemented.

Table 1. Climate and adaptation scenarios

Climate Scenario	Adaptation Scenario	Symbol
Baseline (Historical)	Existing Adaptation	B
Future Low Emission	Existing Adaptation	FL
Future High Emission	Existing Adaptation	FH
Future Low Emission	Additional Adaptation	FLA
Future High Emission	Additional Adaptation	FHA

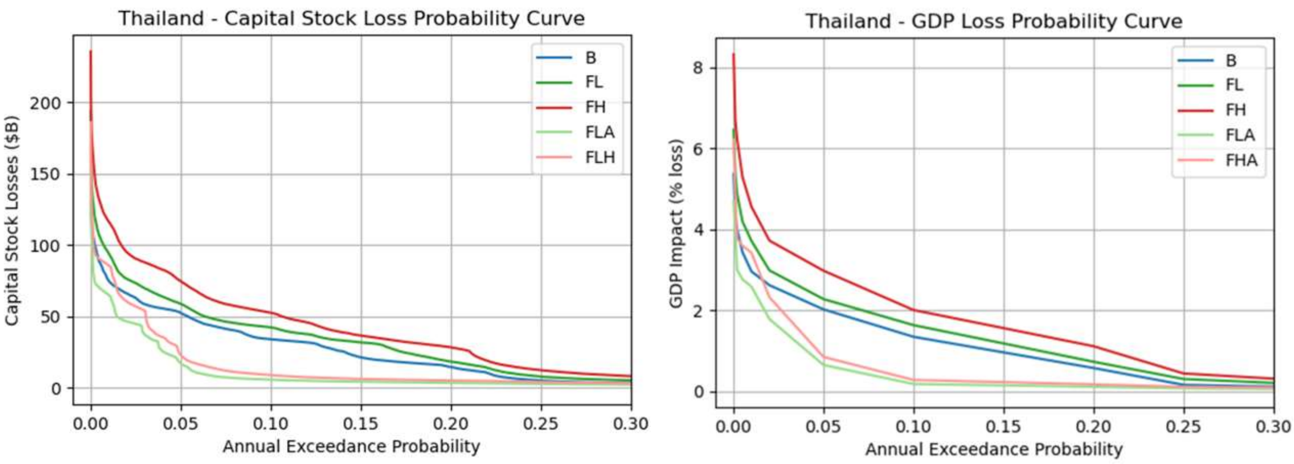
Our analysis shows that an extreme flood scenario could result in significant capital stock and macroeconomic losses in Thailand, with the potential for sovereign credit rating downgrades in the future. Assuming current protection levels, average annual losses (AAL) to capital stock in Thailand are 0.79% ($9 billion) today and could rise to between 0.98-1.3% ($11.2-14.8 billion) in 2075, depending on the emissions scenario. These average annual loss estimates[13] are in line with previous studies (Alfieri et al., 2017, Ward et al., 2020, World Bank, 2021). However, we argue that to fully assess risks, it is important to stress test outcomes for extreme climate shocks, following approaches common for example in the insurance industry. For example, as part of Solvency II regulation in Europe, companies are required to stress test portfolios to a 1 in 200-year event.

We find that a 100-year event today would lead to GDP losses of nearly 3%, which - based on a simplified model – could be linked to a single notch downgrade in Thailand's sovereign credit rating (see Figure 5). In the future, the same probability event would lead to GDP losses between 3.7-4.5%, resulting in a simulated two-notch downgrade. A two-notch downgrade would increase Thailand's probability of default by 4% and lead to increased interest payments of around $1.9 billion a year. In the event of an extremely rare 1000-year return period flood, Thailand's sovereign credit

[13] Our percentage average annual loss figures are in line with previous studies. However, our absolute values are higher as we use capital stock to estimate exposure and previous studies have used GDP-based exposure estimates. In 2022, Thailand's net capital stock to GDP ratio was 2.3.

rating risks falling below the investment grade threshold in the future with GDP losses exceeding 6.5% in a high emissions scenario. This signifies a significant increased risk of default, causing borrowing costs to rise and potentially deterring investment. Such an event has the potential to challenge economic and financial resilience and could lead to reduced access to international capital markets. These sovereign rating impacts equal and exceed the chronic impacts of climate change estimated by Klusak et al. (2023) who find that Thailand's credit rating drops two notches by the end of the century in a high emission (RCP 8.5) scenario. Our estimates do not yet consider the combined impacts of chronic and acute impacts on Thailand's rating, however, these would likely be additional and result in amplified rating risks. This analysis demonstrates the critical importance of accounting for acute climate shocks and leads us to propose the use of probabilistic models within sovereign credit ratings.

Figure 5. Results from our climate risk and adaptation modelling. (top left) Capital stock loss-probability curve for the five scenarios (B=baseline, FL=future low emission, FH=future high emission, FLA=future low emission with additional adaptation, FHA=future high emission with additional adaptation). (top right) GDP loss-probability curve for the five scenarios. (bottom) Sovereign credit rating impacts for the 100-year flood and 1000-year flood across the five scenarios (BBB+ is Thailand's current sovereign credit rating)



			1 in 100 loss year					1 in 1000 loss year				
Grade	Rating	Numerical	B	FL	FH	FLA	FHA	B	FL	FH	FLA	FHA
Investment	BBB+	13	Thailand's current sovereign rating									
	BBB	12										
	BBB-	11										
Non-Investment	BB+	10										
	BB	9										

Importantly, we also show that investing in adaptation can significantly reduce the risks Thailand faces from flooding. Additional adaptation investments can reduce average annual losses from flooding by up to $9.5 billion (64% decrease) in the future. They would also significantly reduce the losses in extreme events. Adaptation would lead to avoided losses of up to $30 billion and $48 billion for a 100-year and 1000-year flood, respectively. These benefits are reflected in the simulated impact on Thailand's sovereign credit rating. The probability of Thailand's rating falling below the investment grade threshold over a 10-year period (the timeframe over which many fiscal decisions are made) is reduced from over 6% in a future high emission scenario to under 1% with additional adaptation. When making the business case for adaptation investments, governments could include the avoided increased cost of debt as an additional benefit of adaptation. For example, our analysis shows that in the event of a 1000-year return period flood event occurring, adaptation investments that reduce a four-notch downgrade to a two-notch downgrade could prevent increases in annual interest payments of over $2.3 billion. Incorporating these results into a cost-benefit analysis[14] show that adaptation investments are cost-effective across all scenarios. Benefit-cost ratios range from 1.27 to 1.59 for the low emission and high emission scenario, respectively.

Our results also have implications for financial resilience for banks and asset owners and demonstrate why stress testing sovereign bond portfolios for climate change is an important part of wider climate stress testing and scenario analyses. To illustrate this, we carry out a preliminary exploration of the potential implications of sovereign downgrades on the financial sector in Thailand. Using the default probabilities associated with our scenarios, recent valuations of Thai sovereign bonds (Thailand Ministry of Finance, 2024), and regional estimates of loss given default (Aslam, 2020) we are able to calculate the Value at Risk (VaR) for the Thai financial sector, assuming different illustrative levels of debt holding (see Table 2). Assuming the Thai financial sector holds 50% of government debt, we find that a 1 in 1000-year flood would result in a VaR for the financial sector of $4.87 billion in today's climate increasing to $12.47 billion in a future high emission scenario. The VaR for the Thai financial sector in this scenario could be reduced by $5.96 billion by investing in additional adaptation. In the event of sovereign default, this could lead to economy-wide losses greater than $150 billion. Assuming banks hold 50% of sovereign debt, this would mean a 10% loss of total portfolio value[15], which has significant implications for financial resilience of banks and asset owners holding these assets. This loss would likely still be an underestimate as it does not account for the broader economic effects or the feedback impacts of the bank-sovereign nexus.

[14] In our cost-benefit analysis we assume construction of the adaptation measures begins today, lasts 30 years, and the benefits of adaptation increase linearly until adaptation construction is complete. The benefits of adaptation are a combination of the avoided average annual losses and the avoided expected annual interest payment increases because of sovereign downgrades. We use a discount rate of 5%, assume annual operational costs of the adaptation infrastructure are equivalent to 1% of the total cost of adaptation, and calculate the discounted benefits out to 2100.

[15] Assuming a total Thai bank portfolio value of $730 billion.

Table 2. Financial sector Value at Risk (VaR) estimates for different levels of sovereign debt holding

Scenarios			VaR ($ billion) for illustrative levels of debt holding			
Climate	Adaptation	Loss Year	10%	20%	50%	100%
Baseline (Historical)	Existing Adaptation	1 in 100	0.68	1.36	3.4	6.8
Future Low Emission	Existing Adaptation	1 in 100	0.73	1.46	3.65	7.3
Future High Emission	Existing Adaptation	1 in 100	1.11	2.21	5.53	11.06
Future Low Emission	Additional Adaptation	1 in 100	0.66	1.31	3.28	6.55
Future High Emission	Additional Adaptation	1 in 100	0.71	1.42	3.55	7.1
Baseline (Historical)	Existing Adaptation	1 in 1000	0.97	1.95	4.87	9.74
Future Low Emission	Existing Adaptation	1 in 1000	1.64	3.28	8.21	16.42
Future High Emission	Existing Adaptation	1 in 1000	2.49	4.99	12.47	24.93
Future Low Emission	Additional Adaptation	1 in 1000	0.75	1.49	3.73	7.45
Future High Emission	Additional Adaptation	1 in 1000	1.3	2.6	6.51	13.01

Implications

Our analysis has shown that acute climate risks pose a potentially significant risk to sovereigns, and we have demonstrated how this can be quantitatively incorporated into stress tests of sovereign ratings. We recommend that governments and financial institutions include such stress tests within their risk management practices, including fiscal risk assessments and climate scenario analyses and stress tests. Sovereign debt is the world's largest and most important asset class–representing 28% of global debt (Volz et al., 2020). Pensions funds, central banks, and insurers are all major holders of sovereign debt. If climate risks are not properly priced into these holdings it represents a potential systemic financial risk. Improper pricing can lead to misinformed investment decisions, resulting in holders unable to meet their financial obligations if the value of sovereign debt deteriorates due to the impacts of climate change. This could then jeopardize the financial security of those reliant on these institutions, such as pensioners.

Our analysis highlights the importance of forward-looking analyses, including stress tests, to complement existing methods, to provide scenarios of possible future pathways under different climate and adaptation assumptions. Our methodology for generating physical climate risk sovereign rating scenarios could be incorporated into financial-sector climate stress tests and fiscal sustainability outlooks, including debt sustainability analyses**.** Financial institutions, particularly in the Global South, are large holders of domestic sovereign debt. As such, sovereign ratings often act as credit rating ceilings for domestic financial institutions and sovereign credit rating downgrades could trigger domestic downgrades, leading to increased costs and challenges in market access, profitability, and liquidity (Feyen and Zuccardi, 2019). This risk transmission channel has been explored by the World Bank in their climate risk stress test of the Colombian banking sector (Reinders et al., 2021). It also points to the need to take account of probabilistic information on climate hazards, in the same way that insurance companies use catastrophe models to price risks that have not yet been observed

A further implication is that incorporating adaptation into debt sustainability analyses and financial stress tests can be important for motivating investment. In doing so, issuers of sovereign ratings could help stimulate the flow of finance towards adaptation and narrow the $194-366 annual adaptation financing gap in developing countries (UNEP FI, 2023). "Adaptation smart" sovereign rating scenarios could act as both a *carrot* and a *stick* in encouraging adaptation action. Showing the downward impacts of climate risks on a country's sovereign rating works as a stick, especially if not enough is being done nationally to adapt. The carrot would be integrating a country's adaptation progress into the sovereign rating scenario and to understand the favourable impacts on their sovereign rating, which could incentivize countries to invest more. Investors and policymakers require clear metrics on the economic return of adaptation investments. We have demonstrated how this could be done quantitatively in Thailand, using a hypothetical flood adaptation scenario. Our findings indicate that avoided costs in terms of reduced borrowing costs and lower probability of default significantly outweigh the initial adaptation investments

Further Work

This discussion paper has contextualized the importance of capturing acute climate shocks and adaptation within sovereign risk analyses, including climate stress tests, debt sustainability analyses and sovereign credit ratings. We have demonstrated how this can be achieved by combining insurance catastrophe risk modelling approaches with future scenarios to stress test outcomes under different assumptions. This discussion paper will be followed by an academic paper that explains the modelling framework in greater detail and quantifies the uncertainty of various modelling components and choices. The quantification of uncertainty is an important next step, as uncertainty is often cited as the reason why rating agencies do not incorporate climate change into their existing methodologies (Fitch Ratings, 2021a). We will also be exploring approaches for incorporating additional climate hazards into our risk modelling framework, combining estimates of chronic and acute impacts, and will be scaling our analysis to incorporate further countries. Future work could also link this type of analysis to the actual adaptation plans of countries, providing quantitative estimates of how countries are progressing on their adaptation targets, and the economic and financial benefits of doing so.

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