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MASTER'S FINAL WORK

DISSERTATION

TOP DOWN MACRO STRESS TESTING WITH PUBLIC DATA

FRANCISCO MIGUEL DE LEMOS NUNES RODRIGUES DOS SANTOS

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SUPERVISION:

PROF. JORGE BARROS LUÍS

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GLOSSARY

BIC Bayesian Information Criterion. 2

BIS Bank for International Settlements. 2

BMA Bayesian Model Averaging. 2

BoP Bank of Portugal. 2

CET1 Common Equity Tier 1. 2

EBA European Banking Authority. 2

ECB European Central Bank. 2

ESRB European Systemic Risk Board. 2

FI Financial Institution. 2

GDP Gross Domestic Product. 2

GST Global Stress Test. 2

HQLA High-Quality Liquid Assets. 2

IMF International Monetary Fund. 2

JEL Journal of Economic Literature. 2

LCR Liquidity Coverage Ratio. 2

NPE Non Performing Exposure. 2

NPL Non Performing Loan. 2

NSFR Net Stable Funding Ratio. 2

OLS Ordinary Least Squares. 2

RWA Risk Weighted Asset. 2

SIB Systemically Important Banks. 2

ABSTRACT

The global financial crisis highlighted significant vulnerabilities within the banking sector, prompting a reassessment of regulatory frameworks to strengthen financial stability. Macroprudential stress testing has become an essential instrument for assessing the stability of financial institutions, providing a holistic perspective on the sector's resilience. This dissertation explores the feasibility of conducting top-down macroprudential stress tests using publicly available data, focusing on the Portuguese banking sector. With data from the Bank of Portugal and by employing an econometric model, the study evaluates the impact of macro-financial variables on Common Equity Tier 1 (CET1) ratio under baseline and adverse scenarios for 2023–2025. Model results indicate that under the baseline scenario, CET1 ratios remained stable, with a slight decline from 16.36% in 2023 to 15.45% in 2025. Under the adverse scenario, CET1 ratios experienced a more pronounced decrease to 14.77% in 2025. Despite this decline, the capital ratios remained above the regulatory minimum of 11.1% for 2023 set by the ECB, underscoring the resilience of the Portuguese banking sector. Comparisons with stress tests conducted by the EBA and ECB reveal consistent trends, with this study's results being slightly more optimistic due to methodological simplifications and the use of aggregate data. The findings highlight the capacity of publicly available data to provide valuable insights into banking sector resilience, despite inherent limitations. This research underscores the practicality of public datasets to inform and enhance transparency in macroprudential policy. It recommends improving data granularity and refining models introducing new variables such as climate and cybersecurity risks, thereby strengthening the utility of stress testing frameworks for financial stability assessments.

KEYWORDS: Macroprudential Stress Testing, Financial Stability, Top-Down Stress Tests, Bottom-Up Stress Tests, Public Data, Portuguese Banking Sector, Common Equity Tier 1 (CET1) Ratio, Regulatory Frameworks, Data Quality and Timeliness, Financial Regulation, IMF Data Gap Initiative, Economic and Financial Stability Risks, Supervisory Activities

JEL CODES: G21, G28, C53, E44, G17

RESUMO

A crise financeira de 2008 revelou vulnerabilidades significativas no setor bancário, que motivou uma reavaliação da regulação e supervisão para reforçar a estabilidade financeira. Os testes de stress macroprudenciais tornaram-se uma ferramenta essencial para avaliar a estabilidade das instituições financeiras, oferecendo uma perspetiva holística da resiliência do setor. Foi realizada uma revisão de literatura sobre testes de stress, onde são apresentados as tipologias mais comuns, o tipo de dados utilizado e o interesse crescente em abordagens *top-down* que oferecem uma visão abrangente da resiliência global do setor bancário. Esta dissertação explora a possibilidade de realizar testes de stress macroprudenciais, numa abordagem "top-down", utilizando exclusivamente dados públicos, com foco no setor bancário português. Através de dados do Banco de Portugal, FMI e BCE e recorrendo a um modelo econométrico, este trabalho avalia o impacto de variáveis macrofinanceiras no rácio Common Equity Tier 1 (CET1) sob cenários de base e adversos para o período de 2023–2025. Os resultados do modelo indicam que, no cenário base, os rácios CET1 permaneceram estáveis, com uma ligeira descida de 16,36% em 2023 para 15,45% em 2025. No cenário adverso, os rácios CET1 registaram uma queda mais acentuada para 14,77% em 2025. Apesar deste decréscimo, os rácios de capital mantiveram-se acima dos requisitos mínimos de capital de 11,1% para 2023 estabelecido pelo Banco Central Europeu (BCE), destacando-se a resiliência do setor bancário português. As comparações com os testes de stress realizados pela EBA e pelo BCE revelam tendências consistentes, embora os resultados deste estudo sejam ligeiramente mais otimistas devido a simplificações metodológicas e ao uso de dados agregados. As conclusões sugerem a capacidade dos dados públicos fornecerem *insights* valiosos sobre a resiliência do setor bancário, apesar das limitações inerentes.

TABLE OF CONTENTS

List of Figures

List of Tables

1 INTRODUCTION

The global financial crisis, led by excessive lending and risk-taking activities without adequate capital and liquidity buffers and a strong supervisory framework , as described by Buch & Dages (2018). The substantial losses for banks and widespread uncertainty about the sector's ability to absorb losses, prompted a significant reassessment of regulatory frameworks to reinforce financial stability and reduce the impact of potential bank failures in the economy, as pointed out by Buch & Dages (2018). Macroprudential stress testing has emerged as an essential tool for evaluating the resilience of the banking sector, and it has been increasingly used to steer supervisory action.

A general survey of the literature reveals a shift from traditional bottom-up approaches, which focus on individual financial institutions, to top-down stress tests that provide a comprehensive view of the entire banking sector's resilience. It also highlights the importance of macroprudential stress testing in assessing systemic risks and informing regulatory policies. However, as claimed by Oura et al. (2012), authorities often face significant challenges in implementing these tests given limitations in the quality or availability of long time series data, which are essential for effective stress testing. Previous studies have primarily relied on granular supervisory data, which is often not accessible to the public, thereby limiting the applicability of their methodologies beyond these agents. Current efforts such as the IMF FSP Data Gap Initiative are being made to increase data capabilities to perform stress tests.

Therefore, this dissertation addresses the research question of whether it is possible to run a relevant macroprudential stress test using publicly available data for the Portuguese banking sector, and how do the results compare to the ones communicated by supervisory authorities? This research question is particularly relevant as it explores the practicality and reliability of using publicly accessible datasets in macroprudential stress testing. Accurate stress testing is crucial for identifying vulnerabilities within the banking sector and informing regulatory practices which enhance financial stability. Given the increasing emphasis on transparency and public accountability, the ability to conduct robust stress tests using publicly available data could significantly benefit regulatory bodies, policymakers, and financial institutions.

To address the research question, an econometric model, based on existing frameworks was developed, taking long data series from the Bank of Portugal and additional information from IMF and ECB databases as inputs. The study evaluates the impact of macro-financial variables on Common Equity Tier 1 (CET1) ratio under baseline and adverse scenarios for 2023–2025, using a top-down approach to assess the resilience of the Portuguese banking sector. By exclusively relying on publicly available data, the research aims to demonstrate the feasibility and limitations of this approach, providing a basis for

comparison with stress test results published by regulatory authorities.

The model results indicate that under the baseline scenario, CET1 ratios remained stable, with a slight decline from 16.36% in 2023 to 15.45% in 2025. Under the adverse scenario, CET1 ratios experienced a more pronounced decrease to 14.77% in 2025. Despite this decline, the capital ratios remained above the regulatory minimum of 11.1% for 2023 set by the European Central Bank (ECB), underscoring the resilience of the Portuguese banking sector.

Comparisons with stress tests conducted by the EBA and ECB reveal consistent trends, with this study's results being slightly more optimistic due to methodological simplifications and the use of aggregate data. The findings highlight the capacity of publicly available data to provide valuable insights into banking sector resilience, despite inherent limitations.

The contribution of this dissertation lies in its empirical demonstration of the applicability and effectiveness of macroprudential stress testing using publicly available data. By focusing on the Portuguese banking sector, the study offers valuable insights into the potential for enhancing transparency and regulatory practices using accessible datasets. The findings intend to inform fellow researchers, academics, and practitioners on evaluating the suitability of public data for macroprudential tests and overcoming potential issues they might face when performing such exercises when using such data.

This dissertation is structured around the following sections: Section 1 provides a cohesive understanding of the theoretical foundations, methodologies, challenges, and opportunities associated with macroprudential stress testing. Section 2 details the data and methodology used in this study, including the econometric model and scenario analysis. Section 3 presents the results of the macroprudential stress tests for the Portuguese banking sector, followed by a comparative analysis with EU-wide stress test results. Section 4 discusses the implications of the findings for regulatory practices and policymaking. Finally, Section 5 concludes the dissertation with a summary of the main findings, how it can contribute to the subject, and recommendations for future research.

2 LITERATURE REVIEW

2.1 Introduction

Stress tests in the financial industry can be traced back to the early 1990s when they were primarily employed by individual banks for internal risk management purposes. As Oura et al. (2012) outlines, these early stress tests were relatively small-scale exercises designed to complement other statistical tools available to bank management for assessing their trading activities. Stress tests gained prominence on a systemic level through initiatives like the Financial Sector Assessment Program (FSAP), launched by the International Monetary Fund (IMF) and the World Bank in 1999. The FSAP aimed to evaluate the health of financial sectors globally, incorporating stress tests as a key component of this comprehensive assessment. This shift of approach marked a pivotal moment, moving stress tests beyond internal risk management tools for individual banks to comprehensive assessments of the entire financial sector's robustness.

According to Baudino et al. (2018), the formalization of stress testing in the regulatory framework began in 1996 with the market risk amendment to the Basel Capital Accord (Basel I). In 2004 banks were required to incorporate rigorous internal stress testing exercises in both Pillar 1 (minimum capital requirements) and Pillar 2 (supervisory review process) under the Basel II framework. However, before the onset of the 2008 Financial Crisis, the implementation of Basel II, introduced in 2004, was not universal. Most internal stress testing models were still in the developmental stage, and their application was primarily limited to individual institutions. The 2008 financial crisis highlighted the severe economic repercussions when banks faced distress, reduced lending, and struggled with losses. In response, regulatory authorities in the U.S. and EU implemented stress testing as a crisis management tool. The U.S. Federal Reserve introduced several programs: the SCAP in 2009, followed by the Dodd-Frank Act Stress Tests (DFAST) and the Comprehensive Capital Analysis and Review (CCAR) Llorent-Jurado et al. (2024) makes the distinction that while CCAR focuses on ensuring that financial institutions maintain robust capital planning processes, the DFAST assesses whether they can absorb losses and continue operations under adverse conditions, aligning with macro stress testing. In Europe, the EU-Wide Stress Test was developed through collaboration between the EBA and ESRB, with the EBA coordinating the tests and communicating results, while he ESRB and ECB provide the adverse and baseline macroeconomic scenarios, respectively as Llorent-Jurado et al. (2024) describes.

The Financial Stability Institute of the BSI defines a stress test as a "forward-looking exercise aimed at evaluating the impact of severe but plausible adverse scenarios on the resilience of financial institutions." Specifically, in the context of the banking sec-

tor, Baudino et al. (2018) describes it as a "simulation exercise conducted to assess the resilience of either a single bank or the entire system to a hypothetical scenario." Importantly, stress testing is not about using forecasting techniques to predict banks' performance under stress. Instead, it focuses on evaluating their capital adequacy iunder a stress scenario, thereby supporting both microprudential and macroprudential policy objectives.

2.2 Microprudential Stress Tests

Stress tests designed with a microprudential objective aim to assess the resilience of individual banks. They can be conducted either by the banks themselves or by supervisory bodies. Banks perform these tests internally as part of their risk management practices, evaluating their capacity to withstand stress scenarios, according to Oura et al. (2012). Alternatively, stress tests can also be carried out by regulatory authorities, providing them with important information on whether specific banks adhere to regulatory standards, have adequate risk mitigation measures in place, and point out situations where a bank might require remedial actions. These include for example adjustments to regulatory capital, as safety buffers, reductions in risk exposures, or improvements in overall capital planning processes. The primary goal is to ensure the stability and health of individual financial institutions, thereby preventing systemic issues caused by weaknesses in any bank, which also grants this exercise a system-wide scope. Stress test results assume an essential role in the supervisory review process, becoming an integral part to the assessment of individual institutions. Supervisory authorities leverage these results to scrutinize the strategies, processes, and risk resilience of each bank comprehensively. The qualitative aspect of the supervisory assessment is enriched by the granular information derived from stress tests. Notably, some authorities utilize stress tests to review and validate the Internal Capital Adequacy Assessment Process (ICAAP) of banks, determine Pillar 2 capital requirements, and evaluate the soundness of individual banks' capital planning Baudino et al. (2018). The insights derived from stress tests at the microprudential level contribute significantly to the supervisory oversight, enhancing the understanding of the specific risk landscape each institution faces.

2.3 Macroprudential Stress Tests

Having sound banks at the individual level does not necessarily translate into financial stability, particularly with smaller and non-SIFI (Systemically Important Financial Institution). As evidenced by Anderson et al. (2018), the Asian financial crisis in the 1990's, shocks that initially seem to be confined to a few institutions, triggered a chain reaction, which expanded through the region and into the global financial system. The 2008

financial crisis motivated authorities to increasingly focus on maintaining a "macro" perspective on the risk assessment of financial systems. Macroprudential stress tests shift the focus to assessing system-wide resilience to shocks, extending beyond a mere aggregation of individual bank results. This "bird's-eye" view aims to capture the behavioural responses of affected institutions and their interactions with each other and the wider economic environment as Baudino et al. (2018) pointes out. Macroprudential exercises are typically top-down, meaning central banks and/or supervisory agencies are usually responsible for conducting them. It ensures that the methodology and assumptions considered are consistent by subjecting several institutions to the same scenario to assess the capital adequacy of the banking sector under adverse macroeconomic conditions. Central banks and supervisory agencies typically conduct these exercises. According to Oura et al. (2012), the results of macroprudential stress tests can inform authorities in calibrating macroprudential policy, with the primary goal of reducing the likelihood of systemic risk and mitigating its effects. As Anderson et al. (2018) states systemic risk corresponds to "the disruption to the flow of financial services that is caused by an impairment of all or parts of the financial system; and has the potential to have serious negative consequences for the real economy". Particularly in times of systemic financial crises, stress tests become instrumental in determining recapitalization needs for both individual banks and the banking system. Furthermore, they play a crucial role in restoring market confidence, a vital aspect in times of financial turmoil. Stress tests typically evaluate two aspects of a financial institution's performance: solvency and liquidity according to Oura et al. (2012)

2.3.1 Solvency Tests

Solvency represents an FI's ability to meet its financial obligations in the short, medium and long term. By analysing an FI's shareholder equity (the sum of its assets minus its liabilities) on the balance sheet, one can have a quick insight into an FI's solvency status. As Banque de France (2020) states a financial institution (FI) is considered solvent when its capital is positive or meets a minimum threshold capital requirement. Sustained solvency is ensured by FIs by maintaining a minimum level of capital, which acts as a financial buffer, allowing the institution to absorb potential losses in case of unforeseen shocks or adverse events. Beyond this baseline, additional capital might be deemed necessary to secure continued access to market funding at an economically viable cost and being a requirement to have access to the liquidity facilities offered by the Central Banks.

Solvency stress tests assess whether a firm has enough capital to remain solvent under a stress scenario by estimating factors such as profits, impairment losses, and valuation changes, as Oura et al. (2012) defines. The primary risks considered are credit risk (from borrower defaults) and market risk (from changes in prices such as interest rates, exchange

rates, and equity prices). Through sensitivity analysis the impact of individual risks or multiple sources of risks simultaneously can be assessed. Furthermore, risk factors may be combined in an ad-hoc approach through a combined shock test, or they may be systematically generated, using a macroeconomic framework. Different parts of the balance sheet are covered in solvency tests. For credit risk, total loans or specific segments (corporate, mortgage, credit cards) may be tested. Market risk is evaluated for securities in the Held-for-Trading (HfT) and Available-for-Sale (AfS) categories. According to Oura et al. (2012) Held-to-Maturity (HtM) securities may be excluded, as these are expected to be paid in full unless the borrower defaults. The author also claims that banks generally do not adjust liabilities for changes in interest rates during solvency tests, because of their positive duration gap. Banks' liabilities, such as deposits and short-term money market instruments, have low sensitivity to interest rate changes, tend to mature or reprice frequently, which minimizes their exposure to fluctuations in market rates.

A financial system or an individual institution is said to pass the stress test if the target capital ratio is above a predetermined threshold or "hurdle rate". Capital adequacy has evolved through the Basel Accords, set by the Basel Committee on Banking Supervision, in response to financial crises and systemic risks, as described by Gabriel (2016).

- Basel I, introduced in 1988 required banks to maintain a minimum capital ratio of 8% of risk-weighted assets (RWA), with assets assigned specific risk weights based on their perceived riskiness. Its versimplification of risk assessments was criticized, particularly for ignoring market and operational risks.

- Basel II (2004) sought to address these limitations by introducing a more sophisticated, risk-sensitive framework. It expanded capital requirements beyond credit risk to market and operational risks. It also introduced a three-pillar system: minimum capital requirements, supervisory review, and market discipline. This aimed to better align banks' capital with their risk profiles and improve transparency. However, despite its improved risk sensitivity, Basel II failed to adequately address liquidity and leverage risks, which became evident during the 2008 financial crisis as Gabriel (2016) points out.

- Basel III was introduced between 2010 and 2017, in response to Basel II weaknesses exposed by the crisis, raising capital requirements significantly. The minimum Common Equity Tier 1 (CET1) ratio was increased to 4.5% of RWAs, with an additional 2.5% capital conservation buffer (made of CET1 capital) and a countercyclical capital buffer in order to avoid the negative effects of the economic cycle on the lending activities.

2.3.2 Liquidity Tests

Financial institutions are faced with a liquidity shortage when they are not able to generate sufficient cash inflows in a stress scenario. Banks with adequate liquid assets can generate enough cash either by selling them or using them as collateral for repurchase agreements without incurring significant losses. However, if most available assets are nonmarketable loans or if their market value substantially drops below their book value (known as a "haircut"), banks might encounter liquidity challenges.

Liquidity concerns may originate from sudden distress with their funding. By the nature of their business, banks engage mostly on liquidity/term structure transformations. Therefore, maturity mismatches are expected to exist in their balance sheets. If a large amount of deposits is suddenly withdrawn, or funding markets (such as repurchase agreements and commercial paper) freeze, a bank might no longer be able to meet its current and future cash flow needs even if it is otherwise solvent (funding liquidity risk) Oura et al. (2012). If the banks cannot sell assets quickly, due to deterioration in its liquidity, without taking a severe loss, market liquidity risk would also have to be considered.

Another situation for liquidity risk occurs due to interlinkages between market and funding liquidity risk, with FIs actively involved in trading in the market. They may find themselves in a liquidity shortage situation when the markets for assets become unstable and may suddenly require more cash to meet certain obligations, such as initial margin (an upfront payment required to enter a trading position) or variation margin (additional payments required to cover losses in existing positions). If they are trading on derivatives, for instance, and FIs are borrowing heavily to make investments (leverage) they might find themselves short on cash if the current market price of the underlying asset is not favourable for the derivative holder), even if the situation improves later or the investment's status changes Oura et al. (2012)

Liquidity stress tests are designed to assess the risk a bank might struggle to generate enough funding from incoming cash flows to meet its short-term payment obligations, particularly when faced with a sudden surge in liabilities during a stress scenario. These scenarios typically involve adverse economic conditions, market disruptions, or other unforeseen events that could impact the bank's ability to manage its liquidity effectively.

The primary objective of these tests is to evaluate whether a bank has sufficient resources to cover its short-term financial commitments in the face of unexpected and adverse conditions. The focus is on the bank's ability to access and mobilize available funding sources during a defined stress horizon, which is the predetermined period over which the stress test is conducted. Various criteria can be employed in a liquidity stress test, including assessing the number of days a bank can withstand a liquidity shock before experiencing negative net cash flows, which would also lead to a decline in stressed

liquidity ratios.

The Basel III framework introduces both the LCR (Liquidity Coverage Ratio) and NSFR (Net Stable Funding Ratio) as part of its liquidity standards designed to enhance banks' liquidity risk management and promote the resilience of the banking sector. The LCR was introduced as part of Basel III to address short-term liquidity risk. It requires banks to maintain a buffer of high-quality liquid assets (HQLA) that can be quickly converted into cash to cover potential net cash outflows over a 30-day stress period. The LCR aims to ensure that banks have sufficient liquidity to withstand short-term funding disruptions without resorting to fire sales of assets or other destabilizing actions.

The NSFR complements the LCR by addressing longer-term liquidity risk. It evaluates the stability and maturity profile of banks' funding sources relative to the liquidity characteristics of their assets over a one-year horizon. The NSFR aims to promote more stable funding structures within banks by encouraging them to rely less on short-term wholesale funding and more on stable, longer-term funding sources.

It is very difficult to dissociate liquidity and solvency stress events as they are often closely related. For instance, a banks' solvency might be compromised due to a liquidity shortage triggered by a funding distress event, in which its assets might be difficult to sell or must be sold in a fire sale

2.3.3 Contagion Effects

The typical financial indicators concerning banks and FIs were explored previously. These can be assessed on an individual basis or system wide. However, because banks do not operate on their own and engage in relationships between them, for example interbank lending, a stress scenario for an individual FI might be propagated to another institution which cascades into more Fis. Therefore, it is also important contagion effects between FIs.

First, we have direct contagion through the solvency channel. This contagion channel works via counterparty risk, where the borrower cannot pay back the lender. If the borrower is in distress (for example because it defaults), this implies it is unable to repay its liabilities to its counterparties. Since these liabilities correspond to other agents' assets, these agents may now get in trouble, thereby affecting their counterparties, triggering a default cascade Aikman et al. (2023).

Alternatively, there is direct contagion via the funding-liquidity channel. This contagion channel works via funding risk. If the lender is in distress (for example because of a liquidity shock), it may decide to increase their cost of lending or pull their funding altogether. This is turn will cause a liquidity shock for the borrower which may also use similar defensive actions with his own counterparties. The literature has identified several

triggers that can cause liquidity to dry up in funding markets. The first potential cause of such an occurrence is solvency or liquidity problems at borrowing institutions. For example, firms suffering increased solvency risk are likely to experience increases in the cost and reductions in the availability of unsecured funding. This creates the possibility of a feedback loop whereby deteriorating bank solvency increases counterparty risk, leading to increases in the cost of funding, eroding bank solvency further Aikman et al. (2023).

Finally, there is also indirect contagion via the market-liquidity channel, which works via market-liquidity risk. Indirect links connect agents holding the same or similar assets via changes in asset prices. Suggested by Aikman et al. (2023) banks that suffer large losses may be forced to reduce risk by selling assets at distressed or fire sale prices. When other banks hold these or similar assets, they will be forced to revalue their holdings at these temporarily depressed valuations, creating the potential for distress to spread through the banking system, triggering further destabilizing fire sales

2.4 Data for Macroprudential Stress Tests

The design of macroprudential stress tests has historically faced significant challenges, particularly due to data limitations. As Anderson et al. (2018) highlights, these constraints are even more restrictive than in microprudential exercises, as they must capture both direct and indirect systemic risks and contagion effects. Despite the availability of public and supervisory data, issues like inconsistency, fragmentation, and high costs make data collection and analysis difficult. For this dissertation, which focuses on the Portuguese banking system, these data challenges are critical considerations.

2.4.1 Accounting and Supervisory Data

Accounting data, primarily obtained from financial reports and annual results, offers valuable insights into banks' assets and liabilities. However, as Anderson et al. (2018) highlights, several limitations affect its use in stress testing:

- **Inconsistency with Market Values**: Accounting data reflects historical values, while market data is forward-looking. This disparity becomes more pronounced during financial distress when liquidity is prioritized over long-term valuations. Consequently, accounting figures may not accurately represent the institution's current financial health.

- **Unreported Risk Exposures**: Off-balance sheet items, including derivative instruments, are often omitted or insufficiently detailed in financial reports. This lack of transparency poses challenges in identifying the full spectrum of risk, especially for institutions most vulnerable to stress.

- **Infrequent Data Updates**: Accounting data is typically updated annually or quarterly, making it difficult to reflect real-time changes in financial conditions. The reliance on outdated figures can lead to flawed assessments in stress tests.
- **Lack of Granularity**: Reports generally provide aggregated data, without detailed breakdowns by branch, subsidiary, or region. This lack of granularity complicates the analysis of cross-border risks and limits the ability to assess intra-group exposures within multinational banks.
- **Poor Asset-Liability Risk Assessment**: The aggregation of balance sheet data obscures specific risks related to assets and liabilities. This diminishes the effectiveness of stress tests in uncovering detailed vulnerabilities, particularly those tied to liquidity or capital adequacy.

Supervisory-level data provides a more detailed view of financial institutions, offering regulators access to comprehensive datasets for banks within their jurisdictions. However, there are notable drawbacks when using this data for stress testing.

Most supervisory data consists of accounting data, which means the limitations discussed in 2.4.1 still apply. Additionally, supervisory data often includes highly sensitive information that is generally not accessible to the public. This confidentiality hinders cooperation between regulatory authorities across different jurisdictions. Nonetheless, as noted by Anderson et al. (2018), academic access to supervisory data is gradually becoming more available. Another challenge regarding supervisory data is the lack of standardized data collection processes across jurisdictions. Anderson et al. (2018) suggests that data published at different levels of aggregation, which reduces the usefulness of supervisory data for measuring systemic risk.

2.4.2 Market Data

Market data is a crucial source of information for stress testing due to its widespread availability across developed and emerging markets, and its frequent updates, ranging from daily to real-time snapshots Anderson et al. (2018). The transparency and public availability of market data make it accessible to practitioners, policymakers, and academics alike, especially in situations where more comprehensive supervisory data may be limited or hard to obtain. This makes market data particularly valuable for price-based models, which are increasingly used in stress testing. Despite these strengths, there are certain limitations of market data that must be acknowledged:

- **Limited Predictive Power**: Although market data is considered forward-looking, it is often better at reflecting current financial conditions than predicting future

events. Market prices largely capture past behavior and sentiment rather than real-time decision-making processes. Additionally, the lag between risk-taking and outcomes, which can span years, means market data may not offer immediate predictive value for short-term market movements, limiting its utility for forecasting stress events.

- **Noise in the Data**: Market data can be affected by noise, meaning it may sometimes distort the true risk profile of financial entities. Particularly during periods of heightened market stress, short-term volatility may obscure fundamental financial conditions. However, even with this noise, market data remains valuable as it often reveals insights not fully captured by regulatory supervisors. Herd behavior can amplify market movements, and while not all market signals should be dismissed, understanding their context is crucial in interpreting stress test outcomes.

- **Completeness and Accuracy**: Market data, while abundant, is not always available for all institutions or in every market. In certain countries or less liquid markets, price data may be incomplete or unreliable, making it difficult to conduct comprehensive analyses. Additionally, shallow or illiquid markets can result in prices that are uninformative or misleading, reducing the reliability of market data as a stress testing tool in those contexts.

2.4.3 Flow Data

In recent years, collection of flow data has increased, aiming to track the speed and extent of capital movements between asset classes or countries. This data is valuable for understanding international financial dynamics, focusing on key aspects:

- **Timing of Inflows and Outflows**: Flow data helps identify the timing of capital shifts, offering insights into the temporal aspects of investor movements.

- **Geographic Allocation**: It assesses the geographic distribution of investments, helping to understand global capital flows.

- **Country and Sector Flows**: Comprehensive flow data includes information on both country-specific and sector-specific investment movements, offering a detailed view of capital distribution.

- **Risk Appetite Indicators**: Flow data can reflect investors' and institutions' risk appetite by analyzing their cash or reserve positions.

Although flow data is increasingly important, its availability varies across countries, markets, and asset classes, which poses challenges for comprehensive analysis. As this

data becomes more complete, it will provide valuable insights for macroprudential policymakers.

2.4.4 Initiatives to Address Data Availability

Since the global financial crisis, several initiatives have aimed to improve data quality. The IMF/FSB/G20 Data Gap Initiative (DGI) has played a central role in these efforts. DGI-1 (2009-2015) focused on conceptual frameworks and enhancing statistical collection, aligning data provision across participating economies FSB (2022). Building on this, DGI-2 (2015-2021) established a structured approach for consistent data collection and timely dissemination, emphasizing data sharing, risk monitoring, and financial interconnections. Progress was noted in areas like Financial Soundness Indicators (FSIs) and data on global systemically important financial institutions (G-SIFIs).

However, challenges remain, particularly in creating databases for analyzing contagion effects. Promising developments include increased access to trade repository data and OTC (Over-The-Counter) derivatives records, particularly under the European Market Infrastructure Regulation (EMIR). These datasets help trace contagion channels in the financial system. The TOTEM internal pricing model validation process used by FIs also provides new opportunities for researching risk transmission across markets. Despite these advances, governance restrictions, especially in Europe, limit researchers' ability to access comprehensive data, such as viewing both sides of cross-border trades. Anderson et al. (2018) argues these restrictions impede a comprehensive analysis of financial dynamics and the complete understanding of market interactions.

2.5 Macroprudential Stress Tests Models and Frameworks

2.5.1 Balance Sheet and Market-Based Models

Balance Sheet Models

Also known as fundamental approach, balance sheet models focus on assessing the impact of adverse economic or financial scenarios through a bank's balance and measure the resilience under such stress conditions. The goal is to determine how changes in economic and financial variables would affect the various components of the banks' balance sheet. In the case of macroprudential stress testing, this would reflect on examining the impact of macroeconomic variables, such as GDP growth, interest rates, and unemployment on the FI's balance sheet. It is a very detailed and informative approach useful in identifying the origin of individual vulnerabilities by the accounting identities, which are provided in prudential reporting. Aikman et al. (2023) points out drawbacks on balance-sheet based approaches as they are backward-looking, data-intensive, which makes them

hard to update frequently. and also not ideal for capturing interdependence and contagion effects between FIs.

Market-Based Models

In the absence of granular data, market-based tests are presented as an alternative, or rather a complement) to balance-sheet models. They can use market information on the default risk of a bank to assess the impact of different stress scenarios on its solvency as explained by Chan-Lau (2013). Their benefits are simplicity, low data intensity and automaticity. However, Constâncio (2015) challenges their usefulness for policymaking. The estimates vary widely, depending on the definition of the capital ratio, the reference threshold, and the underlying stress assumptions which may not be linked to a macroeconomic scenario. Additionally, market-based models are inherently volatile. Their interpretation might lead to a dangerous false sense of comfort in quiet times, and during stress periods they are likely to exaggerate low bank market capitalisation levels and big capital shortfalls, inducing fear and distress. This volatility would also impact resulting capital requirements by varying them in the short term, rendering them unusable by authorities for macroprudential purposes. Constâncio (2015) also highlights the fact that when compared to the Comprehensive Assessment by the SSM, performed in 2014, market-based metrics provided substantially higher estimates of capital shortfalls

2.5.2 BEAST and GST Stress Testing Frameworks

BEAST (Banking Euro Area Stress Test) Framework

The BEAST framework, introduced by the ECB, represents a significant evolution from its predecessor, STAMP€. Baudino et al. (2018) states that unlike STAMP€, which used a modular approach with separate stages for scenario design, impact assessment, and contagion analysis, BEAST integrates these elements into a single, comprehensive model. As describes it combines economic conditions, bank risk parameters, and accounting identities into a unified system, allowing it to capture systemic risk transmission and feedback loops between banks and the real economy, according to Budnik et al. (2018).

BEAST features a dynamic balance sheet approach, enabling banks to adjust their portfolios and interest rates based on stress scenarios, as opposed to the static approach of STAMP€. This dynamic modeling makes BEAST more realistic by allowing banks to react to adverse conditions, as Constâncio (2015) highlights. Additionally, BEAST incorporates feedback loops where changes in the financial sector affect the real economy and vice versa, enhancing its ability to model systemic risks. The model operates quarterly and includes two main components: a macroeconomic block, which tracks key variables

like GDP and inflation, and a bank-level block, which uses detailed bank data to model reactions and interactions Budnik et al. (2018).

Global Bank Stress Test (GST) Framework

The GST framework, introduced by the IMF in 2020, provides a global perspective on bank resilience, particularly in response to the COVID-19 pandemic. GST analyzes 29 major banking systems and uses publicly available data to assess capital adequacy under stress scenarios. GST's methodology includes projecting changes in capital ratios based on financial statements, risk-weighted assets (RWA), and other factors. It employs panel data regression models to estimate the impact of macroeconomic conditions on bank performance, while also accounting for cross-border spillovers and feedback loops as Ding et al. (2022) outlines. However, the reliance on less granular public data means the GST's results should be interpreted with caution, particularly when comparing them to more detailed supervisory data.

Both BEAST and GST frameworks highlight the importance of integrating macro-financial variables with bank-level data to assess systemic risks, though they differ in their approach and data requirements. Unlike BEAST, which relies on detailed bank data and feedback loops, GST uses a more simplified approach due to the limitations of public data. This includes focusing on high-level balance sheet data and using econometric models to estimate the impact of macro-financial variables on bank capital.

2.6 Conclusion

In this chapter, the evolution and significance of stress tests were discussed, from their inception by the IMF to their widespread adoption following the 2008 financial crisis. Stress tests, which focus on solvency, liquidity, and contagion risks, have become key tools for assessing vulnerabilities within the financial sector.

Liquidity stress testing evaluates a bank's ability to manage cash flows under stress scenarios, while solvency stress testing assesses capital adequacy in the face of adverse credit and market risks. These approaches provide valuable insights into potential risks, despite their respective challenges in data availability and modeling constraints.

The review also examined various typologies of stress tests, contrasting balance sheet-based models, which are data-intensive but more detailed, with market-based models, which are easier to update but may be influenced by market volatility. Despite recent initiatives, such as the IMF's Data Gap Initiative, challenges in data availability persist, particularly in achieving the granularity required for public analysis.

Two key models, BEAST (ECB) and GST (IMF), were explored, highlighting the importance of feedback loops between the financial sector and the real economy. While

GST can model stress tests using publicly available data, it remains more aggregated compared to BEAST, which benefits from access to fine-grained supervisory data.

In summary, macroprudential stress testing has become an essential tool in modern financial regulation, offering a forward-looking approach to identifying systemic risks and enhancing market stability.

3 DATA AND METHODOLOGY

In this section, the stress testing model for the banking sector is outlined, spanning from data collection to model processing and fine-tuning. For the macroprudential stress test the following elements were required:

- Historical data about banks indicators, macroeconomic and financial variables
- A baseline scenario, with the expected behaviour if no shocks are introduced in the economy over the stress period; and an adverse scenario with aggravated shocks to test the resilience of the banking sector.
- An econometric model to understand the relationship between banks indicators and macro financial environment and to project changes in the baseline and adverse scenario.

3.1 Macroeconomic, Financial and Portugal's Banking Sector Data

The primary data source for bank indicators is the Bank of Portugal's banking sector time series, covering the period from 1990 to 2022. This dataset includes key financial information such as balance sheet, profit and loss (P&L), and solvency indicators (Risk-Weighted Assets (RWAs) and CET1 Own Funds). As noted by Esteves et al. (2019), the reported values for the banking sector are derived from aggregated data from various financial institutions. Importantly, this database does not provide direct estimates of the total banking system's values. While disaggregated data for individual institutions are accessible to internal users at the Bank of Portugal, they cannot be publicly disclosed due to confidentiality regulations. The dataset includes consolidated data for banking groups and individual data for standalone institutions. The number and scope of groups depend on the specific indicators being analyzed, with detailed descriptions provided in the documentation. According to Esteves et al. (2019), the aggregation process sums the relevant values from different banking groups. For interest rates, a weighted average is calculated based on transaction amounts, ensuring that the sizes of institutions are appropriately reflected. When data points are missing for specific institutions, straightforward interpolation methods are employed to fill these gaps. Such missing data is typically more common among smaller institutions, so the potential bias introduced by these estimates is minimal.

The banking sector data was complemented with Portuguese macroeconomic data, using the IMF WEO (World Economic Outlook) database, along with the Primary Commodity Price System (PCPS) for Brent oil price growth. Financial data such as interest rates and bond yields were collected using the ECB database. Data was gathered on quarter and annual basis. The macro-financial predictions made for the 2023 EU-wide banking

sector stress test were used for the baseline and adverse scenario. This exercise was coordinated by the European Banking Authority (EBA), in cooperation with the European Systemic Risk Board (ESRB).

The EU-wide stress test includes predictions such as developments in real GDP, inflation, unemployment rates, real estate prices, stock prices, exchange rates, interest rates and real gross value added for selected economic sectors, covering three years, from 2023 to 2025. The baseline macro-financial scenario for EU countries is based on the December 2022 projections from the EU national central banks, while the adverse macro-financial scenario was designed by the ESRB's Task Force on Stress Testing in close collaboration with the European Central Bank (ECB). In the adverse scenario, the combination of persistently high commodity prices, tightened global financial conditions and high uncertainty constitutes a strong downward drag on the world economy, which weighs heavily on foreign demand in EU countries. This, coupled with tighter domestic financial conditions and low consumer and business confidence, leads to a decline in EU GDP as EBA (2023*f*) suggests.

Because the scenarios were designed for the banking industry, these predictions were a reasonable choice for this work. Additionally, since the exercise uses the year 2022 as the cutoff data from the 2023-2025 stress test horizon there was no gap between the predictions and historical data available in the Bank of Portugal time series. The data from Bank of Portugal time series is presented on a quarterly basis. The macroeconomic and financial variables selected for this exercise follow the variables considered by the GST framework and are presented in the following table:

TABLE I: STRESS TEST MACROECONOMIC AND FINANCIAL VARIABLES USED

Variable Name	**Units**	**Historical Data Source**
Real GDP growth	Percent change	IMF WEO Database
Inflation growth	Percent change	IMF WEO Database
Unemployment rate	Percentage	IMF WEO Database
3 Month EURIBOR	Percentage	ECB Database
Term Spread between the 10-year and 2-year AAA Euro Area Government Bonds	Percentage	ECB Database
Oil Price (BRENT) growth	Percent change	IMF PCPS

The 3-month EURIBOR was chosen as the short-term interest rate. The term spread was calculated by considering by considering the yields of AAA Euro Area Government Bonds on 10-year and 2-year yield curves, with the projections for 2023-2025 proxied from long-and short-term rates in the EU for the same period. The term spread between

10-year and 2-year AAA Euro Area Government Bonds was calculated by subtracting the 2-year bond yield from the 10-year bond yield:

$$\text{Term Spread} = [\text{10-year Bond yield}] - [\text{2-year Bond yield}] \tag{1}$$

3.2 Methodology

To test the hypothesis of whether a stress test can be performed using public data from the Portuguese Banking System, a solvency stress test was developed involved projecting changes in capital ratios based on the impact of macro-financial variables under both baseline and adverse scenarios. Taking into account the frameworks presented earlier, this work is guided by the Global Stress Test (GST) framework (2.5.2) but modifies it to fit the characteristics of aggregated data from the Portuguese banking sector.

The GST framework according to Ding et al. (2022) encompasses the following steps: first the P&L components and changes in Other Comprehensive Income (OCI) are linked to macroeconomic and financial variables using fixed-effects panel regression models. Probabilities of Default (PD) and Loss Given Default (LGD) are then inferred from projected loan losses, which are then used to calculate Non-Performing Loans (NPLs) and Risk-Weighted Assets (RWAs). Finally, these elements are translated into changes in the Common Equity Tier 1 (CET1) ratio. PD and LGD are pivotal in calculating RWAs, which directly influence the capital requirements banks must maintain.

Adaptations for Portuguese Banking Sector Data

In this work, the GST framework was adapted to fit the nature of the available data from the Bank of Portugal (BoP). Unlike the GST framework, which relies on granular, bank-level data, the BoP dataset contains aggregate historical time series for the Portuguese banking sector, including pre-calculated data for CET1, RWAs, and CET1 capital ratio. This led to significant methodological differences:

- **Direct Modeling of CET1 Ratio:** Utilizing the dataset from the Bank of Portugal, which directly provided CET1 capital, RWAs, and the CET1 ratio, this study modeled the relationship between macroeconomic variables and the CET1 ratio directly.
- **Use of Aggregate Data:** The data represents the entire Portuguese banking sector, capturing sector-wide average behavior across all banks rather than individual bank-level dynamics. Unlike GST's granular approach, the aggregate data limits the ability to explicitly analyze spillover effects or heterogeneity between banks. While sector-wide interactions and dependencies were assumed, given that banks

in Portugal generally operate within the same domestic market context, they were not explicitly modeled in this analysis.

- **Econometric Approach:** The GST Framework employs a fixed-effects panel regression models, as they capture time-invariant characteristics specific to the banks, ensuring robust estimation of relationships between macroeconomic variables and P&L components for individual banks. In this study, the dependent variable (CET1 ratio) was regressed on a set of contemporaneous and lagged macroeconomic and financial predictors (X) using an ordinary least squares (OLS) regression approach, subsequently refined through Bayesian Model Averaging (BMA) to address model uncertainty.

The resulting equation for the model is the following:

$$y_t = a + b_t X_t + \varepsilon_t \tag{2}$$

While this study draws on the GST framework, its methodology has been adapted to the constraints and opportunities presented by publicly available, aggregate data from the Portuguese banking sector. These modifications highlight how stress testing can be effectively applied in data-constrained environments, where access to granular data is limited or unavailable.

3.2.1 Bayesian Model Averaging

Based on the approach by Ding et al. (2022), the analysis employs Bayesian Model Averaging (BMA) to identify the most relevant predictors for the CET1 Ratio. This statistical technique addresses model uncertainty by averaging over multiple models, with different combinations of predictors, rather than selecting a single best model. This approach considers the uncertainty associated with model selection, leading to more robust predictions and inferences Penny et al. (2007). Each model's importance is weighted based on how well it explains the data using Bayesian Information Criterion (BIC). The final predictions and parameter estimates are then averaged, providing a more comprehensive and reliable forecast of the CET1 Ratio.

First the model combinations are generated, iterating over all possible combinations of predictor variables. For each combination, it applies the same constraints as used in the Ding et al. (2022) where each equation of the model should contain at least one of the macro variables: real GDP growth, unemployment rate or one of their lags and complemented with remaining predictors.

Next, using the historical dataset, for each combination of predictors, a linear regression model is fitted using Ordinary Least Squares (OLS). Key statistics (AIC, BIC,

R-squared, p-values) are extracted from each fitted model. Next the posterior probabilities are calculated, by using the models' BIC values as it balances model fit (via the likelihood) with model complexity (penalizing for the number of parameters) as outlined in StataCorp (2023). Each model is assigned a posterior probability, which represents the likelihood of the model being correct based on observed data. The following equation is used to determine the posterior probability:

$$\text{posterior probability}_i = \frac{\text{weight}_i}{\sum \text{weight}_j} \tag{3}$$

These probabilities are used to weight the contributions of each model. The model with the lowest BIC is assigned the highest weight, according to the following equation outlined in StataCorp (2023)

$$\text{weight}_i = \exp\left(-\frac{1}{2}\left(\text{BIC}_i - \min\left(\text{BIC}\right)\right)\right) \tag{4}$$

Coefficients from each model are averaged, weighted by the model's posterior probability. Similarly, the R-squared, BIC values and p-values are averaged using the posterior probabilities which will be used to assess the models' fitness.

This technique contributes to the analysis' robustness. By averaging over many models, the BMA produces estimates that are less sensitive to the specific choice of predictors. Additionally, it acknowledges multiple models may explain the data well and integrates this uncertainty into the final estimates Penny et al. (2007). Finally predictive performance is improved as averaging predictions from multiple models often leads to better out-of-sample performance compared to relying on a single model.

The methodology then moves on to assess the model's performance through key goodness-of-fit metrics, including R-squared and p-values of the independent variables. The relationships between predictors and the dependent variable are analyzed within the economic context, reinforcing the model's credibility and robustness in stress testing applications.

Finally, the averaged coefficients are applied to the model equation to predict the impact on CET1 capital ratios of the Portuguese Banking System under baseline and adverse macroeconomic scenarios for the 2023-2025 horizon.

4 MACROPRUDENTIAL STRESS TEST RESULTS FOR THE PORTUGUESE BANKING SECTOR

This section presents a descriptive analysis of the variables considered in the previous sections, which include Portugal's macroeconomic performance and its banking sector stability from 2012 to 2022. The period under review encompasses significant economic events, including the aftermath of the European debt crisis, the consequent economic recovery phase, and the impact of the COVID-19 pandemic.

4.1 Descriptive Analysis

Real GDP growth is a critical measure of economic performance, adjusted for inflation. Over the period from 2012 to 2022, significant fluctuations are observed in Portugal's GDP growth. Between 2012 and 2013, the economy was marked by recessionary pressures, with GDP contractions peaking at -1.6% in 2012. This period reflects the lingering effects of the European debt crisis, where austerity measures and structural reforms were implemented to stabilize the economy. The negative GDP growth rates indicate a period of economic hardship and restructuring. Moving to the period between 2014 and 2019, this can be considered a recovery phase, where there was steady growth, signalling economic stabilization and recovery efforts. The GDP growth rate improved, with positive figures averaging around 0.5% to 1% in most quarters. This reflects a rebound from the earlier recession, driven by increased economic activity and confidence. In 2020, the COVID-19 pandemic caused a sharp decline in GDP growth, with significant contractions in 2020. The recovery began in late 2021, supported by both national and EU-level fiscal and monetary interventions.

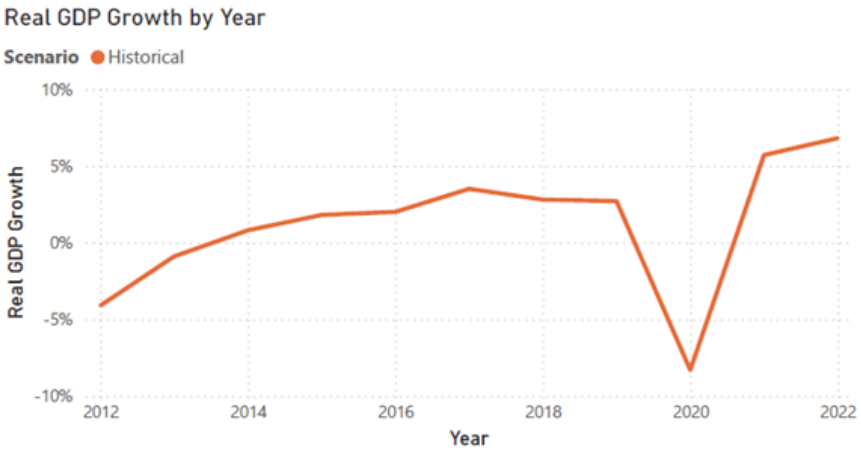

FIGURE 1: Portugal's Real GDP Growth 2012-2022

The unemployment rate offers valuable insights into the conditions of the Portuguese labor market and the broader economic health of the country. Unemployment peaked at 18.5% in early 2013, reflecting significant economic challenges and social issues that arose as a direct consequence of the recession and the structural adjustments being made in the economy at that time. Gradual improvement can be observed between 2015 and 2019 with a steady decline in unemployment rates as the economy recovered, dropping to around 6-8% by the end of 2019. This period saw improved labor market conditions due to economic recovery efforts and job creation initiatives, particularly boosted by tourism activity. The pandemic caused a slight increase in unemployment, but the rates did not approach the highs observed in the early 2010s. By 2022, the labor market demonstrated resilience despite the global disruptions caused by the pandemic.

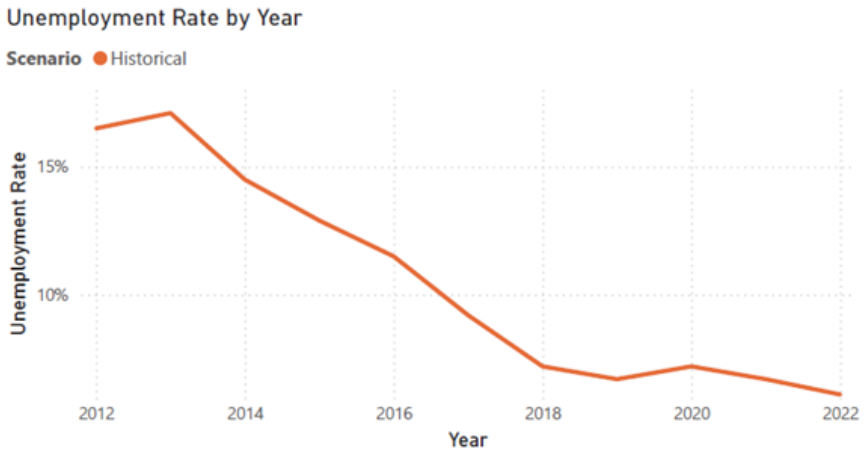

FIGURE 2: Portugal's Unemployment Rate 2012-2022

The 3-month EURIBOR reflects the cost of borrowing in euros and a key interest rate benchmark in the Eurozone. Between 2012 and 2016, EURIBOR rates dropped significantly due to the European Central Bank's (ECB) non-standard monetary policies, reaching negative territory around -0.3%. This was part of the ECB's strategy to stimulate economic growth by lowering borrowing costs. The declining rates indicate the ECB's response to the Eurozone crisis and efforts to support economic recovery. Between 2017 and 2022, rates remained low, hovering slightly negative or near zero, reflecting continued efforts by the ECB to support economic growth through low borrowing costs. This sustained low-interest-rate environment was crucial to encourage borrowing and investment during the financial crisis recovery and COVID-19 pandemic periods.

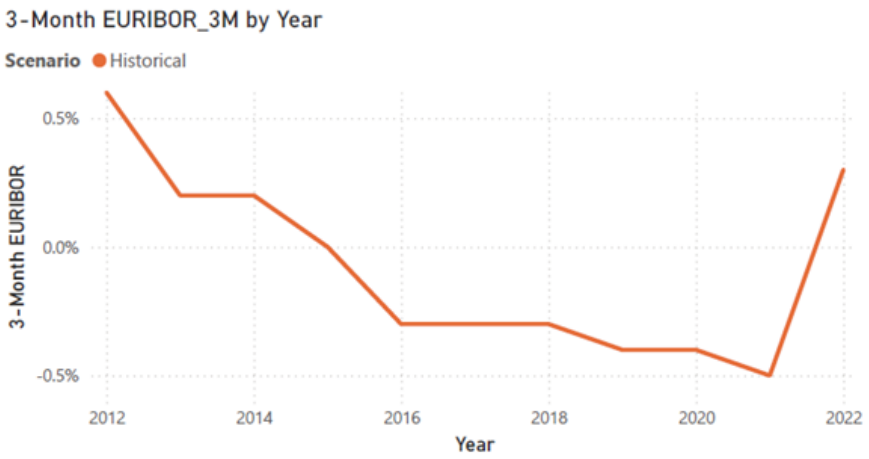

FIGURE 3: 3-Month EURIBOR Interest Rate 2012-2022

The CET1 ratio is a measure of the banking sector's core equity capital relative to its risk-weighted assets. Between 2012 and 2015 there was a significant improvement in CET1 ratios from around 9.4% in 2012 to over 11% by 2015, indicating banks' efforts to bolster financial stability amidst economic uncertainty. Strengthening capital buffers was crucial for restoring confidence in the financial system. The CET1 ratios continued to improve, stabilizing around 13-16%. This consistent strengthening showcases a robust banking sector capable of withstanding economic shocks, including those from the COVID-19 pandemic. The higher CET1 ratios reflect a resilient banking sector that has adapted to regulatory requirements and economic challenges.

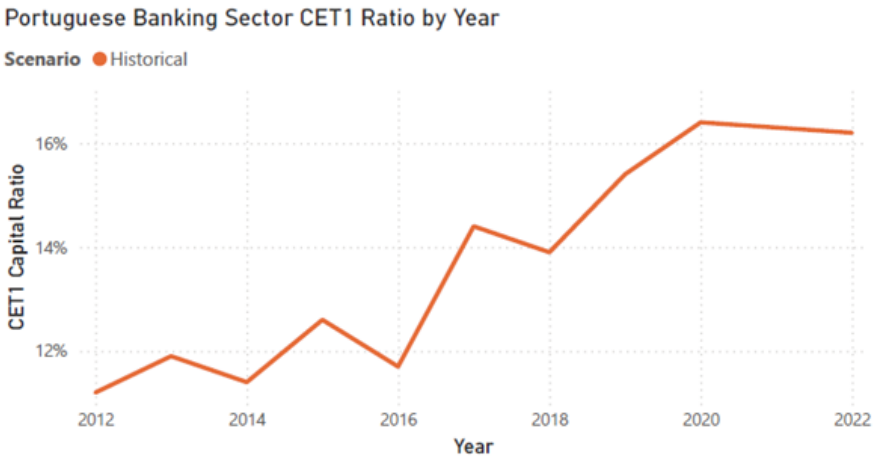

FIGURE 4: Portugal's Banking Sector CET1 Ratio 2012-2022

In conclusion, between 2012 and 2022, Portugal experienced significant economic challenges and recovery phases. The data reveals a trajectory from severe recession to gradual recovery and stability, disrupted briefly by the pandemic. The GDP growth and

unemployment rates reflect these economic cycles, while the 3-month EURIBOR and CET1 ratios highlight the monetary policy environment and banking sector resilience.

4.2 Limitations and assumptions

The EU-wide stress test scenarios were presented annually, while the time series data from the Bank of Portugal, along with the macro-financial data from the ECB and IMF, were reported quarterly. To ensure consistency across the datasets, it was necessary to adjust the data to a common time period.

The Bank of Portugal has disaggregated data for individual institutions, however it is not accessible to the public (only for internal users at the institution's portal) due to statistical and banking confidentiality regulations. This is a common limitation, that was identified in the literature review section 2.4.1 and one which will be challenging to overcome.

In the initial attempt to build the econometric model for the stress test, data from the Bank of Portugal, ECB, and IMF were aggregated to an annual basis to align with the EU stress test scenario. Quarterly data from the Bank of Portugal's time series was condensed to yearly snapshots, with Q4 data used as a proxy for the year-end. This approach was chosen because CET1 capital at year-end is a crucial regulatory and financial measure that better reflects a bank's financial position and performance. However, the model faced significant multicollinearity issues, and the limited number of data points (11 observations, covering the period from 2012 to 2022) made it difficult to produce a robust model.

As a result, the decision was made to run the model using quarterly data. However, since the projection data for the baseline and adverse scenarios were only available on an annual basis, they had to be converted to quarterly values based on a set of assumptions. This approach provided the model with more data points, facilitating the selection of a suitable model, though it required assuming a linear approximation. This simplification may overlook potential seasonal fluctuations, as the indicators were evenly distributed throughout the year. The assumptions used are described below:

- Growth rates (real GDP growth, inflation growth) and EURIBOR 3M were converted using the following formula, assuming that these could be distributed uniformly over the quarters:

$$\text{quarter\_value} = (1 + \text{year\_value})^{(1/4)} - 1 \tag{5}$$

- Unemployment rate was assumed to change linearly across the year, the averaged quarter value was used by dividing the yearly value by 4.

- Term spread values were kept the same as yearly values.

4.3 Model Results

A program was developed, based on existing code by Basener (2020), to implement the Bayesian Model Averaging (BMA) methodology, described in 3.2.1. The resulting outputs, including estimated coefficients and posterior probabilities, are presented in the following image:

```
### BMA Model Summary ###
Number of observations: 44
| Overall R-squared : 0.860221 |
| Overall BIC       : -292.228020 |
```

Variable	Coefficient	Probability	Avg. P-value
const	0.166633	1.000000	0.000000
EURIBOR_3M	0.164961	0.290281	0.069914
Term_Spread_10y_2y_AAA_EuroAreaGovBonds	0.026731	0.157998	0.098571
Unemployment_rate	-0.042581	0.255820	0.097718
brent_price_growth_rate	0.000025	0.246319	0.063368
inflation_growth	0.021210	0.311317	0.068933
lagged_EURIBOR_3M	-1.401080	0.899290	0.007010
lagged_Term_Spread_10y_2y_AAA_EuroAreaGovBonds	-0.062972	0.170872	0.087645
lagged_brent_price_growth_rate	0.000006	0.149091	0.097546
lagged_inflation_growth	0.077575	0.422876	0.049011
lagged_real_gdp_growth	0.002341	0.148609	0.095897
lagged_unemployment_rate	-0.277211	0.863897	0.010372
real_GDP_growth	0.000231	0.140990	0.110045

```
(Note: Coefficients are averaged over all models weighted by posterior probabilities.)
```

FIGURE 5: Model to capture changes in CET1 capital ratios based on the impact of macro-financial variables

The model presents an average R-squared of 0.86, indicating that approximately 86.0% of the variability in the CET1 ratio is explained by the model. This strong value suggests that the predictors included provide a good fit to the historical data.

The Bayesian Information Criterion (BIC) is used for model selection among a finite set of models, with lower values indicating a better fit. The model shows a BIC of -292.228, which suggests that it is well-fitted and parsimonious, effectively balancing model fit and complexity. The posterior probabilities of the coefficients are relevant to understand the relevance of each predictor in the model. A higher probability indicates a stronger belief that a variable meaningfully influences the CET1 ratio. The results for the predictors, along with their interpretation are the following:

- **3-Month EURIBOR**: The positive coefficient of 0.166 suggests that higher short-term interest rates are associated with an increase in the CET1 ratio. In a rising rate environment, banks benefit from an improved net interest margin (NIM), as the rates they charge on loans and other assets tend to increase more than the rates

paid on deposits. This widening margin boosts banks' interest income, thereby strengthening their capital positions. The high posterior probability associated with this coefficient further supports the robustness of this relationship, indicating that the effect of short-term interest rates on CET1 ratios is both significant and reliable.

- **Term Spread**: The positive coefficient of 0.028 indicates that a steeper yield curve, which reflects a larger difference between long-term and short-term interest rates, positively impacts the CET1 ratio. A steeper yield curve typically signals expectations of economic improvement, which can boost lending and investment activities, thereby strengthening banks' capital positions. The high posterior probability associated with this coefficient further supports the reliability of this relationship, emphasizing its significance in the model.

- **Inflation Growth**: The positive coefficients for inflation growth (0.021) and lagged inflation growth (0.077) suggest that inflation can positively influence the CET1 ratio. Moderate inflation may lead to increased nominal income and higher asset values, thereby strengthening banks' capital positions. The significant posterior probabilities indicate that these relationships should be considered in the model.

- **Real GDP Growth**: The coefficient for real GDP growth (0.000231) suggests a positive relationship with the CET1 ratio. However, the small magnitude of this coefficient indicates that its impact may be negligible. While economic growth generally results in higher loan demand and lower default rates, this specific coefficient implies a limited effect within the context of the model.

- **Lagged 3-Month EURIBOR**: The negative coefficient for lagged EURIBOR_3M (-1.401) indicates that past short-term interest rates significantly negatively impact the current CET1 ratio. This suggests that increases in prior short-term rates may constrain banks' capital positions, potentially reflecting higher funding costs or decreased loan demand following previous interest rate hikes. The high posterior probability associated with this coefficient emphasizes its importance in the model.

- **Unemployment Rate**: The negative coefficient for the unemployment rate (-0.043) suggests that higher unemployment is linked to a lower CET1 ratio. Increased unemployment can lead to higher loan defaults, which in turn raises impairments and increases RWAs, thereby weakening banks' capital positions. The lagged coefficient (-0.277) reinforces this relationship, indicating that past unemployment rates have a lasting negative effect on the CET1 ratio, underlining the importance of this variable in assessing banks' capital dynamics over time.

- **Lagged Term Spread**: The negative coefficient for lagged term spread (-0.063) indicates that a narrowing yield curve in previous periods may adversely impact the CET1 ratio. This suggests that a less favorable interest rate environment in the past can constrain banks' profitability and capital adequacy. The associated probability indicates that this relationship is meaningful in the context of the model.
- **Brent Price Growth Rate**: The negligible coefficients for both Brent price growth rate (0.000025) and lagged Brent price growth rate (0.000006) suggest that changes in oil prices have minimal direct impact on the CET1 ratio. The constant term (0.167) represents the baseline level of the CET1 ratio when all other variables are zero, highlighting the inherent stability or baseline capital level of banks.

4.4 CET1 Ratio Projections 2023-2025

Using the coefficients from the averaged model, predictions for CET1 Ratio were made for both baseline and adverse scenarios. The predicted values for CET1 Ratio showed how it would evolve under different economic conditions.

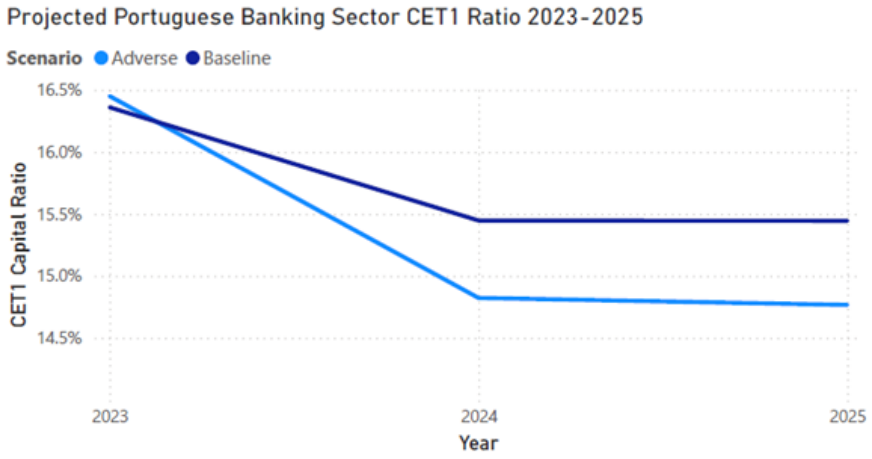

FIGURE 6: Portuguese Banking Sector CET1 Ratio Projections 2023-2025

Considering the results presented in Figure 6, the CET1 ratio under the baseline scenario is projected to decrease slightly from 16.36% in 2023 to 15.45% in 2024 and then stabilize in 2025. This trend indicates a stable economic environment with no significant shocks. In contrast, under the adverse scenario, the CET1 ratio is expected to decline more markedly, reaching 14.77% by 2025. This reflects a scenario of deteriorating economic conditions, exerting greater pressure on banks' capital positions.

The projected CET1 ratios exceed the minimum capital requirements specified in the ECB's December 19th, 2023, press release, which raised overall CET1 requirements and guidance from 10.7% to 11.1%. This highlights the Portuguese banking sector's robust

capitalization, ensuring resilience and the capacity to absorb potential shocks under adverse conditions.

These results further emphasize the critical role of macroeconomic and financial variables in determining CET1 ratios, with interest rates, unemployment, and inflation identified as key drivers. The model demonstrates strong performance, as evidenced by a high R-squared and significant predictors. Overall, the projections suggest that while adverse conditions could lead to notable declines in bank capital ratios, the sector is equipped to withstand such shocks without compromising financial stability.

4.5 Comparison with ECB and EBA Stress Test Results

To evaluate the relevance of the findings in this work, a comparison is made with other stress test exercises. Since the Portuguese Banking Sector is part of the Eurosystem, it is logical to compare the results against the EBA EU-Wide Stress Test EBA (2023*a*) and the ECB Macroprudential Stress Test of the Euro Area Banking System ECB (2023). The 2023 EU-wide stress test assesses banks' responses to standardized adverse scenarios to inform supervisory decisions, focusing on a microprudential perspective. In contrast, the ECB's Macroprudential Stress Test provides additional insights into the resilience of the European banking sector by considering broader interdependencies between banks, markets, and the real economy. This system-wide focus is based on the BEAST framework introduced earlier in 2.5.2. At the end of 2022, the average CET1 ratio of euro area banks stood slightly above 15

The European Banking Authority's 2023 EU-Wide Stress Test results show that the CET1 capital ratio increases by 136 basis points under the baseline scenario, reaching 16.3% in 2025. Conversely, the adverse scenario predicts a capital depletion of 459 basis points, reducing the CET1 ratio to 10.4% in 2025. These results highlight the significant impact of the adverse scenario on banks' capital ratios. The model in this work for the Portuguese Banking Sector reflects a similar declining trend while maintaining a relatively more favorable capital ratio. A focused analysis of this stress test examines individual banks. According to Luz (2024), the largest banks operating in Portugal include Caixa Geral de Depósitos, Banco Comercial Português, Santander, Novo Banco, and Banco Português de Investimentos (BPI), which is owned by CaixaBank from Spain. The CET1 projections for these banks are presented below, along with the average value calculated for the aggregate. Notably, Novo Banco is excluded from the stress test exercise and is therefore not considered.

TABLE II: 2023 EU-Wide Stress Test Results - Largest Banks Operating in Portugal

	Baseline			**Adverse**		
Bank	**2023**	**2024**	**2025**	**2023**	**2024**	**2025**
CaixaBank (BPI)	13.55%	14.53%	15.24%	11.17%	10.46%	9.35%
Santander	13.39%	14.34%	14.44%	10.96%	11.34%	10.33%
BCP	13.63%	14.57%	15.05%	8.81%	8.38%	8.00%
CGD	20.92%	22.62%	23.88%	17.34%	17.83%	17.97%
Average CET1 Ratio	**15.37%**	**16.52%**	**17.15%**	**12.07%**	**12.00%**	**11.41%**

Analyzing the banks' stress test results (EBA (2023*b*), EBA (2023*e*), EBA (2023*c*), and EBA (2023*d*)), it is evident that they align with the broader trends observed in the Euro Area, showing a relatively favorable outlook in both baseline and adverse scenarios. In comparison, the results obtained from the model in this work present a more optimistic outlook. One possible explanation for this discrepancy is the oversimplification in the methodology, particularly the conversion of annual EU-wide stress test scenario values to quarterly values, which assumed a linear relationship. Additionally, the EU-wide stress test is a bottom-up exercise conducted with granular data, which allows for more precise estimations. In contrast, this work's aggregated approach lacks such granularity.

On the other hand, the ECB's Macroprudential Stress Test projects a slight decline in the CET1 ratio of the banking system by 42 basis points under the baseline scenario. Under the adverse scenario, the CET1 ratio experiences a substantial decline, dropping by more than 2 percentage points to 13%. Compared with the EBA stress test, this test shows a milder capital depletion. This deviation can be attributed to methodological differences. The ECB's macroprudential stress test employs a dynamic balance sheet approach, whereas the EBA stress test assumes a static balance sheet. As Constâncio (2015) argues, assuming banks take no action during the adverse horizon is less realistic. he dynamic approach enables banks to mitigate the adverse scenario's impact on their CET1 ratio by reducing credit volumes through deleveraging, adjusting to lower credit demand during economic downturns, and reallocating lending toward the sovereign sector, which lowers RWAs, as described in ECB (2023). These methodological differences help explain why the ECB Macroprudential Stress Test results align more closely with the findings of this work.

5 CONCLUSIONS AND FUTURE WORK

The research conducted in this dissertation emphasizes the vital role of macroprudential stress testing in today's financial regulatory environment, particularly within the banking sector. This study specifically examined the application of macroprudential stress testing to the Portuguese banking sector using publicly available data, providing valuable insights into the feasibility and effectiveness of this approach.

The dissertation explored the theoretical foundations and methodologies of macroprudential stress testing, highlighting a shift from traditional bottom-up approaches—focused on individual institutions—to top-down stress tests that assess the resilience of the entire banking sector. Significant challenges were identified, notably the availability and quality of data, which are essential for effective stress testing. Nevertheless, the study demonstrated the potential for conducting meaningful macroprudential stress tests using publicly available datasets.

By concentrating on the Portuguese banking sector, the research utilized various data sources, including those from the Bank of Portugal and IMF databases, to develop an econometric model for stress testing. The results indicated that relevant macroprudential stress tests can indeed be conducted with public data, albeit with certain limitations. Comparisons with stress tests conducted by the EBA and ECB reveal consistent trends, with this study's results being slightly more optimistic due to methodological simplifications and the use of aggregate data.

In conclusion, this dissertation asserts that publicly available data can effectively support macroprudential stress testing. However, the granularity and comprehensiveness of such data are crucial for achieving more accurate and reliable results. The insights derived from this research can be beneficial for regulatory bodies and policymakers. Conducting robust stress tests using public data enhances transparency and facilitates more frequent assessments. This approach enables a broader range of stakeholders — such as academics and private researchers — to undertake similar analyses without relying solely on central banks, which typically have access to sensitive, fine-grained data. Such efforts contribute to a richer body of knowledge in macroprudential policy, which is increasingly important in a rapidly evolving economic landscape. The Bank of Portugal's time series for the banking sector is a notably detailed dataset — an initiative that should be encouraged among other central banks in the Euro Area to mitigate issues related to data availability. Future studies could explore the potential of flow data to enhance the predictive power of stress test models, as discussed in 2.4.3, and compare results against other tests utilizing supervisory data.

Future research should focus on enhancing data quality and accessibility. While initiatives like the IMF/FSB Data Gap Initiative have made positive strides, continued efforts

are necessary to address challenges such as data fragmentation and inconsistency. Future models should aim to incorporate more granular data and better capture the dynamics of the banking sector, including spillover and contagion effects. Furthermore, the model should be revisited to integrate emerging variables, such as those related to climate change and cybersecurity risks, which are becoming increasingly important for the banking sector.

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