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Physical Climate Risk Stress Test: An Evidence-based Approach

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Abstract

Understanding local context is crucial when assessing the impact of physical climate events on financial systems, as vulnerabilities and risks vary significantly by region. This study highlights the importance of localized analysis by conducting a physical climate stress test in Thailand, focusing on the impact of flooding on home mortgage portfolios.

Thailand is frequently exposed to flooding, a climate hazard that poses significant socioeconomic risks. The most catastrophic flood event occurred in 2011, causing widespread damage and loss of life. The total economic loss was estimated at $46.5 billion, with 16 million people affected and approximately 500,000 houses partially damaged. Despite being one of the costliest flood events for the global insurance industry, the 2011 Thailand flood may have had a different impact on banking institutions, provided borrowers were able to continue repaying their loans.

We present an evidence-based framework to quantify the impact of climate events on banks using historical proprietary data. A vintage-based default model is employed to disentangle the effects of lifecycle, vintage, and environmental factors on default rates. This approach builds on the Age-Period-Cohort model commonly discussed in the literature. By isolating these effects, we estimate the influence of macroeconomic variables, flood impacts, and associated debt-relief measures on default behavior. Additionally, we incorporate extreme value analysis to assess the likelihood of future flood events similar to the 2011 flood. Hydrologic data from regions directly contributing to the 2011 flood is analyzed, with the findings applied to inform stress testing.

Our findings indicate that flooding's financial impact on Thai home mortgages is relatively moderate. Default risks were alleviated by debt-relief programs and rapid economic recovery. The concentration of economic activity in Bangkok and the central plains—regions highly susceptible to flooding—is a significant factor, as businesses and individuals encounter difficulties relocating to less vulnerable areas. This localized resilience is similar to patterns observed after Hurricane Sandy hit New York-New Jersey region, where a rapid economic rebound minimized long-term effects. In contrast, the economic recovery following Hurricane Katrina struggled to return to pre-disaster levels.

These results highlight the necessity of tailored stress-testing frameworks that reflect unique local conditions. By aligning assessments with Thailand's specific context, this study underscores the importance of localized data in financial risk evaluations, offering valuable insights for policymakers and financial institutions aiming to enhance resilience to physical climate risks.

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Introduction

In recent years, there has been a growing recognition of the need to incorporate climate risk into traditional financial stress tests. Climate risk encompasses a range of factors, including physical risks stemming from extreme weather events, transition risks associated with shifts towards a low-carbon economy, and liability risks arising from legal and regulatory changes related to climate action.

In the context of retail lending, physical climate events can significantly impact the lives and financial stability of banking customers. Consequently, banks may face exposure to customers who are unable to meet their loan repayment obligations. Therefore, it is reasonable to prioritize climate-related physical events that have a significant impact on the broader economy, leading to a decline in customers' ability to repay loans.

Central banks and financial authorities worldwide are increasingly adopting climate stress-testing frameworks to assess how financial institutions may be affected by climate-related disruptions. Leading this effort, the European Central Bank has implemented comprehensive stress tests examining both transition risks from decarbonization policies and physical risks from climate events. Asian regulators are Singapore's monetary authority evaluates sector-specific transition risks as well as physical flood event, Hong Kong's financial watchdog analyses exposure to extreme weather and carbon market fluctuations, while Malaysia's central bank incorporates flood risk scenarios into stability assessments. These coordinated initiatives reflect a fundamental shift in regulatory thinking, recognizing climate change as a macroeconomic stability concern that requires systematic integration into financial risk management practices.

To conduct a reliable and insightful physical climate risk stress test, understanding the linkage of climate-related variables/events to the bank performance plays a vital role. Hence, an evidence-based approach is preferred. There are two main steps for physical climate risk stress test. The first step is to quantitatively assess physical climate-related risk on bank performance. Then, impact on economic and bank performance are forecasted based on model developed in the first step (see figure 1).

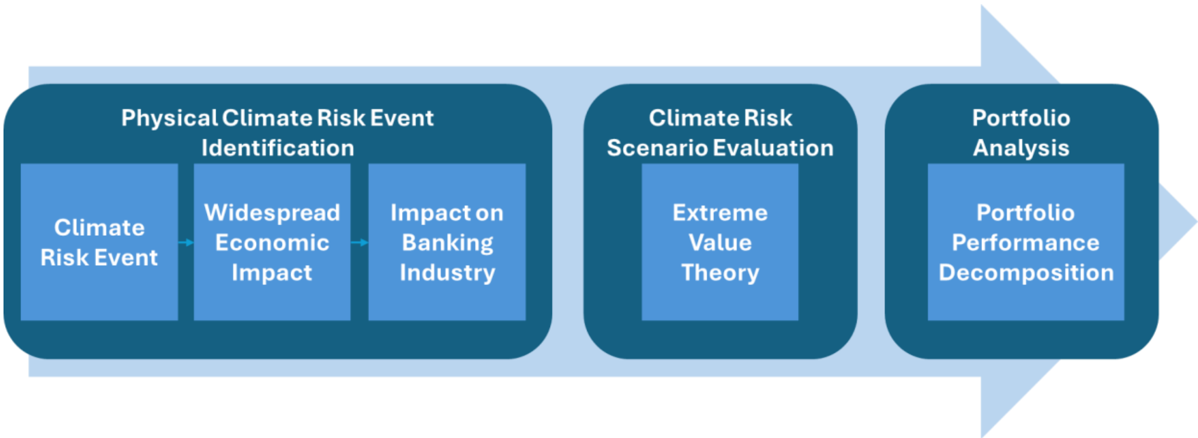


Figure 1: Evidence-based Climate Risk Stress Test Framework

Methods

The objective of the estimation step is to quantify the impact of climate event on bank performance the using historical data which could be comprised of three components which are climate risk identification, climate risk event evaluation, climate impact assessment.

Climate Risk Event Identification

Conducting stress tests for every possible climate event is neither practical nor efficient. Instead, the selection of climate risk events should adhere to three key criteria:

- Historical Significance & Geographic Validity: The events must have a documented history of severe and widespread impact within the region of interest.
- Macroeconomic Relevance: The events should significantly disrupt economic activity (e.g., GDP contraction, supply chain disruptions, or sectoral downturns) to justify their inclusion in bank stress testing.
- Banking Sector Linkage: There must be a clear transmission channel from the climate shock to financial stress in the banking system (e.g., via loan defaults, collateral depreciation, or liquidity strains).

For example, Thailand is highly vulnerable to flooding, particularly in regions such as the Chao Phraya River basin, where economic activity and banking sector exposure are concentrated. While other areas (e.g., the Mekong River region in the Northeast) also experience floods, their economic impact is comparatively limited. By focusing on historically significant and economically disruptive events—such as the 2011 Thailand floods, which caused an estimated $46 billion in economic losses—we ensure that the stress test captures material risks to bank stability.

Climate Risk Events Evaluation

Once a climate risk event is identified, the next step is to assess its severity and likelihood. While extreme climate scenarios (e.g., catastrophic floods or prolonged droughts) are critical for stress testing, their probability must also be quantified to avoid over- or underestimating risk.

Extreme Value Theory (EVT) is a statistical approach well-suited for modeling rare, high-impact events. By applying EVT to historical climate data, we can estimate the tail-risk distribution of extreme events (e.g., 100-year floods) and assess the likelihood of events exceeding historical severity thresholds.

This analysis provides a scaling factor to adjust the estimated economic and financial impact derived from the climate impact decomposition step.

Climate Impact Decomposition: Vintage Analysis

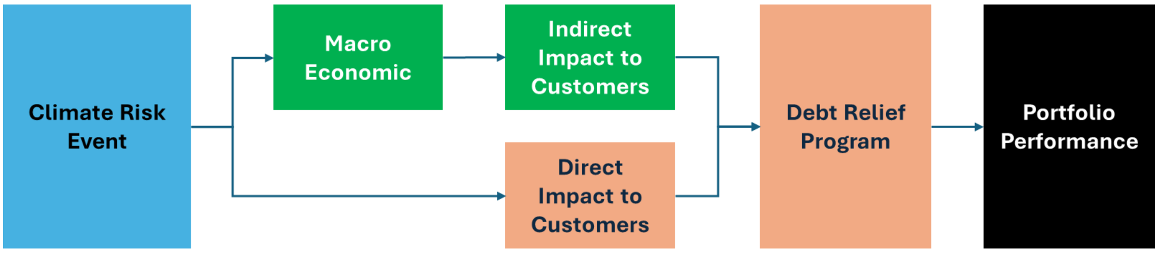


Figure 2: Flood Impact Transmission Channel

Past climate events are examined to quantitatively assess the impact of climate on bank portfolios. One challenge is decomposing the climate impact from other simultaneous effects. For instance, during significant climate events, there are often assistance programs to aid borrowers. This intervention lowers the observed climate risk impact compared to what it might have been without such assistance.

The vintage analysis framework is a modeling approach that can estimate the probability of default within a portfolio. It primarily assesses three key effects on default rates: lifecycle, vintage quality, and environment. In this framework, the main driver is the lifecycle effect where loan lifecycle exhibits patterns depending on nature of loan product. The vintage effect incorporates the quality of the same borrower issued in the same period caused by, for example, underwriting policy. The environment effect, also called period effect means factors that impact borrowers regardless of age or vintage includes macroeconomic variables (MEVs), seasonality, or special events. Within this framework, the estimated default rate from the model can be interpreted as a default rate without any intervention (Breeden 2020).

There are multiple ways to decompose the lifecycle, vintage, and environmental effects. One notable approach is the Age-Period-Cohort (APC) model, where age refers to the lifecycle, period refers to the environment, and cohort refers to vintage. In our approach, we estimate the lifecycle and vintage and combine them with seasonality to establish a benchmark model. The estimated default rate from the benchmark model can be interpreted as the default rate that follows its lifecycle.

Next, we extend the benchmark model to incorporate macroeconomic variables. The result from this model can be regarded as the default rate that incorporates economic risk. If the climate event affects all borrowers equally, the economic risk from the MEV model is sufficient, and this could be considered as a lower bound of the climate impact.

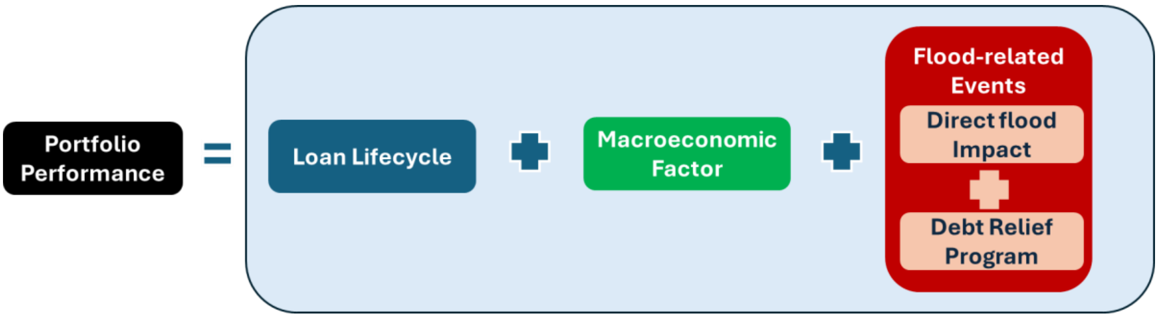


Figure 3: Portfolio Performance Decomposition Framework

However, if the climate affects borrowers unequally, we can estimate the additional climate impact by comparing the estimated default rates of flood-affected and non-flood-affected borrowers. This potential default rate for the vulnerable group could be considered as an upper bound of the climate impact. This information could also be incorporated into the climate scenario narrative by scaling according to the severity of the climate event.

In summary, we develop a probability of default model that decomposes the effects of various drivers into four components: 1) lifecycle-vintage proxy, 2) seasonality, 3) macroeconomic variables, and 4) key portfolio events (Figure 2). These established relationships will be utilized in the forecasting step.

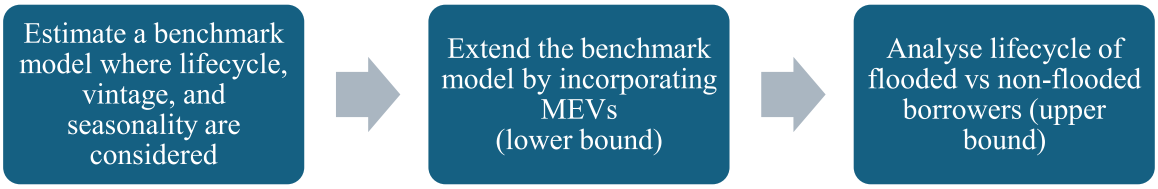


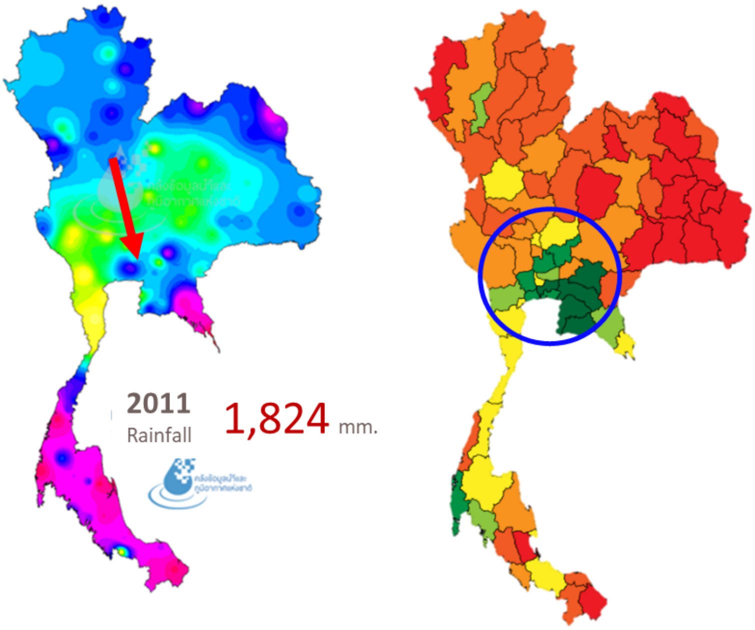
Figure 4: Climate risk decomposition steps.

Results

Flood 2011

The Thailand Flood of 2011 serves as an ideal case for climate risk stress testing. This flood is regarded as one of the most devastating in Thailand's history. (World Bank, 2012; Poapongsakorn and Meethom, 2013). It was triggered by a combination of natural phenomena, unregulated land-use practices, and heavy rainfall during the rainy season. The flooding impacted 65 provinces, with the Chao Phraya and Tha-Jeen River basins experiencing the most severe inundation. The floods began in late July 2011 and subsided by mid-December 2011. The manufacturing sector bore the brunt of the impact, especially due to flooding in industrial estates in Ayuthaya and Pathum Thani. The floods led to a 1.1% reduction in real GDP growth in 2011 compared to pre-flood projections. However, reconstruction efforts initiated in 2012 were anticipated to boost real GDP growth in 2012 by 1.7%. Without these reconstruction efforts, real GDP would have declined by THB 50 billion (USD 1.7 billion) in 2012.

Following the 2011 Thailand floods, the government took several measures to aid in the economic recovery from the disaster. These included financial assistance, tax breaks for affected companies, relaxation of import tariffs, and the rebuilding of damaged infrastructure. In the financial sector, banks responded in two primary ways. Firstly, they implemented debt relief programs, offering options such as skip payments, partial payments, installment plans, and interest rate reductions from November 2011 to January 2012. These programs typically ranged from 1 to 9 months in duration. Secondly, there were soft loans provided under a royal decree, allowing the central bank to lend THB 210 billion to local private and state-owned banks at a minimal interest rate of 0.01%. These banks, in turn, offered THB 90 billion of their own funds for loans to individuals and small and medium-sized enterprises (SMEs) affected by the flood, with an interest rate of 3% and a five-year maturity period.



(A) Rainfall 2011 (B) GDP per capita

Figure 6: Thailand Map of Rainfall 2011 and GDP per capita

Source: Hydro Informatics Institute (Public Organization)

Climate Risk Scenario Evaluation

To ensure climate scenarios are both extreme and plausible, we employ Extreme Value Theory (EVT) to assess the likelihood of severe climate events. Unlike conventional statistical methods, EVT is uniquely suited for this task because it specifically focuses on extreme events—such as catastrophic floods—and quantifies tail risks by linking event severity to their associated probabilities. This approach allows us to model rare but high-impact scenarios critical for stress testing financial resilience against climate shocks.

For our analysis, we utilize key hydrologic measurements, including rainfall and river flow runoff rates, to evaluate flood risks. Specifically, we select river flow runoff rates located at Nakhon Sawan province which is upstream of Chao Phraya River as our primary flood indicator, as these directly capture the water volume contributing to downstream flooding. Runoff data is from Royal Irrigation Department since 1979 is used in the analysis. By integrating EVT with these physical climate metrics, we establish a robust framework to estimate the probability and magnitude of extreme flood events, ensuring our stress tests reflect both historical precedents and scientifically grounded future risks.

The EVT model, illustrated in the figure 8, estimates the likelihood of extreme flood events based on historical river flow data. The black line represents the point estimate of return levels, while the grey shaded area indicates the 95% confidence interval, reflecting uncertainty in the predictions. At the 2011 flood's runoff level (marked by the blue line), the return period is approximately 1-in-50 years, meaning an event of this magnitude has a 2% annual probability of occurrence. However, if the river flow rate were double the 2011 level, such an extreme event would become far rarer, with a return period of 1-in-1000 years.

For supervisory climate stress testing, regulators often adopt a 1-in-100-year event as a benchmark, striking a balance between plausibility and severity. This framework helps anchor climate scenarios in statistically robust estimates, ensuring they are both realistic (grounded in historical data) and demanding (testing financial resilience against severe but plausible shocks). By quantifying the relationship between event severity and likelihood, EVT provides critical guidance for designing actionable stress tests that address tail risks without relying on implausible extremes.

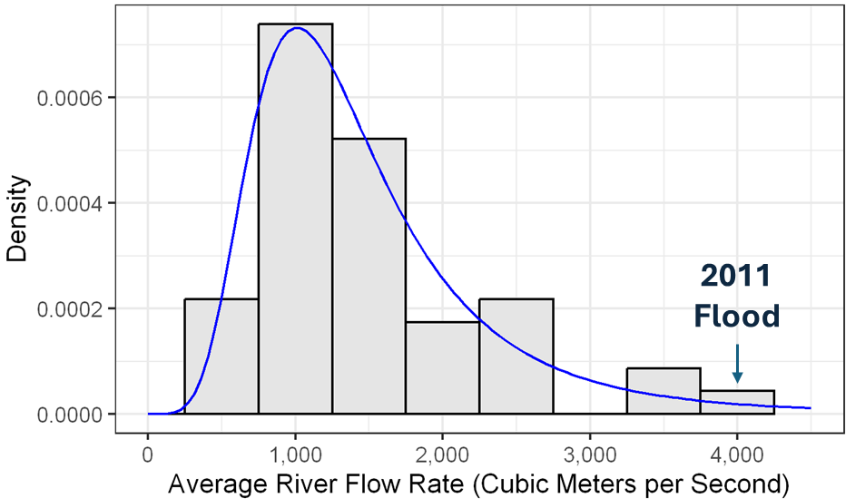


Figure 7: Distribution of Average River Flow Rate from 1978 – 2024

Source: Royal Irrigation Department

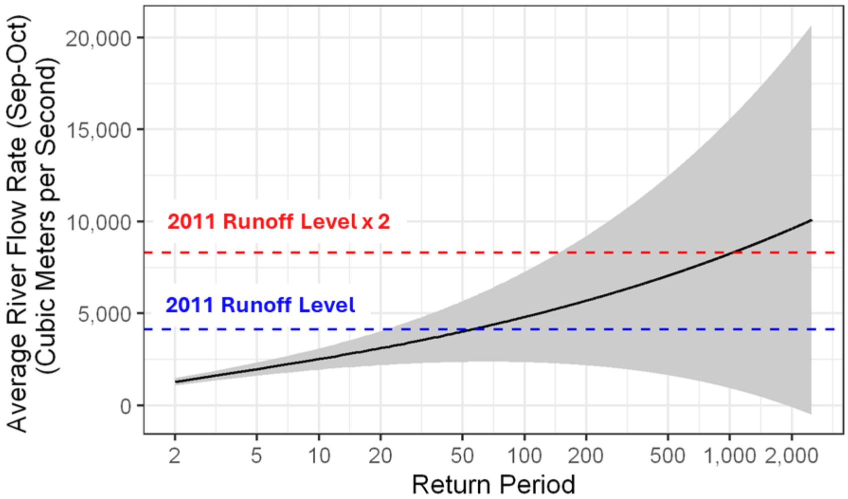


Figure 8: Extreme Value Analysis

Portfolio Analysis

Vintage analysis is employed to evaluate the climate impact on the mortgage portfolio yields several key findings. Firstly, small immediate flood impact in 2011Q4 was observed, evident from the actual default rate being higher than the default rate predicted by the model as shown in Figure 9. Despite the debt assistance program, an increase in default rate occurred due to ineligible delinquent borrowers. Secondly, post-flood, the default rate was expected to rise, but the actual rate was lower than anticipated due to debt relief programs. This discrepancy depicted in Figure 9 suggests economic risk from the flood event and could be seen as a lower bound of flood impact.

Thirdly, comparing the lifecycles of flood-affected and non-flood affected borrowers in the post-flood periods, flood-affected borrowers exhibited increased risk. The higher could-be default rates among flood-affected borrowers can be viewed as an upper bound of flood impact illustrated in Figure 10. Finally, the 2011 flood had a relatively limited impact on the mortgage portfolio which might contrary to expectations. While the flood damaged many residential properties, most homes suffered only non-structural damage, allowing borrowers to repair them without long-term financial distress. In contrast, automobiles exposed to prolonged submersion experienced total losses, leading to a sharp spike in defaults within the auto loan portfolio.

The study reveals that flooding has a modest financial impact on Thailand's mortgage sector, as debt-relief initiatives and a strong economic recovery helped curb default risks. However, the high exposure of key economic hubs, particularly Bangkok and the central plains which are highly flood-prone, poses a challenge, since businesses and residents find it difficult to shift to less vulnerable areas. This pattern of localized resilience is comparable to the aftermath of Hurricane Sandy in the New York-New Jersey region, where a quick economic rebound limited long-term damage. By contrast, regions affected by Hurricane Katrina experienced a slower recovery, struggling to regain pre-disaster economic levels.

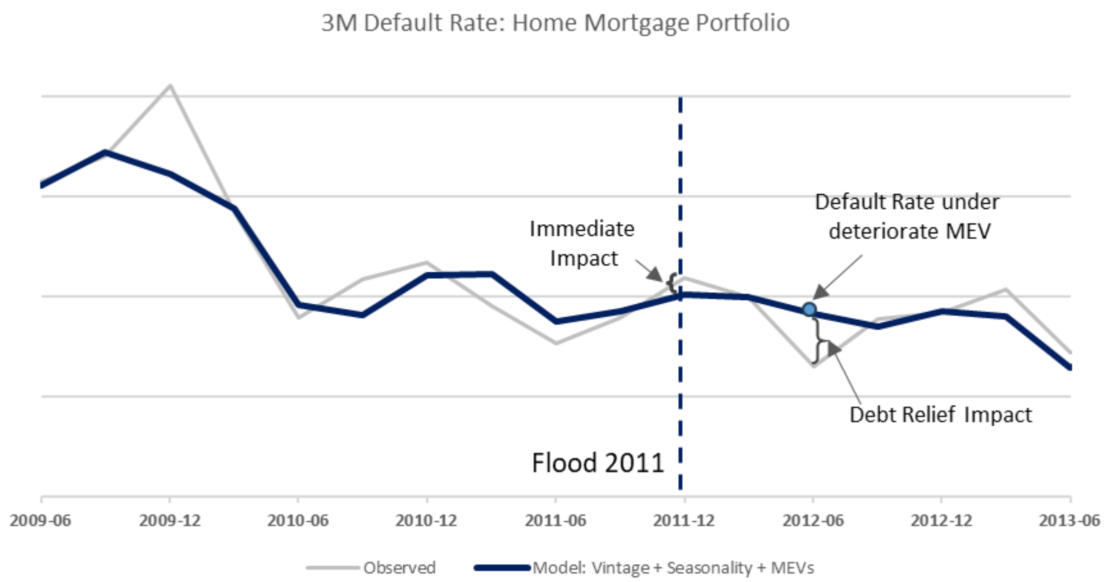


Figure 9: 3-month default rate of a home mortgage portfolio from 2009-2013.

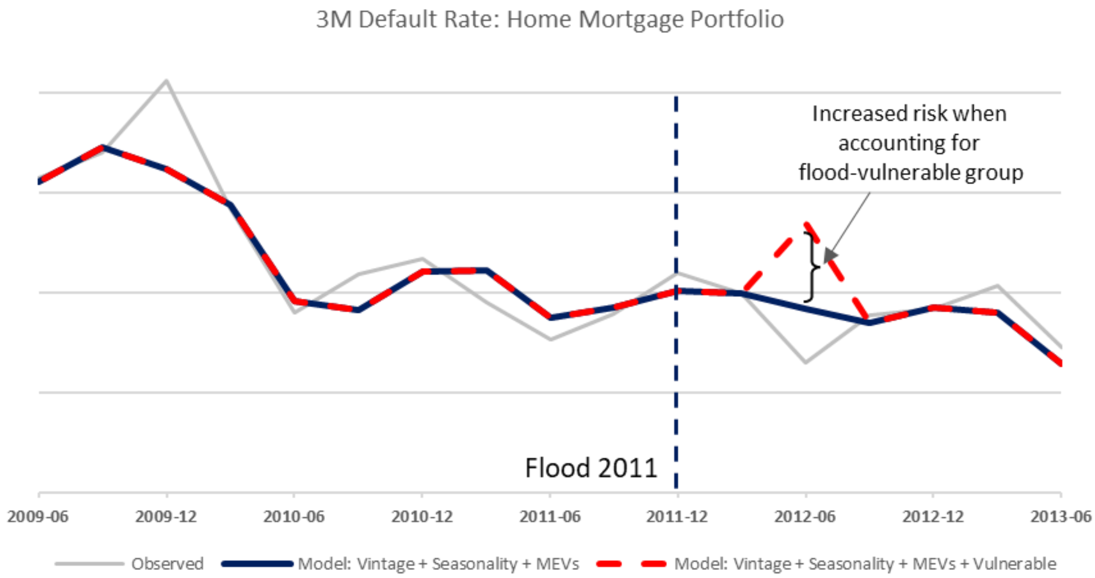


Figure 10: 3-month default rate of a home mortgage portfolio from 2009-2013 with consideration of flood-vulnerable group.

Forecast:

After decomposing the climate impact, the insights gained will become a crucial ingredient for climate risk stress testing. This testing can be seamlessly integrated into the existing current stress test framework as shown in Figure 11.

Climate scenarios are developed and align with publicly available scenarios, for instance, Network for Greening the Financial System (NGFS) or the Intergovernmental Panel on Climate Change (IPCC). Note that in practice, the climate scenarios, narrative, key MEVs are provided to financial institutions by central banks. It is useful to have a benchmark extreme event model to assess the likelihood of the extreme event which could provide us a guidance on how to scale climate-related impact.

Next, the climate scenario narratives and their economic impacts will be fed into the vintage-based model to forecast default probabilities under given climate stress scenarios. Subsequently, these financial parameters information are integrated into the economic stress test framework for comprehensive risk assessment.

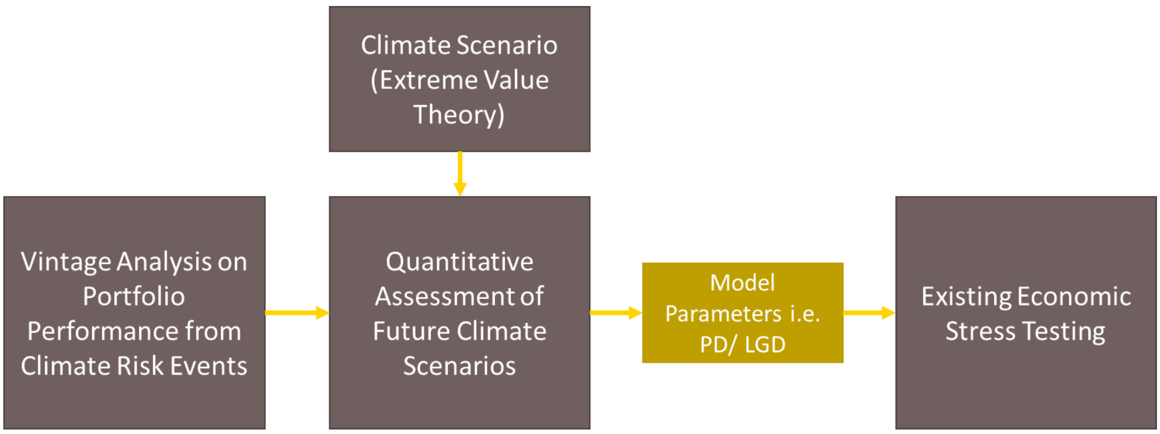


Figure 11: Climate Risk Stress Test Forecast

Discussion

Assessing the true financial impact of floods presents significant challenges due to the influence of external interventions. During Thailand's 2011 flood event, government and bank responses - including debt relief programs and long-term soft loans - substantially mitigated potential defaults, making it difficult to observe the flood's direct financial consequences. Our analytical approach addresses this challenge by decomposing the various contributing factors. This method separates the flood's direct impact and associated relief measures from other influences such as normal loan lifecycle patterns and broader macroeconomic conditions. By isolating these components, we can better understand how climate shocks and policy responses independently affect financial outcomes.

The economic and environmental context surrounding flood risks has evolved considerably since 2011, creating new vulnerabilities and mitigation factors. Household debt levels have risen dramatically, increasing from manageable levels in 2011 to approximately 90% of GDP today. This elevated debt burden significantly reduces households' ability to secure additional loans for flood recovery, potentially amplifying default risks in future flood scenarios. Concurrently, substantial investments in water management infrastructure following the 2011 disaster may reduce physical damage from similar flood events. However, the continued concentration of economic activity in flood-prone regions like Bangkok and the central plains maintains significant exposure to potential financial disruptions. These contrasting developments - increased financial vulnerability alongside improved physical protections - underscore the need for stress-testing frameworks that can adapt to changing risk profiles and account for both enhanced resilience measures and emerging financial vulnerabilities.

This evolving landscape highlights the importance of dynamic risk assessment models that can incorporate both structural improvements in flood defenses and the growing financial constraints of affected populations. Such models are essential for developing accurate projections of how future flood events might impact financial systems under current economic conditions

Conclusion

Many aspects of climate risk are highly uncertain, highlighting the need to consider not just the severity of adverse climate events but also their probabilities.

An evidence-based approach is proposed to quantify extreme physical risk, focusing on modeling what is feasible. It's important to recognize that addressing other issues like chronic physical risk or transition risk may require different methodologies.

Vintage analysis framework, with minor adjustments, can be tailored for various scenarios. The existing vintage-based forward-looking PD model is expanded to distinguish between the impact of climate and government assistance. This framework, incorporating loan understanding, is versatile and applicable to diverse portfolios.

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