Climate Risk Analysis: Integration into Barbados Banking Solvency Stress Testing Framework

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Abstract

This paper presents an in-depth analysis of the integration of Climate Risk Analysis (CRA) into the banking solvency stress testing framework of the Central Bank of Barbados (CBB). Leveraging technical assistance from the International Monetary Fund (IMF), the study explores the potential economic impacts of climate-related risks, particularly in a tourism-dependent economy like Barbados. The analysis incorporates high-resolution data from the Coastal Zone Management Unit (CZMU) of Barbados and utilizes econometric and stress testing tools to project the effects of catastrophic events on key economic indicators such as GDP, unemployment, and non-performing loans (NPLs). The findings underscore the significant vulnerability of Barbados to climate risks, highlighting the necessity for robust risk management frameworks to ensure financial stability. This paper contributes to the growing body of literature on climate-related financial risks, offering insights that are particularly relevant for small island developing states.

1. Introduction

The frequency and intensity of natural hazards have increased significantly across various regions, including the Caribbean, since the 1950s (Arias and others, 2021). Barbados, like many other countries in the region, is highly susceptible to these hazards, particularly floods and tropical cyclones. These natural disasters can result in substantial economic losses. Over the past decade, global economic losses from natural hazards have averaged around $170 billion annually, with peaks reaching $300 billion in some years (UNDRR, 2022). The

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economic impact of these events has grown considerably since the 2000s, reflecting the increased intensity and frequency of natural hazards (UNDRR, 2022).

As climate risks continue to escalate, the need for robust frameworks to assess and mitigate these risks has become increasingly urgent. In response to these challenges, the Central Bank of Barbados (CBB), with technical assistance from the International Monetary Fund (IMF), has embarked on an ambitious project to integrate Climate Risk Analysis (CRA) into its banking solvency stress testing framework. This initiative aims to enhance the CBB's ability to anticipate and manage the financial stability risks posed by climate change, ensuring that the Barbadian economy remains resilient in the face of growing environmental threats (Patankar & Patwardhan, 2016).

The methodology employed in this study leverages econometric techniques and stress testing models to quantify the potential impacts of climate-related shocks on key economic indicators such as GDP, unemployment, and non-performing loans (NPLs). Central to this analysis is the use of high-resolution data from the Coastal Zone Management Unit (CZMU) of Barbados, which provides detailed projections of hazard exposure and vulnerability across the island (Monasterolo & Raberto, 2018). These data, combined with the CLIMADA tool and other modeling frameworks, allow for a comprehensive assessment of the economic losses that could result from catastrophic events (Dietz et al., 2016).

This paper is structured as follows: Section 2 introduces the climate context in which Barbados operates and the description of the damages rates estimated by the IMF using the CZMU dataset. Section 3 reviews the relevant literature on climate-related economic risks and their implications for financial stability, with a focus on small island developing states. Section 4 details the data sources and types of data utilized in the analysis, including the CZMU data and key economic indicators sourced from the Central Bank of Barbados. Section 5 describes the methodology employed in the study, including the integration of climate damage estimates into the macroeconomic framework and the calibration of stress testing scenarios. Section 6 presents the results of the analysis, highlighting the potential impacts of climate risks on the Barbadian economy, with particular emphasis on GDP contraction, unemployment, and banking sector resilience. Finally, Section 7 concludes the paper by summarizing the key findings and discussing the implications for future policy-making and research, emphasizing the need for ongoing efforts to strengthen climate resilience in Barbados.

2. Context

The anticipated increase in the intensity and frequency of tropical cyclones, coupled with the potential for significant sea level rise, poses severe threats to the island's infrastructure, economy, and, by extension, its financial sector. Figure 1, which presents the exposure and damage estimates for various climate-related hazards, illustrates the substantial potential economic losses Barbados could face under different return periods for hazards like rain floods, storm surges, and wind. These estimates highlight the gravity of the situation, with damages in some scenarios reaching as high as 9.10% of the total exposure for a 1-in-100-year storm surge event.

Figure 1: Economic Exposure and Damage Estimates for Key Climate Hazards in Barbados

Hazard	Return period	Exposure (A) BBD, 2017	Damages (B) BBD, 2017	Percentage damage (A / B)
Rain flood	1-in-100	44,999,685,498	1,842,470,612	4.09
Rain flood	1-in-50	44,999,685,498	1,575,989,458	3.50
Storm surge	1-in-100	44,999,685,498	4,093,747,407	9.10
Storm surge	1-in-50	44,999,685,498	2,266,645,569	5.04
Wind	1-in-100	44,999,685,498	1,847,039,485	4.10
Wind	1-in-50	49,435,149,530	905,545,347	1.83

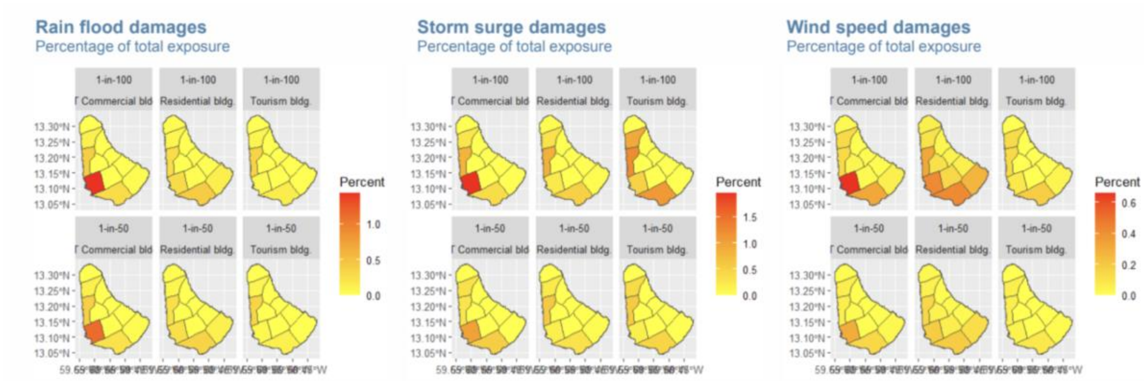
Source: International Monetary Fund (IMF) Technical Assistance Report and Presentation for the Central Bank of Barbados

These risks underscore the need for a robust framework capable of assessing and mitigating the economic impacts of climate-related shocks. The International Monetary Fund (IMF), recognizing these challenges, initiated a series of technical assistance missions aimed at strengthening the Central Bank of Barbados's (CBB) capacity to integrate climate risk into its existing macroeconomic framework. The focus of this assistance is on enhancing the banking sector's solvency stress testing frameworks to account for the potential impacts of climate change. This initiative aligns with global efforts to ensure that financial systems are resilient to the risks posed by environmental changes.

The macroeconomic framework under development by the CBB, with support from the IMF, incorporates a blend of econometric techniques and accounting structures across several key sectors: the real sector, the fiscal sector, the balance of payments, and the monetary sector. This holistic approach ensures that all aspects of the economy are considered when assessing potential risks. Central to this framework is the stress testing of credit risks, where satellite models are used to project the effects of various economic variables such as GDP, unemployment, tourist arrivals, and inflation on non-performing loans (NPLs). The integration of climate risk into this framework involves understanding how climate-induced shocks, such as hurricanes, could exacerbate these economic variables, particularly in a tourism-dependent economy like Barbados.

One of the critical steps in this integration process is the calibration of damage estimates. This involves adjusting models to reflect the observed data accurately, ensuring that predictions of future climate-related damages are as realistic and reliable as possible. The calibration process makes use of historical climate data and sophisticated modeling tools, such as the Climate Impact Data Analysis (CLIMADA) tool, which estimates the economic losses from climate events by analyzing variables like wind speed, precipitation, and storm surges. Figure 2 complements this discussion by visually representing the spatial distribution of damages across Barbados, categorized by hazard type and building type. The maps reveal the geographic variability in damage risk, emphasizing areas that are particularly vulnerable to specific hazards, such as commercial buildings in southern Barbados that face significant risks from storm surges.

Figure 2: Spatial Distribution of Damage Percentages by Hazard Type and Building Category



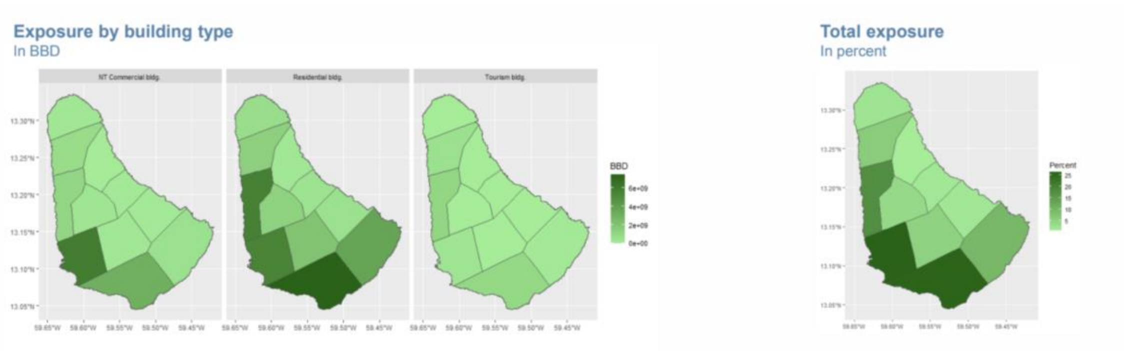
Source: International Monetary Fund (IMF) Technical Assistance Report and Presentation for the Central Bank of Barbados

Damages arise from the interaction of three key components: the severity of the hazard, the exposure of economic assets to these hazards, and the vulnerability of these assets if the hazard materializes.

For exposure, spatially disaggregated GDP datasets are used as a proxy for the distribution of physical assets, consistent with future socio-economic projections up to 2100. Vulnerability is assessed using damage functions from Huizinga et al (2017) for floods and Eberenz et al (2021) for tropical cyclones, which have been adapted for the Barbadian context.

The Coastal Zone Management Unit (CZMU) of Barbados provides essential data for this calibration process, including high-resolution exposure and vulnerability data. This data is crucial for creating detailed risk assessments, as it allows for the analysis of the potential impact of climate events at a granular level. The CZMU's estimates consider various hazards—such as storm surges, rain floods, and wind—and categorize exposures into residential, commercial, and tourism-related assets. Figure 3 offers a deeper look into this aspect by showing the spatial distribution of economic exposure across Barbados, broken down by building type. The map highlights regions with high economic stakes, particularly in the southern and coastal areas, where the concentration of commercial and tourism assets is highest.

Figure 3: Geographic Distribution of Economic Exposure by Building Type in Barbados

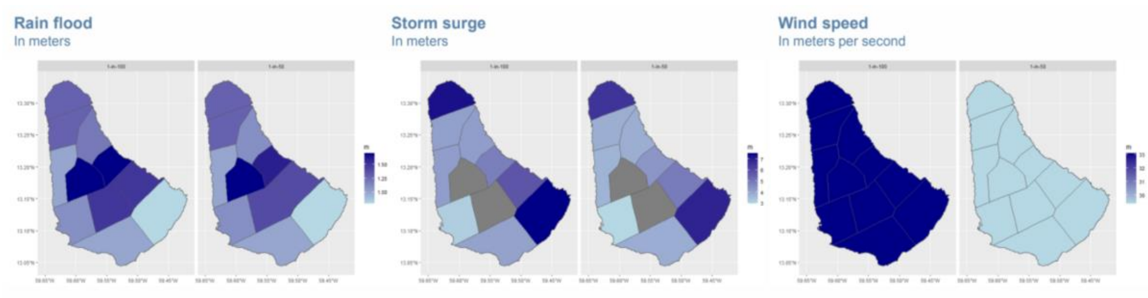


Source: International Monetary Fund (IMF) Technical Assistance Report and Presentation for the Central Bank of Barbados

By integrating this data into the stress testing framework, the CBB can better understand the potential economic losses from climate events and their implications for the banking sector. Furthermore, the macroeconomic framework considers multiple approaches to linking climate damage estimates with broader economic variables. These include multivariate approaches that integrate capital stock, GDP, and unemployment elasticity to assess the indirect effects of climate shocks on the economy. For instance, tourism damages are linked to reductions in tourist arrivals, which in turn affect GDP and employment levels (Monasterolo & Raberto, 2018). By modeling these relationships, the CBB can develop more accurate forecasts and stress scenarios that reflect the potential economic impact of climate change.

Incorporating climate risk into financial stability assessments is not just about addressing immediate concerns; it is also about preparing for future challenges. The IMF's technical assistance to the CBB emphasizes the importance of forward-looking analysis, considering both short-term and long-term climate risks. This includes developing scenarios that account for various climate pathways and their potential impact on the Barbadian economy. Figure 4, showing the projected changes in key climate variables like temperature, precipitation, and the frequency of tropical cyclones, underscores the need for this long-term perspective. The integration of these scenarios into the macroeconomic framework will allow the CBB to anticipate and mitigate the financial risks posed by climate change, ensuring that the banking sector remains resilient in the face of growing environmental challenges.

Figure 4: Projected Intensity of Climate Hazards (Rain Flood, Storm Surge, and Wind) Across Barbados



Source: International Monetary Fund (IMF) Technical Assistance Report and Presentation for the Central Bank of Barbados

This comprehensive approach to climate risk analysis represents a significant step forward in safeguarding the financial stability of Barbados. By embedding climate considerations into its stress testing framework, the CBB is positioning itself at the forefront of global efforts to address the financial risks associated with climate change. This initiative not only enhances the resilience of the Barbadian banking sector but also serves as a model for other small island developing states facing similar challenges.

3. Literature Review

3.1 Overview of Climate-Related Economic Risks

The increasing frequency and intensity of natural disasters, exacerbated by climate change, have drawn significant attention to the economic risks posed by such events. While chronic climate risks, particularly those related to long-term temperature changes, have been the focus of extensive research, the literature addressing acute climate risks, such as floods and tropical cyclones (TCs), remains comparatively underdeveloped (e.g., Burke et al., 2015; Kalkuhl & Wenz, 2020; Kahn et al., 2021). Understanding the economic impact of these acute risks is critical, especially for regions like the Caribbean, where small island nations are particularly vulnerable (Arias et al., 2021).

3.2 Flood-Related Economic Risks

Floods are one of the most significant climate-related hazards, causing substantial economic losses globally. The economic damages caused by floods are primarily determined by the depth and duration of inundation, which affect both the extent and severity of the impact on physical assets. Damage functions, which establish a relationship between water depth and economic loss, are widely used in flood impact assessments. These functions typically express damage as a percentage of the asset value or as an absolute loss figure (Huizinga et al., 2017).

Several key studies have provided valuable insights into the global distribution of flood risks. Alfieri et al. (2017) demonstrated a strong positive correlation between atmospheric warming and future flood risks, noting that these risks are unevenly distributed across different regions. Their study employed a multi-model framework that integrates simulations of river flow and flood processes with datasets on exposure and flood protections. Dottori et al. (2018) further expanded on this by analyzing the socioeconomic costs associated with river floods under different warming scenarios. They found that a 3°C warming scenario would lead to significantly higher impacts, particularly in regions that are already vulnerable to flooding.

The sensitivity of flood risk assessments to data resolution was highlighted by Smith et al. (2019), who used high-resolution population density data to map flood exposure across 18 countries. Their findings suggest that finer resolution data can lead to more accurate exposure estimates, which is crucial for small and densely populated regions like the Caribbean (Eberenz et al., 2021).

Huizinga et al. (2017) made significant contributions to the field by developing globally consistent empirical damage curves, which are now widely adopted in flood risk assessments. These curves estimate fractional damage as a function of water depth and are stratified by asset types, such as residential, commercial, industrial, and infrastructural categories. The application of these damage functions in different geographic contexts, including small island nations, helps improve the accuracy of flood damage assessments.

3.3 Tropical Cyclone-Related Economic Risks

Tropical cyclones are another major source of climate-related economic damage, particularly in coastal and island regions. The severity of TC-related damage is largely determined by factors such as sustained wind speeds, storm surges, and torrential rainfall. The maximum sustained wind speed is particularly important in quantifying the impact of TCs, and it is a key input in damage functions used to estimate direct economic losses (Emanuel, 2011; Czajkowski & Done, 2014).

The majority of research on TC-related economic damages has historically focused on the United States, where detailed damage functions have been developed for various building types and regions. For example, FEMA (2011) and Yamin et al. (2014) provided comprehensive damage functions for different building categories, which are widely used in U.S.-based risk assessments. However, these U.S.-centric models are not directly transferable to other regions, especially small island states like Barbados, where the built environment and infrastructural resilience differ significantly.

Recent efforts have aimed to broaden the applicability of TC damage functions to a global context. Yamin et al. (2014) conducted a comprehensive risk assessment for approximately 200 countries, though the damage functions were primarily calibrated based on U.S. data. This limitation was addressed by Mendelsohn et al. (2012), who developed an integrated assessment model to estimate global TC damages, though their model also relied on U.S. data for calibration. Recognizing the limitations of U.S.-based models, Bakkensen and Mendelsohn (2019) extended their analysis to include a larger set of countries, using models that account for both cross-sectional and time-series data. This approach helps mitigate the risk of overestimating losses when applying U.S.-based functions to other regions (Eberenz et al., 2021).

Eberenz et al. (2021) made a significant contribution to the literature by developing regionally calibrated damage functions, which provide more accurate damage estimates for different parts of the world. Their study utilized historical damage data from the International Disasters Database (EM-DAT) to calibrate these functions for various regions, including the North-West Pacific, where uncertainties are particularly high. The development of these region-specific functions is crucial for accurately assessing TC-related risks in regions like the Caribbean, where the economic impact of such events can be disproportionately severe.

3.4 Financial Risk

Climate-related financial risks, particularly those arising from the transition to a low-carbon economy, have become a focal point of research and policy development. This body of work seeks to quantify and address the potential economic and financial impacts that may result from efforts to mitigate climate change, such as through the imposition of carbon pricing, the phasing out of fossil fuels, and the adoption of renewable energy sources.

Historically, the assessment of these risks has been led by central banks and international financial institutions, which have developed frameworks and methodologies to gauge the vulnerability of financial systems to climate-related shocks. Notably, the European Central Bank (ECB) has been at the forefront of this initiative. The ECB's extensive work in this areahas provided a comprehensive foundation for understanding the interplay between climate transition risks and financial stability. These assessments are integral to the ECB's broader mandate of maintaining financial stability within the euro area, highlighting the increasing recognition of climate change as a systemic risk to financial systems (Reinders et al., 2021).

Parallel to the efforts of central banks, academic research has begun to explore the intricate relationships between climate risks and financial markets. Scholars such as Acharya et al. (2023) have made significant contributions by providing overviews of how climate risks can be integrated into financial models and stress-testing frameworks. Their work emphasizes the importance of considering both physical risks—such as those arising from climate-related natural disasters—and transition risks, which emerge from the economic shifts necessary to achieve climate goals.

The methodological approaches used to assess climate-related financial risks are varied and complex, reflecting the multifaceted nature of climate change itself. These approaches range from straightforward exposure assessments, which identify the extent to which financial institutions are exposed to climate risks, to more sophisticated stress tests that simulate the potential impacts of various climate scenarios on financial stability. For instance, Reinders et al. (2021) and Bresch and Eberenz (2020) have documented the evolution of these methodologies, noting the integration of diverse models and data sources to create more accurate and comprehensive assessments. These advancements have been crucial in helping financial institutions and regulators to better understand the risks they face and to develop strategies to mitigate them.

Despite the progress made, significant challenges remain, particularly for emerging market and developing economies (EMDEs). These regions often face unique obstacles, such as the lack of reliable data and the limited capacity to conduct in-depth assessments. Monasterolo (2020) has highlighted these issues, noting that the scarcity and specificity of data can hinder the ability of financial institutions in EMDEs to fully grasp the risks they face. Additionally, the methodologies and assumptions used in climate risk assessments are often developed in the context of more advanced economies, which may not be directly applicable to the circumstances of EMDEs. This underscores the need for tailored approaches that take into account the specific economic, social, and environmental conditions of these regions.

Moreover, the inherent uncertainties associated with climate change further complicate the assessment of financial risks. Climate change involves numerous unknowns, including the timing and magnitude of its impacts, the effectiveness of mitigation efforts, and the responses of markets and governments. These uncertainties make it difficult to predict the exact nature of the risks that financial institutions will face, which in turn complicates the development of effective risk management strategies. As a result, current climate risk assessments often serve more as exploratory and learning exercises rather than definitive evaluations, aiming to raise awareness and build capacity among financial institutions, supervisors, and central banks (Bolton et al., 2020).

Despite these challenges, climate stress tests have emerged as a vital tool for financial institutions. These tests enable institutions to identify potential vulnerabilities in their portfolios and to develop strategies for managing the risks associated with the transition to a low-carbon economy. By simulating various climate scenarios, stress tests help institutions understand the potential impacts on their balance sheets and develop plans to mitigate those impacts. This process not only enhances the resilience of individual institutions but also contributes to the overall stability of the financial system (Carney, 2015; Grippa, Schmittmann, & Suntheim, 2019).

Furthermore, the implementation of climate stress tests has important implications for regulatory and supervisory frameworks. Regulators can use the results of these tests to inform both micro-prudential and macro-prudential policies, ensuring that financial institutions are adequately prepared for the risks associated with climate change. The development of guidelines for climate risk management and stress testing has also promoted greater transparency and disclosure of climate-related risks, enabling market participants to make more informed decisions (TCFD, 2017).

In summary, the growing body of literature on climate-related financial risk assessment has laid a robust foundation for understanding the potential impacts of climate transition risks on the financial sector. The work of central banks, international financial institutions, and academic researchers has advanced the methodologies used to assess these risks, although challenges remain, particularly for emerging markets and developing economies. As climate change continues to pose significant risks to financial stability, ongoing research and methodological development will be crucial in enhancing the robustness and applicability of climate risk assessments, ultimately helping to safeguard the stability of the global financial system (IMF, 2023; Monasterolo & Raberto, 2018).

4. Data

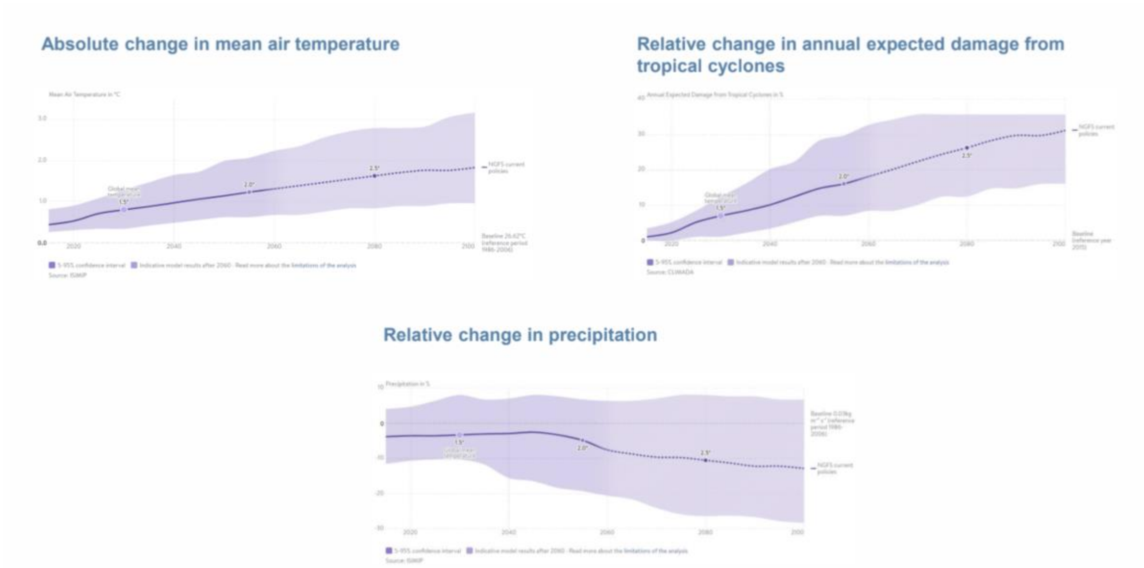
The data utilized in this study is derived from the Coastal Zone Management Unit (CZMU) of Barbados, which provides high-resolution, localized estimates essential for assessing climate risks in the region. The CZMU data is critical for understanding the potential impacts of various climate-related hazards on different sectors of the Barbadian economy. This data is categorized into hazard projections, exposures, vulnerability assessments, and damage estimates.

4.1 Hazard Projections

The CZMU provides detailed hazard projections for three primary climate-related threats in Barbados: storm surge, rain flood, and wind. These projections are available for return periods of 1-in-50 and 1-in-100 years, which are standard benchmarks for assessing the likelihood and severity of such events. Figure 5 complements this section by offering maps that depict the intensity of these hazards, including flood depths and wind speeds, across different regions of Barbados.

The CZMU's storm surge data considers the impact of rising sea levels and the associated flooding risks along the Barbadian coastline. This data is crucial for assessing the potential damage to coastal infrastructure and communities. Similarly, the rain flood projections account for extreme precipitation events that can lead to significant flooding, particularly in low-lying areas. These projections are spatially differentiated, reflecting the varying risk levels across the island. Wind data provided by the CZMU is used to assess the potential damage from high-velocity winds associated with tropical cyclones and other severe weather events. Unlike storm surge and rain flood data, which vary by location, wind risk is considered uniform across the country.

Figure 5: Projected Changes in Key Climate Variables: Temperature, Precipitation, and Tropical Cyclone Damage



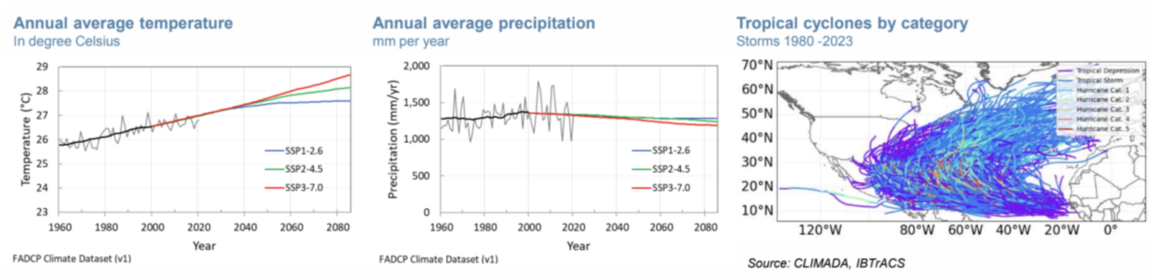
Source: International Monetary Fund (IMF) Technical Assistance Report and Presentation for the Central Bank of Barbados

4.2 Exposures

Exposure data from the CZMU is detailed and categorized into three main types: residential, commercial non-tourism, and commercial tourism assets. This classification allows for a nuanced analysis of how different sectors may be affected by climate-related hazards. Figure 3, as referenced earlier, provides a visual breakdown of this data by building type.

Residential assets include the geographic distribution and estimated value of residential properties across Barbados. This information is crucial for understanding the potential impact of climate hazards on the housing sector. Commercial non-tourism assets cover activities such as retail, offices, and industrial facilities, helping to assess the economic vulnerability of these sectors to climate risks. Given the significant role of tourism in the Barbadian economy, the CZMU also provides specific data on tourism-related assets, including hotels, resorts, and other facilities critical to the tourism industry, allowing for a focused analysis of how climate events might impact this vital sector. Figure 6 offers a historical and projected view of key climate and economic indicators, providing context for the economic data used in this study.

Figure 6: Historical and Projected Trends in Temperature, Precipitation, and Tropical Cyclone Activity



Source: International Monetary Fund (IMF) Technical Assistance Report and Presentation for the Central Bank of Barbados

4.3 Vulnerability Assessments

The CZMU's data includes vulnerability assessments based on FEMA's HAZUS methodology, which provides damage functions that relate hazard intensity (e.g., wind speed or flood depth) to the expected level of damage. These assessments are tailored to the Barbadian context by mapping local building types to the available categories in the HAZUS tool.

These damage functions are adapted for Barbados to estimate the vulnerability of different asset types to climate hazards. The data includes detailed damage curves that link specific hazard intensities to potential economic losses, providing a critical tool for the stress testing framework. Figure 2 illustrates how these vulnerabilities translate into actual damage percentages across different sectors and regions of Barbados, emphasizing the importance of localized vulnerability assessments.

4.4 Damage Estimates

Damage estimates provided by the CZMU are essential for quantifying the potential economic impact of climate events on Barbados. These estimates are calculated for each of the hazards- storm surge, rain flood and wind are expressed as a percentage of total asset value within the affected area. Figure 1 provides a comprehensive view of these damage estimates across different hazards and return periods.

The CZMU provides damage estimates at a fine spatial resolution (~100 meters), allowing for highly localized risk assessments. These estimates are crucial for identifying the areas most at risk and for developing targeted mitigation strategies. The damage estimates are further categorized by sector, enabling a detailed analysis of how different parts of the economy such as residential, commercial non-tourism, and commercial tourism might be affected by climate-related hazards.

4.5 Economic Data

In addition to the CZMU data, this study incorporates key economic indicators sourced from the Central Bank of Barbados. These indicators include the unemployment rate, credit growth, GDP, the level of capital, the level of employment, and the level of inflation. These variables are essential for linking the physical risks identified through the CZMU data to broader economic outcomes. By integrating these economic indicators into the macroeconomic framework, the study provides a comprehensive analysis of how climate-related damages could influence economic stability in Barbados.

5. Methodology

This study employs a comprehensive methodology to assess the economic and financial impacts of climate change on Barbados. The methodology is divided into two key components: the estimation of climate-related damage rates and the integration of these estimates into a macroeconomic production function, and the application of a stress testing framework to evaluate the resilience of the financial sector. These methodologies are informed by the Aide-Mémoire from the IMF's Climate Risk Analysis Technical Assistance (CRA TA) mission (IMF, 2023) and the Central Bank of Barbados's Macro Stress Testing Tool User Manual (Central Bank of Barbados, 2024).

5.1 Estimation of Damage Rate and Production Function Analysis

The first critical step in this study involves estimating the damage rates from climate-related events and using these estimates to calculate Total Factor Productivity (TFP) and the elasticity of capital within the Barbadian economy. This approach is essential for understanding how physical risks from climate change translate into broader macroeconomic impacts (Huizinga, De Moel, & Szewczyk, 2017).

The damage rate estimation is central to quantifying the physical risks posed by climate change. In this study, the damage rates are derived from high-resolution data provided by the Coastal Zone Management Unit (CZMU) of Barbados. The CZMU offers detailed projections of potential damages caused by storm surges, rain floods, and high winds. These projections are provided for different return periods, specifically 1-in-50 and 1-in-100-year events, which represent the probability of these extreme events occurring within any given year (Bresch & Eberenz, 2020).

The methodology for estimating damage rates involves several key steps. Initially, data collection and processing are conducted using the CZMU's spatially differentiated damage estimates, which are segmented across Barbados into residential, commercial non-tourism, and commercial tourism assets. This data is collected at a granular resolution (~100 meters), allowing for precise localization of potential damage zones (Eberenz et al., 2021). Following data collection, damage functions are calibrated using the FEMA HAZUS methodology, which provides a standardized approach to estimating economic losses based on the intensity of natural hazards. This calibration process involves mapping the local building types in Barbados to the FEMA damage categories, thereby enabling the use of established damage curves (FEMA, 2011). These curves relate the severity of the hazard, such as wind speed or flood depth, to the expected percentage of asset damage (Huizinga, De Moel, & Szewczyk, 2017).

After calibration, the damage functions are applied to the hazard projections to simulate the potential economic losses under various scenarios. For instance, the economic impact of a 1-in-100-year storm surge event is simulated by applying the relevant damage functions to the asset exposures identified in the CZMU data. These simulations produce damage rates, which are expressed as a percentage of the total asset value affected by the hazard (Eberenz et al., 2021). The projections also account for future climate conditions, as the CZMU data considers the effects of rising sea levels and increased storm frequency and intensity due to global warming. This adjustment ensures that the damage estimates are forward-looking and reflective of the likely future state of the climate (Bolton et al., 2020).

The next step involves integrating the damage rate estimates into a macroeconomic framework using a production function approach. The Cobb-Douglas production function is employed in this study, expressed as:

$$Y = A \times K(\alpha) \times L(\beta)$$

where Y represents total output (GDP), A denotes Total Factor Productivity (TFP), K is the capital input, and L is the labor input. The parameters α and β represent the output elasticities of capital and labor, respectively (Mendelsohn et al., 2012).

Total Factor Productivity (TFP) is calculated as a residual from the production function after accounting for the contributions of capital and labor. In this study, TFP is derived from historical economic data provided by the Central Bank of Barbados (Central Bank of Barbados, 2024). The damage rates estimated earlier are then incorporated into the production function to adjust TFP downward in scenarios where climate events cause significant capital destruction. The elasticity of capital α, a key parameter determining the sensitivity of output Y to changes in capital stock K, is estimated by analyzing historical data on GDP and capital investment in Barbados. By regressing GDP on capital stock and labor input, the study determines α, which is then used to project how reductions in capital due to climate-related damages will impact overall economic output (Monasterolo & Raberto, 2018).

Various scenarios are constructed to assess the impact of different levels of climate-induced capital destruction on TFP and economic output. For example, in a severe climate scenario, the damage rate is applied to reduce the effective capital stock K, and the production function is used to estimate the corresponding decrease in GDP. This approach provides a quantitative measure of the potential economic losses attributable to climate risks (Battiston et al., 2017).

5.2 Stress Testing Methodology

The second component of the methodology focuses on stress testing the financial sector's resilience to climate-related risks. This is achieved using the Central Bank of Barbados's Macro Stress Testing (ST) Tool, which simulates the effects of adverse macroeconomic scenarios on the banking sector (Central Bank of Barbados, 2024).

The Macro Stress Testing Tool is a model that projects the financial performance of the Barbadian banking sector over a three-year horizon. It is designed to operate under multiple macroeconomic scenarios, including baseline, moderate, and severe scenarios, each of which can be tailored to include climate-related shocks. The key features of the tool include dynamic balance sheet projections, which forecast the evolution of banks' balance sheets under different scenarios. This includes projections of asset growth, credit quality, and capital adequacy. The balance sheet projections are influenced by assumptions about macroeconomic variables such as GDP growth, unemployment rates, and inflation, which are themselves affected by climate events in the severe scenarios (Grippa, Schmittmann, & Suntheim, 2019).

The tool allows for the creation of customized macroeconomic scenarios. In this study, scenarios are calibrated to reflect the potential economic impacts of climate-related damages as estimated in the previous section. For instance, in the severe scenario, the tool simulates a significant economic downturn resulting from a major storm surge, leading to higher non-performing loan (NPL) ratios and reduced credit growth.

The stress testing tool includes a detailed Credit Risk (CR) Module, which is crucial for assessing the impact of climate risks on the banking sector (Bresch & Eberenz, 2020). The CR Module projects the NPL ratio using a satellite credit risk model that links the macroeconomic variables, such as GDP growth and unemployment, to the likelihood of loan defaults. In scenarios where climate events cause substantial economic disruption, the model predicts a sharp increase in NPLs, reflecting the deteriorating credit quality of banks' loan portfolios. The provisioning component of the CR Module estimates the loan loss provisions required under IFRS 9, which directly affect the banks' profit and loss accounts (IMF, 2023). The provisioning rates are adjusted based on the projected NPL ratios and the severity of the economic downturn in each scenario, allowing the model to simulate the financial strain on banks as they increase provisions to cover expected credit losses.

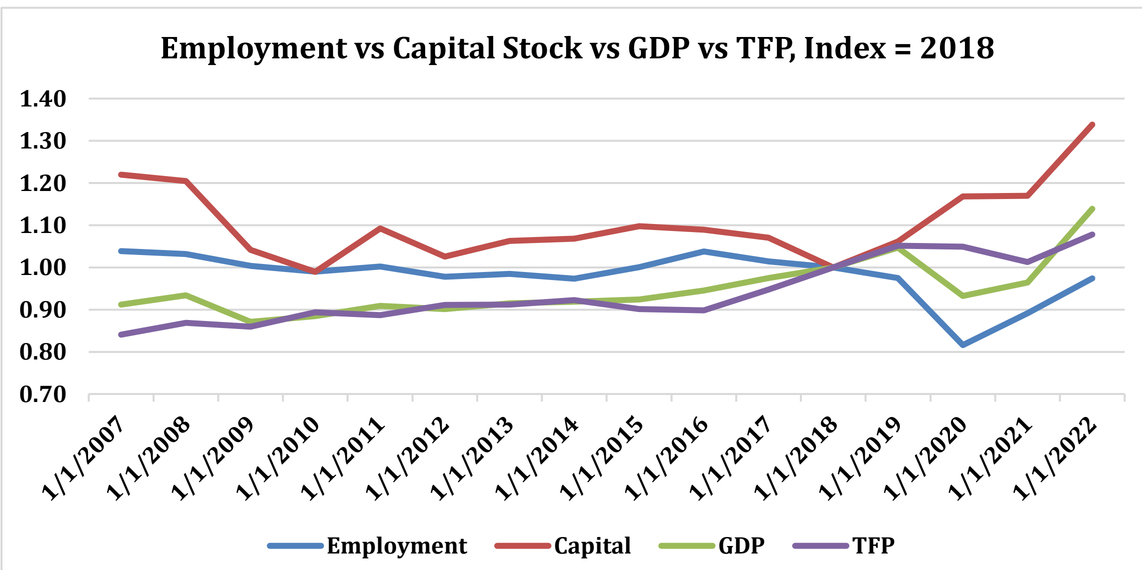
The tool also includes modules for projecting capital adequacy ratios (CAR) and profit and loss (P&L) accounts. The Capital Adequacy (CAP) Module projects the Tier 1 and total regulatory capital of banks against the risk-weighted assets (RWAs) over the stress testing horizon. The model assesses whether banks can maintain their CAR above the regulatory minimums under the different scenarios, particularly in the severe climate scenario where increased credit losses reduce capital buffers. The P&L Module projects the scenario-specific evolution of key income and expense items, including net interest income, non-interest income, and non-interest expenses. The model takes into account the impact of loan losses on net income, with severe scenarios leading to significant reductions in profitability due to higher provisioning expenses and lower credit growth (Acharya et al., 2023).

Moreover, the stress testing tool allows for the inclusion of additional risks, such as sovereign risk and concentration risk, which can be particularly relevant in a climate-impacted scenario. The tool can simulate a sovereign default scenario, reflecting the potential impact of a government debt restructuring on the banking sector. This is particularly relevant for Barbados, which has experienced such events in the past. In the context of climate risk, a sovereign default might be triggered by the fiscal pressures resulting from large-scale climate-related damages (Reinders et al., 2021). Additionally, the tool can assess the impact of the failure of large borrowers on the banking sector. In a severe climate scenario, where economic conditions deteriorate significantly, the failure of a few large borrowers could have a cascading effect on the financial system. The model simulates these potential shocks and their impact on banks' capital adequacy (Bresch & Eberenz, 2020).

6. Results

The integration of climate risk data into Barbados's macroeconomic framework offers an in-depth understanding of the potential economic and financial impacts of catastrophic events (CAT) on the island. This section presents a detailed analysis of these impacts, focusing on key economic indicators such as GDP, employment, and the stability of the financial sector. By examining the outcomes under different climate scenarios, we can assess the resilience of the Barbadian economy and its financial institutions to climate-related shocks. The findings are visually represented across several figures, each highlighting the relationship between specific economic variables and the projected impacts of various climate events.

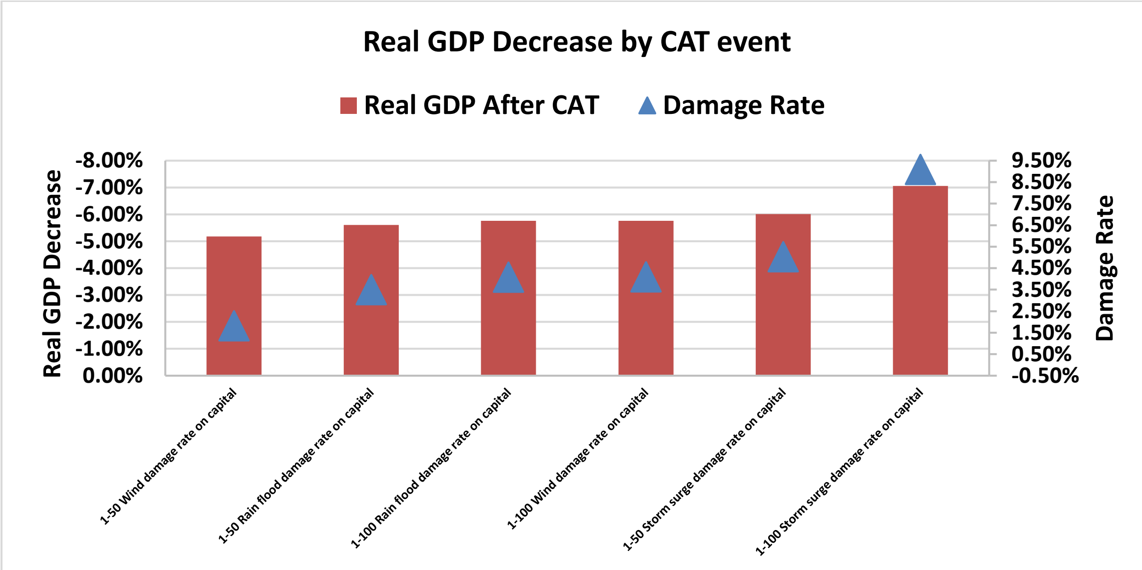
Figure 7: Trends in Employment, Capital Stock, GDP, and TFP (2007-2022)



Source: Author's Calculations

Figure 7 provides an overview of the trends in employment, capital stock, GDP, and Total Factor Productivity (TFP) from 2007 to 2022, with all values indexed to 2018. The data illustrate that while capital stock and GDP exhibited moderate fluctuations throughout the period, employment and TFP remained relatively stable until recent years. Notably, after 2020, a significant divergence is observed: capital stock rises sharply, likely reflecting increased investments or recovery initiatives following adverse events. Conversely, TFP declines, indicating that despite the growth in capital, the efficiency with which inputs are converted into outputs has diminished.

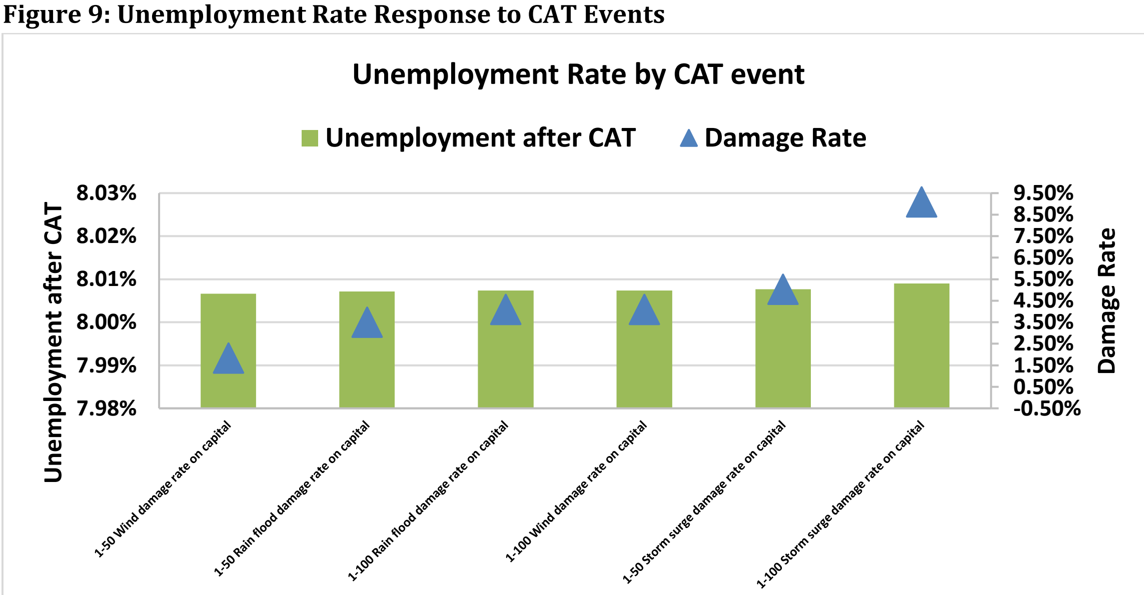
Figure 8: Real GDP Impact from Catastrophic (CAT) Events



Source: Author's Calculations

Figure 8 illustrates the projected decrease in real GDP following different catastrophic events (CAT), including wind damage, rain floods, and storm surges, across 1-in-50 and 1-in-100-year return periods. The analysis suggests that real GDP could decrease by as much as 7.05% in the most severe scenario, which involves a 1-in-100-year storm surge. The damage rate on capital is presented alongside GDP decreases, demonstrating the direct correlation between capital destruction and economic output. These results underscore the significant vulnerability of Barbados's economy to high-impact, low-frequency events, particularly those that result in substantial physical damage to capital assets.

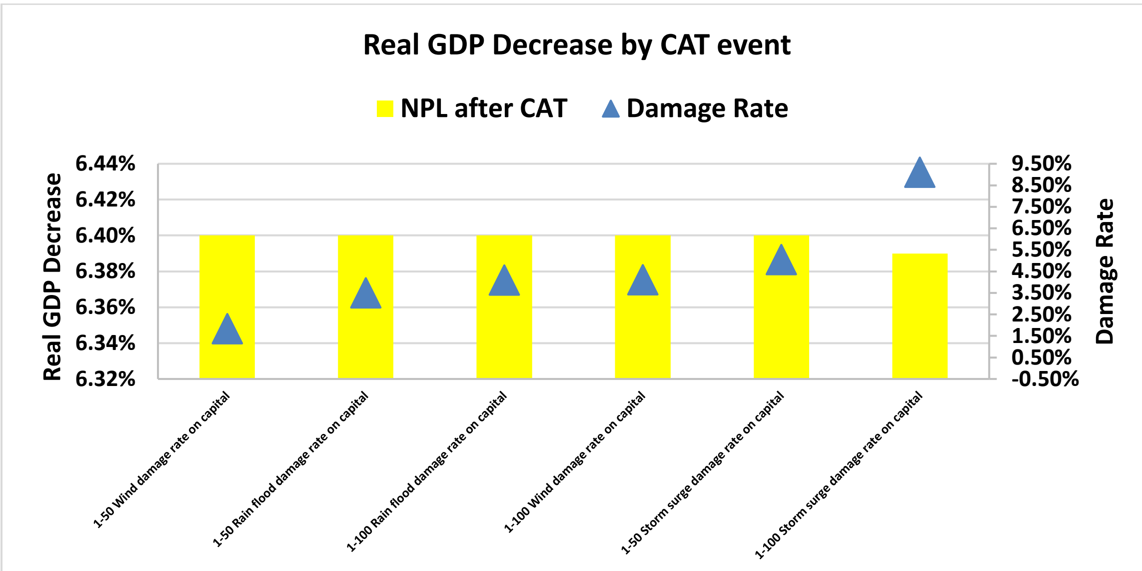
Figure 9: Unemployment Rate Response to CAT Events



Source: Author's Calculations

Figure 9 depicts the expected changes in unemployment rates following the same CAT events analyzed in the GDP impact study. The results indicate that the increases in unemployment rates are modest, ranging from 0.01% to 0.05 from the 8% rate used as baseline. The damage rates associated with these increases further highlight a lack of connection between capital destruction and labor market disruptions. Nonetheless, although GDP experiences more significant declines from CAT events, the rise in unemployment, though smaller, could have long-term effects on economic recovery and household income stability, not captured by the model.

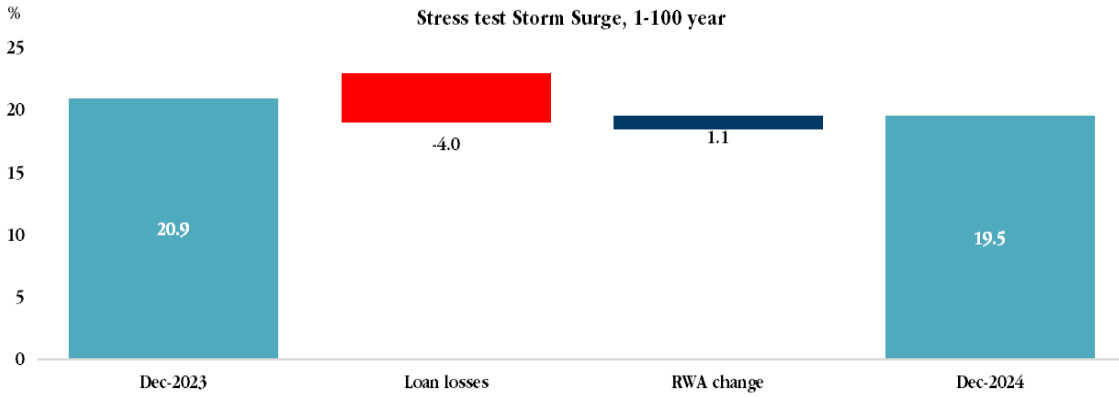
Figure 10: Effects of CAT Events on Non-Performing Loans (NPLs)



Source: Author's Calculations

Figure 10 explores the impact of CAT events on Non-Performing Loans (NPLs) within Barbados's banking sector. The findings reveal a slight increase in NPL ratios following catastrophic events respect to the pre CAT rate (6.04%). This uptick in NPLs, although modest, reflects the financial strain on borrowers due to the economic disruptions caused by climate events. The damage rates linked to each CAT event are presented alongside NPL changes, reinforcing the relationship between capital damage and the stability of the financial sector. The results suggest that even moderate increases in NPLs could have implications for the overall health of the banking sector, particularly if multiple CAT events occur within a short timeframe.

Figure 11: Impact of Catastrophic Event on CAR and Loan Losses: One-Year Stress Test



Source: Author's Calculations

The final results of the climate stress test are depicted in figure 11, which illustrates the Capital Adequacy Ratio (CAR) before and after a catastrophic (CAT) event, with specific attention to the periods of December 2023 (pre-CAT) and December 2024 (post-CAT). The CAR, representing the capital available to banks relative to their risk-weighted assets (RWA), serves as a crucial metric for assessing the resilience of financial institutions in the face of significant economic shocks.

In December 2023, prior to the catastrophic event, the CAR is shown at 20.9%. This ratio reflects a robust level of capitalization, well above the regulatory minimum, indicating that the banking sector was in a strong position before the climate-related shock. However, the occurrence of the CAT event leads to a significant increase in loan losses, which directly reduces the banks' capital reserves. Simultaneously, there is a marked rise in RWAs, attributable to the heightened risk associated with the banks' asset portfolios following the CAT event. This combination of increased loan losses and higher RWAs exerts downward pressure on the CAR.

By December 2024, after accounting for the impacts of the CAT event, the CAR decreases to 19.5%. Although this represents a decline from the pre-CAT level, it remains above the regulatory minimum, suggesting that while the banking sector's resilience has been somewhat eroded, it retains sufficient capital buffers to withstand the shock without immediate solvency concerns.

An important consideration in this analysis is the decision to limit the stress test to a one-year period. This decision was driven by the lack of historical data on the long-term recovery rate following storms in Barbados, as the island has not experienced many such events. The scarcity of data makes it difficult to project the recovery dynamics beyond the initial year following a catastrophic event. Consequently, extending the analysis to cover multiple years would introduce significant uncertainties regarding the long-term capital recovery and economic stabilization processes.

The results underscore the vulnerability of the Barbadian banking sector to climate-related shocks, particularly catastrophic events that can lead to substantial economic disruptions.

The decrease in CAR, while not immediately threatening financial stability, highlights the importance of ongoing risk management and capital planning. Policymakers and regulators should consider these findings when developing strategies to bolster the resilience of financial institutions, particularly in light of the increasing frequency and severity of climate-related events. Additionally, these results suggest a need for enhanced stress testing frameworks that incorporate climate risk scenarios, ensuring that banks are better prepared for potential future shocks.

7. Conclusion

The integration of Climate Risk Analysis into the Central Bank of Barbados's banking solvency stress testing framework represents a critical advancement in safeguarding the financial stability of Barbados in the face of climate change. The study's findings highlight the severe economic vulnerabilities posed by climate-related risks, particularly for small island developing states like Barbados. The potential impacts on GDP, unemployment, and the banking sector financial stability underscore the urgency of enhancing resilience through robust risk management strategies and frameworks. The technical assistance provided by the IMF has been instrumental in developing these capabilities, laying the foundation for future efforts to address the evolving challenges of climate change. Moving forward, it will be essential for the CBB to continue refining its CRA methodologies, incorporating new data, and adapting to the changing climate landscape. Collaboration with international partners and ongoing research will be key to ensuring that the Barbadian economy and financial sector remain resilient in the face of growing environmental challenges. This work not only strengthens Barbados's financial stability but also serves as a model for other small island developing states facing similar risks.

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