Macroprudential stress tests under Basel III: The role of funding liquidity risk

Thesis submitted for the degree of Doctor of Philosophy at the

University of Leicester

by

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May, 2020

Abstract

The thesis is composed of three main chapters each with an independent objective. The *first* inspects the main funding risk drivers employing a multivariate copula estimation. The *second* looks at the systemic liquidity risk asking whether macroeconomic fluctuations can trigger and create simultaneous liquidity shortages in banks' funding position using agent based model(ABM). The *third* examines the funding liquidity risk's procyclical behaviour to macroeconomic changes using a feedback mechanism.

The findings of the three chapters, are as follow: Chapter 2, detects and quantifies the main funding liquidity risk drivers and shows that commercial banks' Net Stable Funding Ratio (NSFR) substantially decreases when macroeconomic adverse conditions are applied. In Chapter 3 the results suggest that banks face simultaneous liquidity shortages when the economy's agents operate under economic recession. Chapter 4 indicates that funding risk is pro cyclical to the macroeconomic fluctuations while large banks' responses assist on withstanding substantial liquidity shortages when macroeconomic shocks are applied.

This study contributes to the literature in three folds: 1) Introduces a new stress test scope by assessing funding liquidity risk and its interrelations with the macroeconomic environment. 2) Provides evidence on prudential policies by incorporating systemic liquidity risk in macro prudential stress test framework. 3) Measures funding liquidity risk pro-cyclical, by developing a second round effects mechanism.

To Angelos

Declaration

This is to certify that to the best of my knowledge, the content of this thesis is my own work. This thesis has not been submitted for any degree or other purposes. I certify that the content of this thesis is the product of my own work and that all the assistance received in preparing this thesis and sources have been acknowledged.

Chapter 2, *Macroprudential Liquidity Stress Test: Investigating the funding risk drivers* is a joint work with Dr. Carlos Dıaz and Professor Daniel Ladley. Chapter 3, *Disentangling the systemic aspects of Liquidity Risk: A multi agent stress test application for European banks* and Chapter 4, *When liquidity risk becomes procyclical: A multi agent feedback process* are a joint work with Professor Daniel Ladley. An early version of Chapters 3 and 4 has been presented in the International Banking and Finance Society (IFABS), in July 2018 and in the Workshop on Economic Science with Heterogeneous Interacting Agents, in June 2019

Acknowledgements

I would like to take this opportunity to express my gratitude and appreciation to the many people and institutions that were fundamental in the completion of my thesis.

First and foremost, I will be forever indebted to my supervisor and co-author Professor Daniel Ladley who has always supported and encouraged me during my PhD. I am extremely grateful to my supervisor for introducing me to computational economics and providing me the opportunity to work with him and complete my thesis. I am also grateful for his patience and the continuous training he offered for improving my skills in C^{++}, along with the valuable advice he provided in many aspects of my PhD life. My background in banking and finance combined with Professor Ladley's computational expertise, was a great motivation to evolve and gave me the chance to be selected among numerous candidates for work in both ECB and BoE. He has always been there for me, helping me to change my attitude, to be patient and never give up in my PhD marathon while working hard for achieving all of my goals.

It goes without saying, that special thanks belong to my second supervisor Professor Mohamed Shaban for the cooperation and his great advice on my thesis. Also, many thanks to my ex-supervisor Professor Meryem Duygun for the opportunity she offered me to work with her for Nottingham University, Business school and for the successful completion of IFABS conferences in Barcelona, Brunei and Oxford. I am really thankful to Professor Shaban and Professor Duygun for their encouragement at all the stages of my PhD as well as their friendship along the way.

My deep appreciation goes also to my co author Dr Carlos Dıaz who embraced my ideas and helped to overcome many obstacles during this stressed period. Carlos, there are no words to thank you for your patience, support and training in Copulas models.

I also want to express my gratitude to the academic staff of the ULSB. Special thanks to Dr Don Egginton, Dr Aris Boukouras and Dr Mihalis Kavaratzis for their support they provided me during the periods I was in off campus study. Not to mention, that special gratitude also goes to the administrative staff of ULSB. Teresa and Samantha thank you very much.

My deep appreciation to my colleagues in ECB and Bank of England for the constructive feedback provided me for both my research but also for my career.

Many thanks to my academic buddies: Evangelos, my good friend, you were the person introducing me to my supervisor, I will always thank you for this. George, Christiana and George many thanks for all these laughs during our gatherings Nikos, Prodromos, Katerina, Andreas, Eleni, Amalia and Dimos you are more than friends, I feel so lucky having you in my life. Natassa - extremely grateful for all your Latex help.

Angelos, my other half, my friend, my family, my husband. You mean so much for me. Thank you for being in my life, for believing in me and encouraging me. You are the reason I decided to do the PhD, you are the reason I believe in myself, you are the reason I came to realise my ambitions. I am so happy and lucky having you in my life.

I would also like to give thanks to my parents in law, Andreas and Marguerita, who were supportive and stood by my side. Andreas, my mentor in macroeconomics, as Director of Statistics in BoG, gave me the chance, introduced me to the central bank affairs and helped me to achieve personal and professional success.

Last but not least, I would like to thank my parents and my sister, for standing by me during these years and believed in me and support every decision I took. Lina, I am so proud that my sister is such a successful career woman. Mom and Dad, you are my role models. You were a great motivation for me to complete my thesis.

Overall, I would like to acknowledge the School of Business (Finance division) for accepting me and funding my studies and providing me the opportunity to grow as an individual. In addition, special thanks to my M.Sc. professor, mentor and supervisor Mike Tsionas, who stood by me in a difficult moment of my life, believed in me and helped me to continue my studies at a PhD level.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

Over the last decades, financial stability has become for both regulators and policy makers a key to maintain confidence and promote the safety and soundness in the financial system (Acharya et al., 2009). Financial stability has received a great interest from academics and practitioners, in terms of definition (Allen and Wood, 2006), scope (Goodhart et al., 2012) and measurement with the use of early warning (Drehmann and Juselius, 2014) and financial soundness indicators (IMF, 2006, 2008).

Central bankers and policy makers, in order to cross-border resolve weak banks, introduce in late 70ś the Basel Committee on Banking supervision (BCBS) (Goodhart, 2011). In 1988, BCBS published a set of minimum capital requirements as the foundation for banking risk regulation, known as Basel I Accord (Balthazar, 2006). Basel I counts for a ratio of bank capital to risk-weighted assets for credit risk and in turn for market risk (Accord, 1998). In 1999, Basel II is developed in order to provide updates to the current regulatory framework. Basel II includes several major differences to amend Basel I regime. Basel II introduces internal models for credit risk (internal ratings-based, IRB approach) and adds regulations for operational risk. Also, Basel II implements the pillar-framework. Pillar I stands for minimum capital requirements, Pillar II is the supervisory review of Pillar I results while Pillar III which is related to market discipline and information disclosure, for sustaining the transparency in the financial system (Penikas, 2015)

Regulators and policy makers continuously revise and enhance the existing regulatory regimes to maintain stable financial systems . Accordingly, Basel II reforms on credit, market and operational risk capital requirements are under enhancement to improve Financial Institutions' (FIs) resilience (BCBS, 2006). For this scope Basel III regulation is introduced. On December 2009, Basel III publishes the first consultative paper as a response to 2007-2009 financial crisis (BCBS, 2009b). Basel III framework amends existing capital requirements by introducing capital buffers and leverage ratio which estimates banks' capital capacity to meet on and off balance sheet exposures. Furthermore, a single rulebook for remuneration of risk-taking is proposed (Cappiello, 2015). The single rulebook includes sound practices and principles for back-testing counterparty credit risk models and for monitoring deposit insurance systems. In parallel, Basel III regulation reveals the need to monitor additional aspects of FIs such as banks' funding performance (BCBS, 2017). Specifically, Basel III regulatory framework proposes liquidity risk quantification with the use of two liquidity measures. These two liquidity measures refer to liquidity coverage ratio (LCR) and net stable funding ratio (NSFR).

The LCR and the NSFR have two different objectives but in parallel a complementary scope. In particular, the NSFR measures banks' ability to sustain sufficient levels of equity and wholesale funding (i.e. deposits). Under the NSFR specification banks should be able to withstand shortages in their funding position arising from exposures to investments and lending transactions. The LCR key objective is to promote the short-term resilience of the liquidity profile of banks. On the other side, LCR measures banks' liquidity risk profile. LCR aims to ensure that banks hold adequate stock of high-quality liquid assets that can be easily and immediately monetised at the minimum cost and price impact. Unlike the LCR, which is a short term measure, the NSFR assess banks' medium and long term resilience (BCBS, 2017).

Aside from the revisions in the regulatory reforms, regulatory and policy authorities have proceed to prudential policies establishment, in the form of different frameworks. The prudential policies framework aims not only to monitor the individual banks' performance and resilience, but also to investigate potential threats which can trigger the economic system as a whole (systemic risk). The rise of prudential policies at both the micro and macro level, does not comprise a new concept, as these terms were introduced during the late 70's (Clement, 2010). However, the financial crisis of 2007-2008, which indicated a global turmoil triggering a series of domino effects, led policy makers and regulators to set prudential policies as primary targets in the policy agenda.

The macro prudential framework focuses on "the stability of the financial system and its interrelations with the macro-economy " (Clement, 2010). It considers systemic aspects and pro cyclical behaviour of the financial risks (Hirtle et al., 2009), to capture the main linkages of the macro and the financial side of the economy. The micro prudential policy complements the macro prudential framework, hence it consists of the performance of individual banks. The micro prudential concept includes the assessment of individual banks' risk profile and solvency through the behaviour of idiosyncratic risks (Houben, 2013).

Under the financial stability scope, the prudential policies and regulatory reforms are strongly linked. The assessment and the evolution of the macro and micro prudential framework is based on the regulatory requirements, developed for promoting the safety of the financial system as a whole. For this purpose, a series of financial stability tools have been used for monitoring the resilience of FIs. Such tools comprise of the early warning (Drehmann and Juselius, 2014) and financial soundness indicators (IMF, 2006, 2008). However, the use of these tools has proved rather mechanical than analytical as these tools can only detect the sensitivity of banks to specific system vulnerabilities, without providing further information on banks' performance. Specifically, the quantification of the banks' losses, capital needs and shortages arising in banks' balance sheets under severe financial events, is not taken into account.

The parallel rise of the financial stability tools and their limitations, has led regulators and policy makers to require for analytical operational frameworks for a complete financial assessment of banks (Borio and Drehmann, 2008). These analytical frameworks are known as stress test models. Stress tests hold a significant position in the assessment of the financial fragility as they comprise a diagnostic process on banks' resilience when acting under adverse but plausible scenarios (Quagliariello, 2009). In addition, stress tests attract up to date academics' and policy makers' interest, who have provided substantial advancements in such core area (Foglia, 2009).

Stress testing originates in early 90ś to complement other statistical techniques for evaluating risks arising on banks trading books (Peria et al., 2001; McGee and Khaykin, 2013). While stress tests for market risk comprise a standard practice at large international banks, their development for credit risk appears in 1999 as an outcome of the revisions to the international regulatory capital regime. Banks develop individual regulatory stress tests to review the robustness of the internal based models and the adequacy of capital (BCBS, 2009a; Schuermann, 2014).

Unlike stress tests conducted by individual banks, policymakers introduce the macro prudential stress tests. In the late of 90ś the International Monetary Fund (IMF) and the World Bank establish the Financial Sector Assessment Program (FSAP). FSAP introduces macro prudential stress tests in order to capture the impact of severe, but plausible scenarios on the stability of financial system. FSAP stress tests scope is to examine the key macro financial linkages between financial stability indicators and the wider economy (Jobst et al., 2017).

Macro prudential stress tests comprise the key tool for monitoring the stability of the financial system. Post to financial crisis period, regulatory stress tests change from small-scale exercises to the system-wide risk assessment programs BCBS (2009a). In Euro Area, the first system-wide stress test is performed by the Committee of European Banking Supervisors (CEBS). From 2011 and onwards, the European Banking Authority (EBA) carries out the annual system-wide stress tests for all EU systemically important banks. The focus of this regulatory stress-testing is on the adequacy of banks' capital resources for addressing both micro and macro prudential policy. The scenarios are based on macroeconomic indicators' evolution, as developed by the European Central Bank and European Systemic Risk Board (ESRB). EBA estimates the impact of these scenarios on EU banks following a static balance sheet approach.

Despite the rise of evidence in the area of stress tests for assessing the resilience of FIs, shortcomings have emerged and are still apparent. These shortcomings stem mainly from the scope and the methods used for applying stress test models. The scope of stress tests refers to the types of financial risks incorporated in these simulations. The literature indicate a great focus on asset quality review and the amount of capital needs when losses arise due to credit risk (Foglia 2009; Sorge 2004), while the role of liquidity risk in stress testing is at an early stage. Stress test studies counting for liquidity risk are limited and range from simple sensitivity to scenario analysis (Ong and Čihák, 2010) with a great focus on rather market (Wong and Hui, 2009) than funding liquidity risk.

Funding liquidity risk has received attention in the academic literature (see for example Ong 2014; Hesse et al. 2012; Vento and La Ganga 2009; Čihák 2007; Diamond and Dybvig 1983), however an up to date assessment of this type of risk within a stress test application, is currently lacking. Specifically, the performance of funding liquidity risk led by macroeconomic fluctuations remains unanswered, as the current literature lacks studies focusing on the main linkages between the macro economy and the funding liquidity risk. Whilst policy makers and regulators require analytical stress test assessments in order to address the objectives of the regulatory and prudential framework, liquidity stress tests have proved unable to meet these requirements yet. In addition, due to the missing link between liquidity stress tests and economic stress, liquidity risk is lacking systemic treatment. Finally, a complete assessment of the prudential regime combined with the newly implemented regulatory reforms, the funding risk (represented by the LCR and the NSFR) and funding risk's evolution under macroeconomic fluctuations (Athanasoglou et al., 2014), is still missing.

Supplementary to the inability of current stress test applications to fully address the scope of prudential and regulatory regime, are the variety of stress test methods have been developed so far. These methods can range from traditional risk management tools (i.e. logit probit models) to more analytical econometric applications, such as the vector autoregressive models. However, most methods indicate a series of limitations which led stress tests unable to act as forward looking and standalone tools (Borio et al., 2014). These limitations stemming from the traditional techniques used so far. Examples include the assumption of linearity, the inability to model and detect the main macro financial linkages, the lack of systemic risk quantification combined with the lack of advance mechanisms counting for second round effects, made stress tests unable to deliver the necessary information for policy response.

The most common stress test methodologies in scenario analysis are the structural and the reduced form models. Structural models include logit, probit (see for example, de Bandt and Oung 2004; van den End et al. 2006; Martin 2007; Marcucci and Quagliariello 2008; Kalkbrener and Overbeck 2017) and copula estimations (see for example Hamerle and Rösch 2005; Boss et al. 2006b; Kalkbrener and Packham 2015; Paraschiv et al. 2015). Logit and probit models are developed for sensitivity rather than scenario analysis stress test. Logit model is a regression where the dependent variable is categorical, while in probit model, the dependent variable is binary (i.e. in case of stress testing pass or fail) (Albert, 2016). Whilst logit and probit models have been used for examining individual risks sensitivity, their application to macroprudential stress tests is unable to provide information on systems of banks in order to reveal the key macrofinancial linkages.

Moving to the reduced form approach, the use of time series and panel data models can assist in assessing distressed periods, when stress tests are focused on specific countries or banks (Sorge, 2004). In the reduced form approach fits the satellite model developed by Čihák (2007) which comprises a series of polynomial functions aiming to link the macro with the financial side of the economy. The satellite process provides a framework for assessing most of the risks banks might face as they can contain multiple risk factors. The main advantage of satellite models is that through stochastic estimations, they can capture the relation between scenarios (macroeconomic environment) and risk factors (microeconomic environment) (Henry et al., 2013). Also, Canova and Ciccarelli (2013) highlight the ability of panel vector autoregressive models (VAR) as a stress test method in order to investigate the key macro-financial linkages. In particular, panel VAR captures the interdependencies between the macro and the financial side of the economy and allows for cross sectional heterogeneity. Despite the flexibility panel VAR models display as they incorporate macro-financial linkages in an unrestricted way, the key limitations of these models when applied on a stress test process stem from the assumption of linearity that leads to financial risks underestimations and the lack of policy response. Particularly, VAR models estimate the effects between macroeconomic indicators and banking risks, without being able to quantify the volume of shortages and losses banks face due to the adverse economic scenarios.

This thesis contributes to the area of stress tests by filling both theoretical in terms of the scope and methodological limitations. Particularly, we identify the main macro financial linkages and contribute to the stress tests' scope by assessing funding liquidity risk and its interrelations with the macroeconomic environment. In addition, we provide significant evidence on the scope of prudential policies as it examines the existence of systemic liquidity risk, when banks' funding position is triggered by macroeconomic shocks. We also quantify the volume of liquidity shortages when systemic risk arise. Another contribution is that our analysis measures funding liquidity risk evolution, by developing a second round effects mechanism, where liquidity risk pro-cyclical behaviour is assessed. Furthermore, as funding liquidity is represented by the Basel III LCR and NSFR measures, we also provide insight to the regulatory regime regarding the newly implemented liquidity ratios' performance and ability to capture financial and economic vulnerabilities.

In order to address the methodological limitations stress tests indicate, we contribute to the existing sensitivity analysis stress test models and quantify the direct links between the macro and the financial side of the economy, with the use of a multivariate copula estimation (MCE). To the best of the author's knowledge, this is the first study that uses the MCE, in this estimation for carrying out liquidity stress testing. Multivariate copulas models are functions which measure the interdependence among variables. These estimations enable us to separate the marginal distributions from the dependency structure of a given multivariate distribution. Copula approaches are useful to expose and understand the various fallacies associated with correlation as they count for the nexus between two or more variables. Unlike VAR models, the copulas estimations perform for nonparametric modelling which allow us to overcome the assumption of linearity and normality(Nelsen, 2007). These models apply for both discrete and continuous data.

Our novel approach goes a step forward from the traditional copulas estimations which count for the correlation and interdependence among variables. We extend the framework of Koliai (2016), by measuring the marginal effects of each macroeconomic variable on the NSFR. Specifically, our approach contributes to copula models by developing the marginal effects which quantify the effect of each macroeconomic variable, on the funding position of banks, the deposits and the non-performing loans.These marginal effects, similar to the coefficients of a regression model, measure the change in the expected value of the target variable against a marginal increment of each of the conditioning variables. These marginal effects are asymptotically normal, and p-values can be approximated for them. We examine the funding position of 30 systemic European commercial banks with the use of a multivariate copula estimation.

The copulas estimations play a key role in risk management, as they measure the interconnectedness of shocks over asset prices and portfolios of assets. However, copulas estimations are not always applied properly and are generally static in nature, requiring a substantial amount of observations for producing robust outcomes. Our analysis overcomes the static nature limitation, as we count for the key macro-financial linkages at a given point of time (the respective scenarios). Regarding the amount of observations included in our analysis, this is marginally sufficient to provide robust results, thus our analysis can be further benefited from more data, especially bank level data.

Besides the use of MCE, we also develop an agent based model (ABM) for investigating the complexity of the financial system and addressing policy response related to micro and macroprudential framework. Agent Based models fall into the category of computational economics and their use in stress tests remains limited (Demekas 2015 and Bookstaber et al. 2018). Agent based modelling comprises a forward looking approach, where parts of a system are modelled as autonomous decision making agents who are interrelated (Darley and Outkin 2007). Agent based models simulate aspects of real world conditions. Agent-based models are simulation processes, where a system/economy is defined as a group of heterogenous decision-making entities, the agents. Each agent individually assesses its situation and makes decisions on the basis of a set of rules (functions). The agents are bundled data or behavioural methods under a dynamic, complex and adaptive system. ABM are based on repetitive and iterated actions between agents. This is achieved through evolutionary algorithms which explore dynamics out of the reach of pure statistical and econometric methods.

An agent based model is the approapriate method to be used for performing macroprudential stress tests. Through the use of agent based models we simulate the interrelation between the macroeconomic, the real sector and the financial side of the economy in order to produce adverse but plausible scenarios. We also model and iterate parallel actions agents proceed. Additionally, we incorporate multiple feedback processes necessary for investigating banks' responses to adverse economic conditions and agents' decisions. Our ABM process is based on Ladley (2013); Leduc and Liu (2016); Hałaj (2018) work. Specifically, we provide more details on agents' decisions and banks' balance sheet structure and evolution. Also the existence of systemic risk and funding risk pro cyclical nature after the implementation of multiple feedback actions, are also investigated in the vein of Basel III framework.

Our ABM, not only allow us to estimate the key macrofinancial linkages but also to quantify shortages and losses banks face simultaneously. The flexibility of our ABM assist on quantifying systemic liquidity risk, while the dynamic specification with the use of evolutionary algorithms reveal funding liquidity risk pro cyclical behaviour. Our ABM is a unified stress test approach, which performs multiple feedback processes and provides valuable information for macroprudential surveillance and supervisory engagement.

Despite ABM capabilities, on key disadvantage of ABM is the reliability of the process and the outcomes produced. As ABM are able to produce large datasets due to lack of real data, the forms of model calibration are debatable, while the outcomes of the ABM process raise concerns. For this scope, in order to overcome this issue, we calibrate and set up our process based on accurate data for banks, real sector agents and the economy. Particularly, we use real rather than simulated data to set up out model, collected from reliable databases such as the ECB datawarehouse, the IMF database and Bankscope (new Orbis).

The use of agent based modelling overcomes limitations of other computational economic approaches, which lack of flexibility for generalisations based on unrealistic economic assumptions (Fagiolo and Roventini, 2016). ABM also overcomes the limitations of the traditional methods have been developed so far, such as the structural and reduced form approaches which proved unable to capture the dynamic evolution and the complexity of the financial system, to perform as early warning systems and to act as standalone tools. The assumption of linearity and normality and the static nature of the traditional stress test models led these tools under-perform in times of market distortion (Bookstaber 2012).

The thesis aims at answering the following research questions:

I) Is there a strong interconnectdness between funding liquidity risk and the main macroeconomic indicators?

II) Is liquidity risk a systemic concern when banks operate in a system of economic recession ?

III) Does Liquidity risk demonstrate a pro cyclical behaviour when banks face simultaneous liquidity shortages in their funding position ?

Chapter 2 provides a multivariate copula estimation model, for assessing and quantifying the simultaneous effects of the macroeconomic environment on the Net Stable Funding Ratio (NSFR) of banks, as developed by the Basel III regulatory framework. In this analysis we contribute to the copula estimation models and we extend the multivariate analysis by deriving the marginal effects. The marginal effects are used to quantify the interrelation between the NSFR and key macroeconomic variables. From the joint distribution of the banking and macro variables, we extract these marginal effects and we identify the main liquidity risk drivers. This analysis is applied under three main scenarios, a good, a baseline and bad (stressed) economic scenario. From this analysis the unemployment rate, the GDP growth rate and the Account Balance (deficit) comprise the main funding liquidity risk drivers. The NSFR illustrates substantial decrease in both the baseline and the stressed scenarios, while it indicate a good performance when the economic system is operates under the good scenario.

Chapter 3 investigates the role of funding liquidity risk and its systemic aspect for banks under a macro prudential stress test scenario analysis. We develop a dynamic multi-agent based model to assess and quantify the liquidity position of systemically important banks located in Southern European countries. In this chapter the key liquidity indicator is the liquidity coverage ratio (LCR). Our model considers banks' interaction with households, firms and the government under stressed economic events. In addition we measure the probability of simultaneous liquidity shortages banks face and we also count for the time needed in order the system of banks to face systemic risk. In addition, to provide a deeper insight on banks' funding performance they key balance sheet terms, such as deposits and liquid assets, are also evaluated and quantified at each time step. The results of this analysis, demonstrate the importance of funding liquidity risk, under the examination of adverse macroeconomic scenarios. Specifically, the LCR, under stressed economic conditions, displays simultaneous shortfalls below the critical value for all the banks in our system. In parallel, our analysis indicates that the LCR's reaction to macroeconomic shocks goes beyond the 30-days period of stress specified by the regulatory guidelines (BCBS, 2017). A key finding is that the size of the banking system contributes to the systemic risk reduction. With regards to economies that include a large number of banks, the levels of the LCR go slightly below the critical value, even under stress conditions. Furthermore, the decisions and rationality of firms and households lead to further investigation of the LCR behaviour, as households' contribution to the LCR deterioration is greater than firms' contribution.

For the last research objective, Chapter 4 addresses the second objective by developing a unified macro prudential stress test model counting for multiple feedback processes. With the use of a multi agent stress test approach, we investigate the evolution of liquidity risk when banks operate under adverse but plausible macroeconomic shocks. In this chapter, the interaction of banks with firms, households and the economy, reveals funding risk's pro cyclical behaviour, when systemic risk appears. In order to address the objective of capturing second round effects, banks develop a series of responses for facing the economy's vulnerabilities. These responses are represented by a series of adjusted liquidity channels such as the increase in high quality liquid assets, the restriction in loans' supply and the sales of assets in case of illiquidity. These channels are used to uncover the second round effects, arising in banks' funding position. Our results illustrate the pro-cyclical behaviour of funding liquidity risk, under the examination of adverse macroeconomic scenarios. Additionally large banks (in terms of assets), when the adjusted liquidity channels are activated, maintain the LCR above or close the critical value. Large banks' LCR drops as the economic recession continues. However it takes longer for these type of banks to go below this threshold. With regards to small banks, these go below the threshold and even adjusted responses are activated. These banks are unable to recover or maintain their funding position.

Chapter 2

Macroprudential Liquidity Stress Test: Investigating the funding risk drivers

Abstract

This paper investigates the role of liquidity risk on the Southern European banking system under macroprudential stress test analysis. We examine the funding position of 30 systemic European commercial banks with the use of a multivariate copula estimation. The model assesses and quantifies the effects of the macroeconomic environment on the Net Stable Funding Ratio (NSFR) of banks, as developed by the Basel III regulatory framework. We calculate the probability of liquidity shortages, under good, bad and baseline scenarios. We generate the marginal effects from the joint distribution of the NSFR and key macroeconomic variables modelled using the Gaussian copula, by identifying the main liquidity risk drivers. The results show that Unemployment, GDP growth rate and the Account Balance (deficit) are the main liquidity risk drivers. The NSFR, in most cases, decreases by 60% under the stressed but plausible events. Banks should adjust for the different levels of the NSFR, the level of deposits and non-performing loans(NPLs) for contingency planning purposes. Our results provide robust evidence for policy makers and regulators who wish to monitor banks not as standalone financial institutions but rather as an integral part of the financial system.

JEL classification: G01; G17; G21; C15

Keywords:Stress Tests; Liquidity Risk; Regulation; Gaussian Copula

2.1 Introduction

The stability of the global financial system is a prerequisite for maintaining confidence and promoting economic growth. Therefore, it is a key objective for policy makers to maintain a sound and stable financial system. Over the last decade, there have been multiple tools introduced by academics and policy makers for assessing the soundness of financial institutions. Recently, the concept of stress testing emerged as a primary tool to assess the resilience of FIs. The main focus of assessment in using such tools is banks' capital adequacy (Quagliariello, 2009).

However, as stated by Constâncio (2016) *While the impact of liquidity stress is captured to a certain degree by the funding and liquidity shocks, the exercise remains primarily an assessment of solvency. Exercises have so far been conducted under static balance-sheet assumptions, meaning that all balance-sheet elements are kept constant throughout the time horizon of the test.* Therefore, less attention was given by policy makers and academics to the implication of liquidity risk on FIs stability. Moreover, there are issues with the common stress testing approaches currently used by policy makers, in terms of the breadth, applicability and effectiveness (Acharya et al. 2014).

The aim of this study is to provide a valid macro prudential liquidity stress test, with the use of the Regulatory NSFR, which captures the dynamics of the financial system, thus filling the gap in the literature. The proposed model identifies and quantifies the main macro financial linkages that drive to liquidity shortages in the Southern European Banking system. The study also measures the levels of deposits and NPLs, as two main components in assessing the funding position of commercial banks. This study main focus is on the effect of liquidity risk on financial stability. We define liquidity risk, as the risk of FIs to meet its obligations. Illiquidity in FIs may arise from a range of reasons including asymmetric information (increase uncertainty in the wholesale and retail market), interbank exposures (liquidity pressure on interbank counter parties), and asset fire sales (BIS, 2013b).

Post the financial crisis, the Basel committee developed liquidity regulations with the aim of preventing future failures. These regulations are represented by the NSFR and the Liquidity Coverage Ratio (LCR) which require banks to maintain sufficient levels of long and short-term funding respectively, to prevent banks becoming illiquid during an acute liquidity shortage. In particular, BCBS (2015) develops the LCR in order to investigate whether a bank holds sufficient levels of high liquid assets to mitigate short term outflows while the NSFR acts as a prudent toolkit for monitoring banks' funding capacity in the long term.

Banks borrow funding through deposits and wholesale funding and provides lending facilities through loans to households and firms. Through these operations, banks develop a mismatch, between the assets they hold and the liabilities they should meet. This mismatch entails a series of risks. For this scope the LCR and the NSFR have two different objectives but in parallel a complementary scope. The difference between the LCR and the NSFR does not only rely on the time horizon but also on their specification. In particular, under the NSFR regime, banks should keep sufficient levels of equity and wholesale funding (i.e. deposits) in order to withstand shortages arising in their funding position due to exposures to investments and lending transactions. In particular, the NSFR requires banks to maintain a stable funding profile in relation to their on and off-balance sheet assets and activities. The objective of the NSFR is to reduce the probability that shocks affecting banks' usual funding sources might erode their liquidity position, increasing its risk of bankruptcy. The NSFR standard requires from banks to diversify their funding sources and reduce their dependency on short-term wholesale markets. In parallel, the key objective of the NSFR is to reduce the funding risk over a broader time horizon.

The LCR key objective is to promote the short-term resilience of the liquidity profile of banks. The LCR measures banks' liquidity risk profile by ensuring that banks hold adequate stock of high-quality liquid assets that can be easily and immediately monetised with the minimum cost and the minimum price impact. Therefore, unlike the LCR, which is short term, the NSFR measures a bank's medium and long term resilience. The stable funding requirements for each institution are set based on the liquidity and maturity characteristics of its balance sheet asset?s and off-balance sheet exposures.

A macro prudential framework focuses on "the stability of the financial system and its relation with the macro-economy" (Clement, 2010). Such a framework includes indicators for capturing and assessing the main linkages of the macro and the financial side of the economy. Macro prudential stress tests have been carried out by many major financial regulators around the world. The International Monetary Fund (IMF) and the World Bank, introduced the Financial Sector Assessment Program (FSAP) in 1999 (Moretti et al., 2008). The aim of the program is to provide a comprehensive macroeconomic framework capable of assessing the solvency of individual banks on a set of countries, in terms of capital adequacy (Cihak, 2004).

Furthermore, the Bank for International Settlements (BIS), has developed multiple macro prudential stress tests which range from re-evaluating frameworks, to studies focused on expanding the scenarios by including links to the financial side of the economy(BIS, 2012). The Federal Reserve Bank (FED) in the United States and the European Banking Authority (EBA) both provide frameworks with general guidelines for estimating potential threats to financial institutions (Acharya et al., 2014).

These frameworks, however, seem to focus on capital adequacy only and therefore have largely ignored the requirement for sufficient banks' liquidity in periods of stress (Goodhart, 2006; Schiozer and de Freitas Oliveira, 2016; Jobst et al., 2017), where bank liquidity is closely associated with the state of the economy. For instance, individuals' withdrawals and deposits are likely to worsen and boost institutional liquidity, respectively. The relationship between the banks' liquidity and the macro and financial environment helps to further understand the liquidity position of the bank. Therefore in the last decade, regulators focus on macro prudential regulation as a key indicator of financial stability.

The most common method for developing and applying a stress test is the reduced form approach (Sorge, 2004). Two models are commonly used under this approach, Vector Autoregressive Models and Satellite Models (Čihák, 2007; Pesola, 2011; Quagliariello, 2007; Hesse et al., 2012). Additional limitations present in many of the approaches to stress testing liquidity. Both methods have limitations stemming from heavily relying on econometric estimations (see Acharya et al. 2014 for a detailed disucssion). In addition, this satellite model does not capture the dynamic effects of stressed risk factors (Borio et al., 2014).

In this paper we propose a multivariate copula estimation (MCE) approach, which allows us to overcome the main limitation of the reduced form model approach (Koliai, 2016). The MCE measures the dependency among variables even if they do not follow the same distributions (Patton, 2009). It is a useful approach in this case as it allows all variables to be endogenous, hence distributional assumptions on the marginal densities of the variables modelled, are not required. Consequently, it is not necessary to assume linearity when carrying out this test. Once the marginal distributions have been characterised, the MCE allows to flexibly model the dependence structure between several random variables.

To the best of the author's knowledge, this is the first study that uses this estimation for carrying out liquidity stress testing. The use of MCE allows to assess and quantify the interaction of the macroeconomic factors with the financial factors. To apply this approach, we go beyond the calculation of the joint distribution of bank liquidity risks as we incorporate an estimation of the simultaneous macro effects on banks' funding position. In our analysis, we extend the framework of the traditional copula processes (see for example Koliai 2016), by measuring the marginal effects of each macroeconomic variable on the NSFR. The marginal effects provide important insights for stress testing as they describe the sensitivity of a given financial institutions balance sheet to the macro environment. Therefore, overcomes the limitations arising from the traditional econometric approaches, such as the reduced form models. This approach also assesses the existence of liquidity risk by identifying the main macroeconomic indicators leading to critical shortages in the funding position of the banks. contingency planning.

Our results illustrate the importance of funding liquidity risk, under the examination of adverse macroeconomic scenarios. Specifically, the NSFR under stressed economic conditions, display higher probability to fall compared to the non-stressed one, for the EU banking system. The main macroeconomic channels, that lead to liquidity shortages, are the Unemployment rate, GDP growth rate and Deficit, indicating the substantial role of Macro prudential Policy in the area of Financial Stability.

The remainder of this chapter is structured as follows: Section 2.2 reviews the relevant liquidity stress test literature. The methodology is presented in Section 2.3, discussing the data, scenarios and model specification. Section 2.4 presents the results whilst Section 2.5 is the conclusion.

2.2 Related Literature

This section provides the relevant literature within liquidity risk and stress test models as well as he existing studies using copulas estimation for capturing financial stress. Additionally, a comparative analysis of the traditional stress test approaches is provided. This section denotes whether funding liquidity risk is assessed within the current stress test frameworks and reveals the need to investigate the main macro financial linkages.

2.2.1 Stress tests under structural and reduced form models

Stress tests originally appeared during the early 90^{s} in CreditMetrics and CreditMetrics^{+} models (Boston, 1997) assessing credit and market risk under adverse scenarios. In 2000, stress tests became a key component in assessing FIs stability (Bhattacharyay, 2004). The major expansion of stress tests is observed after the recent financial crisis in 2008. Their purpose was mainly to measure the capital adequacy of FIs (focusing on banks) under adverse economic scenarios (Quagliariello, 2009).

Stress test methodologies and applications comprise a multistep approach. One of the starting points in this approach is the scenario design where the shocks and the respective risk mapping, are developed. The choice of an exogenous shock or a set of shocks is usually based on historical extreme events, where shocks may be drawn from the tail of historical distributions (Borio et al., 2014) or hypothetical and hybrid scenarios (Breuer and Krenn, 1999; Adrian et al., 2020). The latter are used when both historical and hypothetical scenarios are combined (CGFS, 2005).

The most common stress test methodologies in scenario analysis are the structural and the reduced form models. Structural models include logit, probit and panel estimations (see for example, de Bandt and Oung 2004; van den End et al. 2006; Martin 2007; Marcucci and Quagliariello 2008; Kalkbrener and Overbeck 2017) as well as multivariate copula functions (see for example Hamerle and Rösch 2005; Boss et al. 2006b; Kalkbrener and Packham 2015; Paraschiv et al. 2015).

Stress test approaches carried out with structural models and specifically copulas estimations, mainly focus on financial rather than macroeconomic and macroprudential analysis. In particular a study developed by Brechmann et al. (2013) examines the interconnectedness of the international financial markets with the use of vine copulas [1]. The authors investigate contagion effects among financial institutions through a financial stress test approach. In the model developed, contagion risk is assessed through the dependence of CDS spreads from the transactions among insurers, international institutions and banks. On a similar direction of financial stress testing with the use of copulas estimation, is the analysis developed by Paraschiv et al. (2015), who assess the contagion risk and count for dependency evolution on commodity futures portfolios. The use of copulas approach highlights that under market stress the joint dynamics among the commodities' returns, provide "superior prognosis" and a forward looking approach necessary for stress testing techniques.

A study developed by Koliai (2016) acts as a stress test process with a good-performance-flexibility balance for an analytical scenario design. The scope of Koliai (2016) analysis focuses on FIs' portfolios of different asset categories such as equities and commodities with the use of pair copulas estimation and provides the dynamic perspectives (evolution of assets' returns) of the key financial risks. Whilst the

[1] Vine copulas leverage from bivariate copulas and enable extensions to arbitrary dimensions. Vine copulas use in finance focuses more on the tail risks vine copulas have been shown to effectively model tail risk in portfolio optimization applications

use of copulas estimation reveals the complexity of FIs' transactions and portfolios of assets when adverse conditions are applied, the link between macro and micro prudential perspectives which can provide valuable information for policy makers, is missing.

Moving to the reduced form approach, the use of time series and panel data models can assist in assessing distressed periods, when stress tests are focused on specific countries or banks (Sorge, 2004). In the reduced form approach fits the satellite model developed by Čihák (2007) which comprises a series of functions aiming to link the macro with the financial side of the economy and provides a framework for assessing most of the risks FIs might face (can contain multiple risk factors). The main advantage of satellite models is that through stochastic estimations, they can capture the relation between scenarios (macroeconomic environment) and risk factors (microeconomic environment) (Henry et al., 2013). Also, Canova and Ciccarelli (2013) highlight the ability of panel vector autoregressive models (VAR) as a stress test method in order to investigate the key macro-financial linkages. In particular, the authors explain that panel VAR capture the interdependencies between the macro and the financial side of the economy and allow for cross sectional heterogeneity. Despite the flexibility panel VAR models have fin order to incorporate macro-financial links in an unrestricted way, the key limitations of these models when applied on a stress test process stem from the assumption of linearity and the estimation of the effects between the micro and the macro environment without allowing for the impacts quantification (as the Copulas estimation can provide). The inability to quantify the impact of shocks and linkages arising in the financial system, especially when FIs acting under stress, leads stress test models lacking of significant information necessary for policy decision and FIs contingency planning.

Recent studies in the area of stress test models with the use of panel VARs investigate FIs solvency and asset quality. Budnik et al. (2019) develop a VAR approach for a macroprudential stress test for the euro area banking system. The study examines the 91 largest euro area credit institutions across 19 countries by linking banks' reactions to changing economic conditions and assesses a broad set of interactions and interdependencies between banks, other market participants, and the real economy. Whilst the results highlight the importance banks to maintain sufficient capital and to improve the quality of the assets banks' hold, the use of VAR models for a stress test scenario analysis omits the magnitude of the impact on banks' solvency while banks' ability to fund their activities and liabilities is neglected.

Despite, the rise of structural and reduced form methods for performing stress tests, the current literature partially addresses the key objectives policy makers require from the current stress test applications. Particularly, the current studies rely on financial rather than macroprudential stress tests and the vulnerabilities financial institutions might face are not fully revealed. Even copulas estimation are able to develop and capture the complexity of the financial system by overcoming strict assumptions applied on the reduced form approaches, their use in stress testing remains limited and the requirements of prudential regulation for informative stress testing is not addressed . The current literature explain the capabilities of copulas estimations to reveal the key financial vulnerabilities and to capture the dynamics of a complex system such as the financial one. However, the lack of the key linkages between the macro and the financial side of the economy combined with valuable policy information for enhancing the macroprudential framework, underlines that macroprudential stress tests with the use of copulas methods still emerge.

2.2.2 Liquidity stress tests

Liquidity risk has been the subject of substantial academic interest. This includes numerous studies of individual institutional failures, for instance the seminal work of Diamond and Dybvig (1983) and approaches to liquidity risk monitoring and measurement (see for example Vento and La Ganga 2009). Nevertheless, liquidity stress tests remain at an early stage (Constâncio, 2016). Current work in this area is primarily based on assessing liquidity risk by examining banks reserves, overdrafts, credit, interbank loans and the incoming payments from other banks

(BIS, 2014a). For instance Hesse et al. (2012) builds on Čihák (2007) balance sheet approach and quantifies liquidity risk through a cash flow analysis. In this model the authors attempt to link liquidity and solvency risk using information on the wholesale funding market. The importance of how liquidity risk is treated is considered, however, the main drivers of liquidity risk during a financial or a sovereign crisis period, can not be assessed.

Matz and Neu (2006) propose a framework for conducting liquidity stress tests. They develop the Liquidity at Risk measure (LaR) and use it for the estimation of the net cumulative liquidity gap for banks under extreme events. Whilst this measure captures liquidity risk it differs from regulatory measures. In the context of the assets and liabilities maturity mismatch, Cihák and Ong (2010) develop a liquidity stress test for one Icelandic bank, in order to assess the solvency profile of this bank. Through the liquidity gap approach (maturity mismatch), the authors estimate the bank's funding position in one year horizon and identify the nexus between the liquidity and the solvency of the bank. However, the use of a static balance estimation combined with the limited sample, do not reveal the main liquidity risk drivers and the funding risk evolution, while the heterogeneity of the banking system is missing.

Further the above work diverges in terms of the scenario design, sample size and the variables representing liquidity risk (Ong, 2014). Specifically, Financial Sector Assessment Program (FSAP) models investigate liquidity risk by assessing the number of days a bank would be illiquid after a shock (Moretti et al., 2008). The main issues with FSAP liquidity stress tests is their inability to assess the evolution of liquidity risk over time as well and to identify the main macroeconomic and financial drivers that can lead to liquidity shortages.

The majority of studies related to liquidity stress tests focus on the micro rather than the macro side of the economy whilst omitting key macroeconomic risk drivers affecting banks' funding position . Such a case is the study developed by Wong and Hui (2009) who use Monte Carlo simulation to measure the interaction between default and liquidity risk during a downturn in stock prices. Similarly, by examining the interrelation of liquidity risk with other types of risk, Van Den End (2009) attempts to endogenize both market and funding liquidity risk for Dutch banks while considering first and second round effects. The Monte Carlo simulation results suggest that liquidity risk is non-linear and liquidity buffers should increase under stress events. To this point, Van Den End (2012) further develops this work to assess the effect of adverse financial scenarios on the Basel III liquidity ratios (LCR, NSFR) in a stress test framework. Despite, the author incorporates the Regulatory liquidity measures, within a scenario analysis stress test framework, the main funding risk drivers as well as the interaction of the Basel III liquidity measures with the key macroeconomic indicators, is neglected.

Similarly, the IMF (Adrian et al., 2020) provides information on the steps followed to perform liquidity stress tests for individual banks globally. In their most recent work, they perform LCR sensitivity rather than scenario analysis. Despite banks' funding position is assessed with the use of the regulatory liquidity measure, the set of parameters included so far, highlight that macro prudential liquidity stress tests still emerge. Particularly, Adrian et al. (2020) make use of market level information such as run-off rates, rollover rates, and haircuts, without taking into consideration the key macro-financial linkages under a scenario analysis process.

Currently as the literature stands there is no comprehensive and complete in terms of scenarios and macro-financial linkages, macroprudential stress test framework. A unified approach, which can capture simultaneous macro-financial shocks and their magnitude, and assess alternative sources of banking risks, will improve the ability of stress tests to act as standalone tools in the financial stability framework.

2.3 Macroprudential Framework

In order to identify the relationship between the deposits, NPLs and expected bank liquidity through the NSFR, we employ a copula approach. The latter allow us to assess potential liquidity risk under different macroeconomic scenarios. For each scenario, we compute the probability of the NSFR being above one to show whether each bank is sufficiently liquid. In parallel, we calculate the marginal effects of each macroeconomic variable. This illustrates the sensitivity of the NSFR under the different economic conditions and provides information for the main liquidity risk drivers. In the second stage we measure the level of deposits and non-performing loans under varying NSFR levels. Given the expected value of the NSFR, from the first stage, we recover the volume of deposits and NPLs. In order to do so, the copula process applied to decide the relationship between the deposits and NPLs. This means that for any value of the NSFR, we are able to determine the level of deposits and NPLs the banks would hold, for any given scenario. This process is necessary as it provides valuable information for banks to make contingency plans against liquidity shortages. Given that lending and saving is an indispensable part of the banks'operations, by quantifying these changes in banks'balance sheets we can identify actions needed after severe liquidity shortages.

2.3.1 Data

We perform the above analysis on commercial banks in the the banking systems of Cyprus, Greece, Italy, Portugal and Spain. We focus on the Southern European banking sector because , even during the crisis, these banks were considered well capitalised but still were unable to prevent significant losses on their balance sheets and at the same time many of the banks were found to be illiquid. As such liquidity risk was neglected (Greenlaw et al. 2012; Schuermann 2014). The following subsections 2.3.1.1 and 2.3.1.2, provide details on the data used for carrying out this analysis and the descriptive statistics of the macroeconomic and bank level variables.

2.3.1.1 Macroeconomic Data

To define the scenarios we focus on seven macroprudential indicators; Gross Domestic Product, Unemployment, Inflation, Gross Debt, Account Balance, Foreign Direct Investment and 12M Euribor, based on the report developed by the ECB (2016) which provides the main macroprudential indicators . Each of these variables is collected for each country in our sample. The macro level data are on annual span from

1980-2016 and come from World Bank, the European Central Bank and the OECD databases. In our analysis, we use historical information scenarios from 1980-2016. This data set is selected in order to capture not only the global financial turmoil but also the macroeconomic trends of each country separately. Using these data we define three scenarios: Baseline, Good and Bad (Stressed). The baseline scenario assumes the current state of the economy in each country. The good case takes the peaks of each economy while the bad scenario assumes the periods of the greatest recessions. In all cases the bad scenarios arise during 2010-2011. The use of historical scenarios provides us with the stressed cases an economy may face and in parallel is in line with stress test frameworks, which aim to use extreme but plausible events.

Table 2.1: Scenario Analysis

Macroeconomic Variables	Greece			Cyprus			Italy		
Scenarios	Non-Stressed	Stressed	Baseline	Non-Stressed	Stressed	Baseline	Non-Stressed	Stressed	Baseline
GDP	5.80	-9.13	-0.58	9.92	-5.94	1.59	4.19	-5.48	0.95
INF	0.02	27.08	0.17	0.02	13.45	0.60	0.02	21.18	0.52
UNEM	2.66	27.48	25.03	1.80	16.13	14.23	6.13	12.64	11.39
GD	21.24	178.40	176.49	44.57	108.67	99.25	79.10	133.03	128.93
AC	0.00	-14.38	-0.22	2.85	-15.64	-4.82	2.96	-3.52	2.27
FDI	18.11	-3.24	-0.49	45.29	-2.04	5.23	1.91	-0.86	-0.11
12M	0.17	7.11	0.48	0.17	7.11	0.48	0.17	7.11	0.48

Macroeconomic Variables	Portugal			Spain		
Scenarios	Non-Stressed	Stressed	Baseline	Non-Stressed	Stressed	Baseline
GDP	5.71	-3.58	2.64	7.86	-4.03	1.40
INF	0.02	15.19	0.67	0.02	33.51	0.81
UNEM	8.23	26.10	19.72	3.86	16.18	11.56
GD	21.90	-9.65	0.98	3.08	-14.43	0.93
AC	0.00	-14.38	-0.22	2.85	-15.64	-4.82
FDI	11.08	-1.06	0.19	7.69	-31.08	0.36
12M	0.17	7.11	0.48	0.17	7.11	0.48

Table 2.1 provides the three scenarios used for the systemically important banks located in Greece, Cyprus, Italy, Portugal and Spain. The scenarios arise from the historical information of the macroeconomic indicators of each country, from 1980-2016. The stressed scenario corresponds to the bad economic state while the non-stressed to the peak of each economy. The baseline scenario, is each country current economic state.

2.3.1.2 Bank Level and NSFR Data

With regards to the individual banks within balance sheet and income statements for systemically important banks located in Greece, Cyprus, Italy, Portugal and Spain, are collected. This gives 30 banks in total (cross dimension) with annual data from 2004 to 2014 (time series dimension) in a panel. Although the initial search provided results for more than 41 Financial Institutions (FIs), 11 were eliminated to ensure the panel was well defined.We consider only banks, which are rated by one or more of the rating agencies Moody's Standard & Poor's and Fitch and which are used in European system-wide stress tests (European Banking Authority 2014, 2016). In addition to avoid double counting of banks we consider only banks with consolidated statements and therefore exclude subsidiaries and branches as separate financial entities. Thirdly, we consider only large banks where book value of assets exceeds 1000 Euro millions for all years examined. Finally, any bank whose data is incomplete of not qualified under the International Reporting Standards is excluded. The bank level data are collected from Bankscope and Bloomberg databases.

Table 2.2: Summary Statistics of Banking Variables in the NSFR

Banking Variable	**Definition**	**Min.**	**Max.**	**Mean**	**Std.**
NSFR	Net Stable Funding Ratio	0.255	2.287	0.86	0.22
Required Stable Funding	**Definition**	**Min.**	**Max.**	**Mean**	**Std.**
NIBCL	Non-Interest Bearing	-340.10	94,344.00	7,367.63	14,502.17
LLR	Loan Loss Reserves	0.00	12,759.90	947.85	2,296.41
OR	Other Reserves	0.20	19,823.00	1,649.45	3,696.04
SDebt	Senior Debt	-3,955.00	206,869.30	24,333.81	46,429.36
Sub.D	Subordinated Debt	0.00	30,200.30	3,096.05	5,680.44
HC	Hybrid Capital	0.00	8,708.00	639.47	1,482.10
TE	Total Equity	-3,074.30	89,449.00	9,025.23	17,055.78
CD	Current Deposits	0.00	291,665.40	30,356.85	52,710.92
SD	Saving Deposits	78.70	173,105.00	16,071.25	33,329.95
Term.D	Term Deposits	1.80	282,532.50	23,659.19	42,288.23
TtD.	Total Deposits	80.5	578,884.00	61,202.16	104,431.46
Available Stable Funding	**Definition**	**Min.**	**Max.**	**Mean**	**Std.**
RMBS	Residential Mortgages	0	84,002.00	161,11.25	14,363.83
CL	Consumer Loans	179.40	429,477.00	35,966.96	87,032.37
CML	Commercial Loans	0.00	248,779.00	27,619.20	38,852.71
OL	Other Loans	0.00	727,143.00	62,121.85	130,365.57
Non-Performing Loans	NPLs	1.70	47,955.30	4,148.10	7,485.24
FxA	Fixed Assets	0.30	16,889.00	1,556.72	2,597.78
GW	Goodwill	0.00	27,548.00	2,214.14	5,315.84
OtI	Other Intangibles	0.00	24,255.00	718.43	2,095.52
OtA	Other Assets	0.60	48,894.00	2,139.33	4,623.17
LtB	Loans to Banks	23.40	77,860.30	7,875.28	14,152.33
DRV	Derivatives	0.00	129,248.00	8,828.70	22,734.35
SECU	Securities	0.00	17,652.60	3,191.61	4,354.39
OEA	Other Earning Assets	0.00	57,859.90	3,367.90	11,949.35

Table 2.2 provides the summary statistics of the banking variables used for constructing the Net Stable Funding Ratio. The data are balance sheet items collected from 2004-2014 on annual span .

In order to develop the NSFR ratio apart from the assets and liabilities collected from the banks' balance sheets, we also assign a respective weight for the NSFR specific elements. In order to assign the weights we based our analysis on the BIS (2014a) technical documentation. Figure 2.1, displays analytically the required and the available funding components with the respective weight.

Required Stable Funding (weighted sum)	**Available Stable Funding** (weighted sum)
100%	**100%**
Residential Mortgages	Loan Loss Reserves
Consumer Loans	Other Reserves
Commercial Loans	Non-interest Bearing
Other Loans	Senior Debt
Impaired Loans (NPLS)	Subordinated Debt
Fixed Assets	Hybrid Capital
Good Will	Total Equity
Other Intangibles	
Other Assets	**85%**
35%	Current Deposits
Loans to Banks	**70%**
Derivatives	Saving Deposits
Securities	Term Deposits
Other Earning Assets	

Figure 2.1: NSFR Components and Respective Weights for Banks' Available and Required Stable Funding

The funding position of banks is assessed with the use of Basel III Net Stable Funding Ratio (NSFR) (see Vazquez and Federico (2015) and BIS (2014a) for further details). The NSFR is the fraction of the Available Funding Ratio (ASF) over the Required Funding Ratio (RSF). Specifically, the NSFR is calculated as the weighted sum of liabilities (ASF) over the weighted sum of the assets (RSF) and it is specified as follow:

$$NSFR(it) = \frac{ASF(it)}{RSF(it)}$$

where i and t is the bank and the year-period respectively.

2.3.2 Model

In this section we propose a method to jointly model the NSFR and macroeconomic variables. To illustrate the methodology, let $X = (X_1, \ldots, X_m)'$ be an m-dimensional vector formed by the variables of interest. The marginal densities are modelled nonparametrically using the Gaussian kernel and the automatic optimal bandwidth, also known as Silverman's 'rule of the thum' (S). Once the marginal densities are defined, the joint distribution can be recovered via copulas. From Sklar 's theorem, if the marginal cumulative distribution functions (cdfs) are continuous, then there is a copula function $C(x_1, \ldots, x_m) : [0,1]^m \to [0,1]$ such that the joint cdf is defined as

$$F_{1,\cdots,m}(x_1, \ldots, x_m) = C\left[u_1, \ldots, u_m | \mathbf{R}\right], \tag{2.1}$$

where $u_j = F_j(x_j)$ $(j = 1, \ldots, m)$ are the corresponding marginal cdfs and $\mathbf{R}$ contains the copula parameters that define the degree of dependence between the random variables. In this case we have decided to use the Gaussian copula, given its flexibility to model high-dimensional vector. In this case, $\mathbf{R}$ is estimated as the sample rank correlation coefficient between the observations of the variables in our sample. From (2.1), the joint probability density function (pdf) can be obtained as

$$f_{1,\cdots,m}(x_1, \ldots, x_m) = c(u_1, \cdots, u_m) \prod_{j=1}^{m} f_j(x_j), \tag{2.2}$$

where $f_j(x_j)$ $(j = 1, \ldots, m)$ are the marginal density functions and $c(\cdot)$ the pdf of the Gaussian copula, defined as

$$c(u_1, \ldots, u_m) = \frac{1}{\sqrt{\mathbf{R}}} \exp\left[-\frac{1}{2}\mathbf{y}'(\mathbf{R}^{-1} - \mathbf{I}_m)\mathbf{y}\right], \qquad \mathbf{y} = \left(\mathbf{\Phi}^{-1}(u_1), \ldots, \mathbf{\Phi}^{-1}(u_m)\right)',$$

where $\mathbf{\Phi}^{-1}(\cdot)$ is the inverse cumulative distribution function of a standard Normal, and $\mathbf{I}_m$ is the identity matrix of order m. Once the joint density is recovered via copulas, we proceed further. We are interested in modelling the behaviour of one variable, say X_1, given the values of the rest of variables. To this aim, it is interesting to obtain the conditional density of X_1 given the remaining variables, which can be obtained, by numerical integration as

$$f_1(x_1|X_2 = \bar{x}_2, \ldots, X_m = \bar{x}_m) = \frac{f_{1,\ldots,m}(x_1, \bar{x}_2, \ldots, \bar{x}_m)}{\int_{-\infty}^{\infty} f_{1,\ldots,m}(x_1, \bar{x}_2, \ldots, \bar{x}_m) dx_1}, \quad (2.3)$$

where $\{\bar{x}_2, \ldots, \bar{x}_m\}$ are predetermined (known) values for the conditioning variables. These values will determined the different scenarios that we will consider in the analysis. [2] This conditional density function will be very useful to extract three different measures that we will use in our analysis: first, we can calculate the probability of our target variable X_1 to be above a given level a as

$$Prob(X_1 > a) = \int_a^{\infty} f_1(x_1|X_2 = \bar{x}_2, \ldots, X_m = \bar{x}_m) dx_1. \quad (2.4)$$

Second, we can calculate the expected value of our target value conditional on the values of the rest as

$$E(X_1|X_2 = \bar{x}_2, \ldots, X_m = \bar{x}_m) = \int_{-\infty}^{\infty} x_1 f_1(x_1|X_2 = \bar{x}_2, \ldots, X_m = \bar{x}_m) dx_1. \quad (2.5)$$

Finally, we can calculate the marginal effect of each of the conditioning variable on the target variable by numerical differentiation as

$$\beta_j = \frac{\partial E(X_1|X_2 = \bar{x}_2, \ldots, x_j, \ldots, X_m = \bar{x}_m)}{\partial x_j}, \qquad j = 2, \ldots, m. \quad (2.6)$$

These marginal effects, similar to the coefficients of a linear regression model, measure the change in the expected value of the target variable against a marginal increment of each of the conditioning variables. These marginal effects are asymptotically normal, and p-values can be approximated for them. Notice that all these measures defined in equations (2.4)-(2.6), depend on the values of the conditioning events. Hence, we will have different measures depending on the scenario consid-

[2]The process described in equations(1),(2) and(3)have been also applied for estimating the relationship between the deposits and NPLs, in order to be able to define their levels under the three scenarios.

ered. This will allow us to study how the sensitivity of our target variable to the conditioning variables change depending on the the scenario considered.

2.4 Results

In this section we present the results of the Copulas estimations discussed in Section 2.3. As oppose to the current macroprudential stress test models, we use copula analysis in order to quantify the interconnectedness between the macro and the financial side of the economy by overcoming the main limitations reduced form approaches such as VAR models present.

We show the relationship between the economic state and banks' funding position, through the Regulatory liquidity measure, the NSFR. Our analysis reveals the strong interrelation between the key macroprudential indicators and banks' funding position. The results underline that under adverse economic states (stressed scenario) the key macro-financial linkages lead to liquidity shortages and increase the probability of systemically important banks being unable to meet their liquid needs.

Apart from the key macro-financial linkages and the expected value of the NSFR under the different economic states, we further our analysis by showing the levels and degree to which deposits and NPLs need adjustment in order to cope with the updated banks liquidity demands. Through this process, we contribute to the key prudential requirements for developing analytical stress test exercises able to disclose important information for both policy makers and banks' contingency planning.

In estimating the NSFR and in turn the levels of NPLs and Deposits, we focus on 30 systemically important banks located in Cyprus, Greece, Italy, Portugal and Spain. Each bank acts under three scenarios: baseline, good and stressed. Each scenario considers the effect of the macroeconomic environment of each country during the relevant period. In order to define the scenarios for the macroeconomic variables, we use annual historical observation from 1980-2016. During this period we observe that the peaks of the economy are stronger and more persistent compared

Table 2.3: Expected Value of the NSFR under non-stressed, stressed and baseline scenarios

Countries	Good	Stressed	Baseline
Greece	119.67	44.4	78.14
Cyprus	120.55	53.16	97.00
Italy	108.12	79.68	89.67
Portugal	87.09	89.74	81.93
Spain	90.4	88.3	100.00

Table 2.3 provides the expected value of the NSFR under the good, stressed and baseline scenarios. The NSFR is shown in percentage points and is displayed on a country level - calculated as the mean of the values for all banks in each country. The medians were also calculated, not shown, and follow a similar pattern.

to the crisis periods (for instance 2009-2011).[3]

2.4.1 NSFR under the different Economic States

The copula estimation provides the expected value of the NSFR under the three different scenarios (baseline, good and stressed) as well as the marginal effect of each macro variable on the NSFR (conditional on the other macro variables). Therefore, we quantify how responsive is the NSFR to a marginal change of each macro variable and assess the main liquidity risk drivers.

Table 2.3 provides the NSFR expected value under the three economic scenarios, namely the good, the baseline and the stressed scenario. We initially observe that for all countries, the NSFR is responsive to the economic conditions. In particular, when the economic state is good, the NSFR for Greece, Cyprus and Italy is above the 100% threshold. The expected value of the NSFR highlights that under economic rise, banks located in Greece, Cyprus and Italy have adequate liquidity. An exemption to this is Portugal, which even under a good economic state is below the threshold without presenting substantial variation across the different scenarios. Also for the case of Spain, the NSFR requirement is just only met.

[3]To assess the robustness of our results we use two further data sets, one quarterly data from 2000 to 2016 and the other annual from 2004-2014. We find that in each case the results are qualitatively similar.

Under the stressed scenario, which comprises a marginal change of the baseline economic conditions, the NSFR on country level is below the threshold. The greatest reductions between the baseline and stressed scenarios are for Cyprus, where Cypriot banks face facing a substantial liquidity reduction by 44%. Whilst under the baseline scenario, Cypriot banks display an average threshold equal to 97%, when the economic conditions deteriorate, the expected value of the NSFR drops reaching at 53%. In addition, substantial changes on the NSFR under baseline and stressed scenarios are observed for Greek, Italian and Spanish banks, where the NSFR decrease by 34%, 10% and 12% respectively.

Portugal is an exception to this rule. The macroeconomic stressed period for Portugal is during the 2008-2010 financial crisis. While banks in Portugal were under heavy stress during this period they were also being supplied by liquidity by the government and Financial Authorities which artificially increased banks' funding position, and in turn the NSFR during the stressed period (Gaspar, 2012).

Taken together these results, we highlight the need for macroprudential analysis of liquidity provision and in particular the use of stress tests. The expected value of the NSFR is sensitive and strongly linked to the state of the Economy, as well as to the fluctuations arising in an economic system. Changes in the macro environment are very capable of pushing financial institutions into a state whereby they are unable to meet their liquidity needs. The use of different scenarios highlights the degree of sensitivity of the NSFR. Banks in Cyprus, Greece and Italy were highly liquid a few years ago during the good state of the Economy, but are currently in a position whereby they fail the tests.

In the next subsection we go on to examine the liquidity risk drivers through the development of the marginal effects. The quantification of these effects provide the magnitude of the interconnectedness between the NSFR and the key macro indicators. The results below, assist to identify when macro-financial linkages strongly respond to the macro environment fluctuations and result in the funding positions of banks to shrinking.

2.4.2 Sensitivity Analysis and the key Liquidity Risk drivers

Table 2.4 shows the marginal effects of the macro-economic variables on the NSFR. The marginal effects quantify the sensitivity of the NSFR on a change of one macroeconomic variable conditional on the other variables remaining unchanged. The results are presented for each country, averaged across the banks within that country, for each of the three scenarios, the good the baseline and the stressed scenario. Significance levels are not included, however, all values are significant at the 99% level and therefore these marginal effects indicate the key drivers of liquidity risk.

By comparing across scenarios it is possible to identify common linkages between the macro economy and bank funding position within each country. Across all scenarios there is a positive effect of GDP on the NSFR ranging from 0.05% to 4.34%. The strongest effect across all scenarios is demonstrated by Cyprus in the baseline scenario (4.34%). The reason for this is that Cyprus was subject to a severe financial crisis during 2015 - 2016. The baseline scenario considers the state of the macro economy just after this period a point at which the economy has started to recover and banks are rapidly improving their liquidity post-crisis (Rapanos et al. (2014)).

In the case of the good and the stressed scenarios, the strongest marginal effects on the NSFR comes from the GDP growth rate, and are observed for Spain. However, these effects in all states are negative. This negative sign is not the expected one as over this period Spain's GDP growth rate decreases due to macroeconomic instability (Borio, 2014). In parallel, the Spanish Banking System is involved in the Financial Assistance Programme in order to cope with the financial vulnerabilities. Therefore this mismatch between the NSFR and the GDP rate, indicates the artificial liquidity provided in the Spanish banks through the financial assistant programmes received which their main focus is to increase the capital position of the banks.

Moving on to the unemployment rate (Table 2.4), a negative effect on the funding position of most of the banks exists, which falls in line with the rise of unemployment across the EU region. An exception to this is Cyprus and Portugal, where the marginal effect of this rate is positive. This is due to the behaviour of the unemployment rate which in both countries ranges between 8% and 12% under both stressed and non-stressed period. The almost stable level of the unemployment rate on these two countries, illustrates that this economic indicator is stable and not substantially volatile even during crisis period. This is further evidence that our results provide causality effects between the NSFR and persistent macroeconomic indicators such the unemployment rate. In parallel, the Greek economy indicates a stronger effect of the Unemployment in the baseline scenario (-1.80%) compared to the good (-0.10%) and the stressed (-0.80%) case which indicates the deterioration of the Greek economy in the post crisis period (Louzis et al. (2012)).

The account balance indicates the economic activity of a country. Significant positive effects are displayed for the Greek and Spanish banks across the majority of scenarios. This is a signal that these two economies remain under stress while their economic activity shrinks compared to the stressed period. The decrease of the volume of exports over the volume of imports represents the restricted economic activity of these two countries. Our observation here falls in line and enhances the "fly to quality" argument, in other words the conservative lending policy of banks post crisis, leads to lower exports due to the higher lending cost of firms (Provopoulos (2014) andCarballo-Cruz (2011)).

The foreign Direct Investment indicator also related to liquidity risk. In most case it has the expected sign (Table 2.4) under both the good and stressed scenarios. In the baseline scenario, the FDI affects negatively the funding position of Greek and Portuguese banks, (-0.22% and -0.60% respectively). This negative sign arise from the financial assistance and recapitalisation programmes provided to these banks in order to cope with the Regulatory requirements which occurred at the same time that the investment activity in these two countries continued to shrink (Cline and Wolff (2012)).

Regarding the interbank interest rates (Table 2.4), these indicate a negative effect for Greece and Cyprus whereas for the rest of the countries the relationship is positive. The reason is that the Greek banks were restricted from borrowing from the international markets and at the same time the Cypriot banking sector was facing a recession in parallel with a bailout program which also restricted their access to the interbank market (Xiouros (2013)) .

2.4.3 Stress Testing and the optimal level of Deposits and NPLs

In the last step of our analysis, we identify the level of deposits and NPLs under which the banks are able to handle the liquidity shortages arising from the macroeconomic fluctuations. Table 2.5 indicates the volume of deposits and non-performing loans under the stressed scenario. We select the largest banks (in terms of assets) from each country in our sample in order to provide further information on the banks actions after a liquidity shortage and to assess the severity of liquidity risk. Here we focus on the largest bank in each country in order to show how individual balance sheets are impacted.

National Bank of Greece, Alpha Bank and the Italian Banca Monte dei Paschi funding positions under stress are between 30% and 60%. The Basel III liquidity regime requires a level of 100% for the NSFR meaning these three banks have a very low level of liquidity and they should decrease the volume of the deposits and NPLs as indicated by the negative sign of these two variables. This behaviour can be explained in two facets. Firstly, the increased amount of NPLs indicate the exposure these banks have through their lending activity and the need to invest in safer assets. In parallel, the amount of deposits highlight that these banks continue accepting funding through the deposits activity without being able to cover this funding in case of substantial deposit withdrawals.

Despite the behaviour of these Greek and Italian banks, the level of the NSFR, for the rest of the banks, indicates that these banks are able to meet their liquidity needs. in other words by comparing our results with the NSFR expected value on country level, the largest banks NSFR performance highlight that the size of the

Table 2.4: Marginal Effects of the Macroeconomic Variables on the NSFR

1980-2016		Good					Stressed				
Country	No of Banks	GDP	UNEM	AC	FDI	12M	GDP	UNEM	AC	FDI	12M
Greece	6	0.09	-0.10	0.14	0.00	-0.13	0.63	-0.80	1.45	0.32	-0.87
Cyprus	2	0.05	0.03	0.00	0.00	-0.13	0.14	0.07	0.04	0.01	-0.87
Italy	13	0.56	-1.87	0.78	0.50	0.29	0.33	-0.48	-0.02	0.18	1.58
Portugal	3	0.00	2.03	0.08	-0.31	1.90	0.66	2.45	-0.05	0.00	3.21
Spain	6	-2.26	-3.65	2.13	0.41	6.59	-1.91	-4.22	2.69	0.75	9.17

Baseline

Country	No of Banks	GDP	UNEM	AC	FDI	12M
Greece	6	1.13	-1.80	3.60	-0.22	-0.22
Cyprus	2	4.34	2.10	2.60	0.33	-0.22
Italy	13	0.87	-0.49	0.51	0.08	0.35
Portugal	3	0.57	0.80	0.15	-0.60	0.48
Spain	6	-1.29	-3.19	3.66	0.46	8.92

Table 2.4 provides the marginal effects of the macroeconomic variables on the NSFR under the three scenarios on the country level (again calculated form the means of observations of each bank within each country). The marginal effects are in percentage points and illustrate the sensitivity of the NSFR on a marginal change of one macroeconomic variable conditional on the others, under the three economic states.

bank (in terms of assets) affects their ability to serve their liquid needs.

Overall, these results explain that the NSFR captures the dynamic treatment as it reflects successfully on the different economic states (scenarios), while the liquidity stress test in a macroprudential framework is significant and necessary when assessing the financial stability and should be complementary to the asset quality exercises conducted so far. By including a direct assessment of liquidity risk within a stress test framework , banks are able to assess their capital position and absorb the losses coming from their funding position.

In parallel, the NSFR is responsive to marginal changes of the macro environment, which are quantified through the calculation of the marginal effects.The statistical significance of the marginal effects in 99% confidence level, reveals the main macro financial drivers and provides information on the steps should be followed not only from the financial stability perspective but also from the monetary and economic policy point of view. This analysis should be the focus of banks management in order to enhance banks' efficiency after significant liquidity shortages. As banks need to cope with liquidity risk fast in periods of crisis where their capital base is already at a critical stage, the estimation of the NPLs and Deposits volume, is necessary for banks to withstand shocks.

Table 2.5: Volume of Deposits and NPLs under stressed and baseline scenario

Banks	NBG	ALPHA	BoC	BMdS	CdE	IntS	BpE	BdS	BCP
NSFRst	0.33	0.34	0.33	0.59	1.17	0.83	0.45	0.97	0.68
NPLsst	- 78,257.39	-152,150.92	11,316.74	-67,455.35	1,099.60	428,300.00	1,408.23	92,420.35	1,055.44
Depositsst	- 20,683.81	-118,703.32	7,672.58	-3,873.28	20,350.38	478,702.17	41,529.81	1,725,605.63	36,392.00
NPLscurrent	. 10,574.00	12,780.40	3,487.80	23,089.30	616.40	31,979.00	7,796.50	27,217.00	3,482.70
Depcurrent	. 40,865.20	42,606.10	12,623.60	71,986.70	15,666.30	210,166.00	72,675.50	567,538.00	49,802.80

Table 2.5 provides the volume of deposits and non performing loans that banks should keep in order to cope with the respective level of liquidity given the stressed and the baseline value of the NSFR. We selected the largest bank(s), in terms of assets, from each country. These main banks are the National Bank of Greece(NBG), the Alpha Bank (ALPHA),the Bank of Cyprus (BoC), the Banca Monte dei Paschi di Siena (BMdS),the Credito Emilliano (CdE), the Intensa Sanpaolo (IntS), the Banco Popolare d' Espagnol(BpE) the Banco de Santader (BdS) and the Banco Commercial Portuguese(BCP).

2.5 Conclusion

In this analysis, we develop a macroprudential liquidity stress test in order examine the role of funding liquidity risk with the use of the regulatory NSFR liquidity ratio, and the interconnectedness with the key macroprudential indicators. We assess the levels of the NSFR under three scenarios, the good, the stressed and the baseline scenario.

In parallel, we quantify the changes of the NSFR to marginal macroeconomic fluctuations with the use of a novel extension to Gaussian copula analysis. In particular by extending traditional multivariate copulas, we introduce in our analysis the development and the calculation of the marginal effects. The marginal effects assist on capturing the magnitude of the key macrofinancial linkages interconnectedness. The results of our analysis reveal the need to complement the asset quality review in the wide stress test process, with the examination of liquidity risk arising from the funding positions of bank.

The sensitivity of the NSFR over the marginal fluctuations of the macroeconomic and interbank indicators illustrate that funding liquidity risk can arise in periods of economic recession. The GDP, Unemployment, Account Balance, Foreign Direct Investment and the interbank interest rate are shown to be the main liquidity risk drivers as they can significantly deteriorate the funding position of banks by up to 50%. Our results provide evidence that considering liquidity risk when conducting stress tests is an important input. Similarly, NSFR proved to be a significant indicator to be included in the regulatory framework when counting for liquidity risk.

This analysis acts as a useful statistical analysis for carrying out macroprudential stress tests and reveal the high interconnectedness between the two key sides of the economy, the macro and the financial one. Copulas method overcomes limitations of the traditional stress test estimations and provides a more realistic estimation of the financial system complexity. In particular this method by relaxing the key assumptions of the econometric approaches, reveals the most severe macro scenarios and the key risk drivers which can trigger banks' performance and ability to serve their liquid needs. Despite the advantages this process displays, one caveat which arises is the limited dataset used. While copulas estimations require a great amount of observations, we use a marginally sufficient number of observations. However, the statistical significance of marginal effects, indicate that our data are sufficient to produce a robust analysis.

The use of Copulas models indicate that they comprise indispensable tools for carrying out stress tests and quantifying the magnitude of the macro environment effects over banks' funding activity. However, in order to have a more complete assessment on the banks' funding position, an estimation of the LCR performance and its interconnectedness with the macro environment is required. The LCR assessment will uncover banks' ability to hold high liquid assets for serving their liquid needs in the short run. For this scope in the next Chapters 3 and 4, we perform a computational agent-based process which captures the complexity of the financial and overcomes data limitation faced for the liquidity measures development.

Future work of this analysis includes the extension of the current Copulas estimations by incorporating the calculation of the impulse responses for the NSFR. By estimating the impulse responses we can further improve the capability of our model for capturing dynamic interactions, as we can assess the time needed for the NSFR to recover and reach the required by the Regulatory authorities, threshold.

Overall, our model is an analytical macroprudential stress test framework which contributes to the prudential policy regime by providing valuable information for the interconnectedness of the macroeconomic environment and the funding position of banks. Given that most of the stress test analysis are lacking contingency plans when assessing the financial position of banks, the copula estimation accompanied with the novel extension of the marginal effects, provide us with a guide to examine the NSFR response to adverse macroeconomic conditions. Also our model is capable to estimate the optimal level of deposits and NPLs that banks should hold in order to act prudently and cope with severe liquidity shortages. These findings are up most importance for regulators and policy makers alike, particularly in designing robust and early warning frameworks for establishing and maintaining financial stability.

Chapter 3

Disentangling the systemic aspects of Liquidity Risk: A multi agent stress test application for European banks

Abstract

This paper investigates the role of liquidity risk and its systemic aspect for banks under a macro prudential stress test scenario analysis. We develop a dynamic multi-agent based model to assess the resilience of systemically important banks, with a specific focus on Southern European commercial banks. In this paper the key liquidity indicator is the liquidity coverage ratio (LCR). Our model considers banks' interaction with households, firms and the government under stressed events to measure the probability of simultaneous liquidity shortages. Simultaneously, we assess the ability of LCR to capture systemic effects and the expected shortfall. Our results indicate that when LCR drops below the critical value, it signals the existence of systemic liquidity risk. The implications of our results to policy makers suggests extending the 30-days assessment, as LCR's responses to the shocks are lagging. This study provides guidance for policy makers and regulators on forward looking models when designing system wide stress tests to capture systemic liquidity risk.

JEL classification: C63; G01; G17; G18; G21

Keywords: Financial Stability; Macroprudential Policy; Stress Test; Liquidity Risk; Regulation; Agent Based Models;

3.1 Introduction

The stability of financial system became main objective for regulators and policy makers in the last decade. The importance of such objective seem to be exagravated after the financial crisis of 2007-2008. Therefore, the development of new tools to detect vulnerabilities in the financial system deemed essential. Academics and practitioners contributed to the solution with this matter by developing stress test models, as a primary tool to assess and promote the stability of FIs. In parallel, to the rise of these tools, policy makers and regulators introduced frameworks for enhancing the credibility of the financial system as a whole through both the Prudential Regime (Lim et al., 2011) and the implementation of the Basel III regulation. The latter complements the reforms regulations relevant to capital requirements, leverage and liquidity of banks (BIS, 2013a).

The aim for developing both macro and micro prudential policies is to sustain the resilience of the financial systems through a series of guidelines and tools. On one hand, the macro prudential framework focuses on "the stability of the financial system and its interrelations with the macro-economy" (Clement, 2010). This framework includes indicators for capturing and assessing the main linkages between the macro and the financial side of the economy. It also considers the systemic aspects of the financial risks (Hirtle et al., 2009). However, the micro prudential framework is concerned with the performance of individual FIs. It assesses their risk profile and solvency of each FI, through the behaviour of idiosyncratic risks (Houben, 2013). These regulatory requirements are developed for ensuring the behaviour and performance of FIs and the safety of the financial system as a whole.

There is abundant literature on regulatory reforms and financial stability. However, limited studies attempt to combine between the implications of prudential regime and regulatory reforms (see for example Herring and Carmassi 2008,Hirtle et al. 2009, Borio 2011). The regulatory reform literature has a parition that focus on the leverage and liquidity requirements, in terms of their impact on FIs performance and risk behaviour (Banerjee and Mio 2018, Acosta Smith et al. 2017, Bahaj et al. 2016 and de Ramon et al. 2016). Other studies opt to investigation the LCR and NSFR interrelation within a monetary policy framework (Balasubramanyan and VanHoose, 2013). King (2013) Lallour and Mio (2016) and Flori et al. (2019) consider the implication of liquidity requirements performance on banks' business model. However the literature lacks studies that investigate the contribution of liquidity requirement performance to the macro prudential performance as a measure of systemic risk.

Stress test models emerged in the literature as applaudable approach that links between prudential reforms and regulatory framework. Nonetheless, the main focus of these studies is stress testing for credit risk (Quagliariello, 2009) instead of other types of risk such as the liquidity risk. According Acharya et al. (2014), liquidity risk has received little attention in the literature within stress test framework. Additionally, there are issues with currently used stress testing approaches concerning both the breadth of applicability and effectiveness. Central banks and policy makers developed a series of macro prudential stress tests (Moretti et al., 2008) . Their aim is to provide a comprehensive macroeconomic framework capable of assessing the solvency of individual banks on a set of countries, in terms of capital adequacy (Cihak, 2004). Similarly, both The Federal Reserve Bank (FED) in the US and the European Banking Authority (EBA) provide frameworks with general guidelines for estimating potential threats to financial institutions (Acharya et al., 2014). These frameworks, however, focus on capital adequacy only and therefore have largely ignored both the requirement for sufficient liquidity for banks and the role of systemic liquidity risk (Goodhart, 2006; Schiozer and de Freitas Oliveira, 2016; Jobst et al., 2017).

We define by systemic liquidity risk as the probability that multiple financial institutions will face liquidity shortages at the same time (Schumacher and Barnhill, 2011). Traditionally, the SLR assessment focuses mainly on the development of indices (Christiansen et al., 2011). However, most these studies seem to neglect the quantification of the probabilistic measures of SLR (Jobst, 2014) . We argue that it is essential to include new measurement for SLR from liquidity perspective that driven by macroeconomic shocks, in order to further develop the macro prudential framework to accommodate for new systemic risk perspectives. We believe that the proposed approach is essential for countries that experience sovereign crisis preceded the financial crisis. Specifically, during the European Sovereign crisis as well as in the post crisis period, the wide stress test results indicate that the majority of banks successfully passed the stress exercises. However, we observed that even large banks continued facing difficulties to meet their obligations. For this scope, the interrelation between the macro environment and the funding position of banks which has been partially examined in the EU wide stress test exercises, requires further investigation. This investigation can reveal the strong nexus between the macro and the financial side of the economy providing valuable information for banks' behaviour during the post crisis period.

This study provides three major contributions to the literature. I) Develops a macro prudential liquidity stress test, using the LCR to capture the dynamics of the financial system. In this vein this study is the first to consider the implication of the systemic risk on Basel III liquidity measure (LCR) under a state of economic stress. II) Quantifies the systemic liquidity risk by measuring the simultaneous liquidity shortages resulting from the main macro financial linkages. It adds to the very limited studies that usually use rather probabilistic than analytical measures. III) Develops an agent based model, that deals with complex financial systems and act as a general stress testing tool. The latter can provide further insight on the interactions among the different market participants. We add to the scant literature that use ABM in stress test applications, without considering a system of countries and macroeconomic endogenous shocks.

Agent based models in the area of computational economics, capture the complexity of the financial system, through the reaction and the interaction of different types of agents acting under the same economy/system (Demekas, 2015). Agent based models for stress testing are at an infant stage, in terms of design and application (Bookstaber et al., 2018). These models capture complex financial transactions which occur simultaneously. Our results advocate the importance of using ABM in liquidity stress testing. We conduct the analysis by setting up a system where agents i.e. banks, households, firms and the government interact in the same economy. Our framework counts for both normal and stressed periods, where the transactions of banks with other agents are modelled to reflect the development of LCR through banks' balance sheet.

The model is characterised by a finite number of steps where all agents maximise their returns under decisions constraints. This process goes beyond the traditional stress test approaches as it captures the evolution of the LCR over time as well as assessing the time required in order for banks funding position to indicate simultaneous shortages. Our approach to measure SLR provides important insights for stress testing. Hence it describes the sensitivity of a given financial institution's balance sheet to other agents' macro led decisions. Once these states are obtained the corresponding levels of key balance sheet terms, such as deposits and liquid assets, can be identified allowing for contingency planning.

Our results illustrate the importance of funding liquidity risk, under the examination of adverse macroeconomic scenarios. Specifically, the LCR, under stressed economic conditions, displays simultaneous shortfalls below the critical value of 70% for all the banks in our system. In parallel, our analysis indicates that the LCR's reaction to macroeconomic shocks goes beyond the 30-days period of stress specified by the guidelines (BIS, 2014b). The LCR's largest drop that we observe on a period of 60-days, reaches 40% on average for the whole system. Another characteristic is that the size of the banking system contributes to the systemic risk reduction. With regards to economies that have large number of banks the levels of the LCR are slightly below the threshold of 70% , even under stress conditions. However, in the case of shrinking systems such as Portugal the LCR shortfall is 37%. The decisions and rationality of firms and households lead to further investigation of the LCR behaviour, as households' contribution to the LCR deterioration is greater than firms' contribution.

Consequently our results highlight the substantial role of macro prudential policy in the area of financial stability. It also points to the need of developing analytical stress test frameworks. We provide clear evidence that the linkage for prudential policy and macro level transactions, can reveal further information for banks' business model and assist in contingency planning.

The remainder of this paper is structured as follows. Section 3.2 reviews the relevant literature. The methodology and model specification is presented in Section 3.3, while results are given in Section 3.4. Section 3.5 concludes.

3.2 Literature Review

This section discusses the relevant literature within the macro prudential framework, liquidity risk and its role in the system wide stress tests. The section denotes whether prudential policies assist on promoting the safety and soundness of the financial system as well as well as the ability and performance of the Basel III regulatory requirements to enhance the main scope of prudential policies. In addition a discussion and analysis for the treatment of systemic risk is also provided. A review of the most relevant studies reveals how the new generation stress tests approaches can uncover systemic aspects of liquidity risk and enhance prudential policies' objectives as well as the main obstacles so far.

3.2.1 Prudential Policies and Regulatory requirements

In response to Financial instability, Regulators and Policy makers reveal the design and the implementation of prudential policies for the Banking and the Financial sector (Galati and Moessner, 2013). Macro prudential policy aims at mitigating systemic risks and their propagation to the whole financial system (Claessens et al., 2013). The scope of this policy is to count for the main interrelationships arising between the real sector and the financial one by denoting the main macro financial linkages. Despite the interest of academics and practitioners prudential policies have attracted after the financial crisis of 2008, the implementation and the performance of these reforms is still at an infant stage. Prudential framework continues to be subject of debates and amendments, as combined with the lack of unified and well specified approaches. This is why it has become apparent that the policies up to date cannot fully address the complexity of the financial system and the behaviour of financial risks when the system is threaten by different types of shocks (Galati and Moessner, 2013).

In parallel to the macro prudential is the micro prudential policy which complementary to the former one sheds light on the performance of individual FIs instead of the system wide assessments (Crockett, 2000). While macro prudential policy has been developed for detecting the existence of systemic risk within the Financial system, the micro prudential one focuses on the idiosyncratic risks, in other words the factors that affect and trigger a FI's performance and resilience at the microeconomic level. Macro and micro prudential policies aim to promote the soundness and the safety of the financial system while in parallel their purpose is to ensure that the Regulatory reforms are sufficient requirements for maintaining the stability in the Financial and Banking system.

For this scope relevant studies assess the performance of the newly implemented Basel III requirements and contribute to the macro and micro prudential framework. The reforms for banks' leverage (leverage ratio (LR)) and liquidity (net stable funding ratio (NSFR) and liquidity coverage ratio (LCR)), agreed and applied by the Basel Committee on Banking Supervision during 2010-2017 (BCBS, 2017), have been examined through a series of studies. Banerjee and Mio (2018) and Acosta Smith et al. (2017),investigate the leverage ratio ability to incentivise banks for increasing their loss absorbing capacity which lead banks to more prudent strategies regarding their risk appetite. In parallel, studies on capital (de Ramon et al. 2016 and Bahaj et al. 2016) and the newly implemented liquidity ratios examine whether the banks' lending policy changes while banks' lending preferences and cost of funding sources are still under investigation (Acharaya 2014, Banerjee and Mio 2018, Birn et al. 2017). Although, these studies examine the regulatory reforms' performance and their contribution to the Prudential Framework that policy makers aim to enhance, the evidence has been provided so far, lies only on the micro level while the combination of the micro and macro prudential policies is still missing.

Furthermore, similarly to the micro prudential policy studies, macro prudential reforms have been addressed through the examination of their interrelation with the monetary policy. Beau et al. (2012) with the use of a DSGE model examine the interrelation of these two main frameworks which comprise the two main targets for Central Banks. Through their study, they investigate whether Monetary and Macro prudential policy converge in terms of their objectives or they reach to different outcomes regarding the price stability based on the inflation and credit growth behaviour. Similarly to this study, Popoyan et al. (2017) assess the macroeconomic impact of macro prudential reforms and their interactions with Monetary policy in order to shed light on banks resilience through the capital requirements. In this paper the authors carry out a detailed analysis with the use of an agent based model for capturing the complexity of the system. However, the lack of systemic treatment of financial risks in order to conclude to the level of capital for banks is necessary.

Moreover, another study developed by Lim et al. (2011) aims to reveal the importance of systemic risk and its role for a solid macro prudential reform through a panel estimation of the main macro prudential toolkits and their ability to decrease the volume of procyclicality based on a set of financial shocks. Nevertheless, the results indicate that for a group of countries in the sample macro prudential policy toolkit has little impact. To this point, more analytical linkages between the micro and the macro prudential tools combined with the use of forward looking models would be necessary for a complete assessment which can reach to substantial remarks for the Prudential framework performance.

Currently as the literature stands there is no comprehensive and complete in terms of process and design, macro prudential analysis combined with the regulatory regime. A framework which can incorporate the macro and micro prudential reforms combined with the performance of newly implemented regulatory requirements such as the liquidity requirements, LCR and NSFR , would provide valuable information to the existing Prudential Framework.

3.2.2 Stress Tests and Prudential Policy

Prudential policies are also incorporated to stress test models either through a sensitivity estimation or scenario analysis (Quagliariello, 2009). Macro prudential stress tests provide the link between the macro and the micro side of the economy. One framework of tests is the Financial Sector Assessment Program (FSAP) which was introduced in 1999 (Moretti et al., 2008) as a joint effort between the IMF and the World Bank. Several macro prudential stress tests have been developed since then by the Bank of International Settlements (BIS), the Federal Reserve Bank (FED) in US and the European Banking Authority (EBA), which provide general guidelines and frameworks for estimating potential threats to financial institutions (BIS 2012 and Acharya et al. 2014).

In parallel, the rise of prudential policies assisted on a series of studies to be developed with the use of stress tests estimation. Jesus and Gabriel (2006) develop a model for assessing the interrelation between the borrowers' risk profile and the collateral provided when setting up loan contracts with banks. The analysis focuses on loan loss provisions (LLPs) while the lack of a direct link to the macro environment combined with the use of LLPs instead of Non performing loans does not provide a complete assessment of the credit risk within a macro prudential stress test framework.

On a similar path of mapping the macro side of the economy to the credit risk is the study developed by Vazquez et al. (2012) who assess the interrelation between credit risk and the macroeconomic environment for the Brazilian Banking system in order to reveal the pro-cyclical behaviour of the assets quality. The authors conclude to a strong relationship between the real sector and the volume of pro-cyclical credit exposure with the use of a panel estimation. However, the lack of systemic treatment of the credit risk does not allow for a complete assessment required in macro prudential stress tests.

Levy-Carciente et al. (2015), through a network analysis assist on the role of credit risk in the prudential framework by carrying out a macro prudential stress test model for the Venezuelan banking system. This study focuses on banks' assets portfolios and their sensitivity to external shocks. The process goes a step forward from the traditional static stress test approaches and notifies a dynamic assessment of credit risk. Nevertheless, this analysis does not provide a concrete framework for the link between the macro and the micro side of the economy while the volume of exogenous shocks does not count for simultaneous losses on assets portfolios.

Despite the rise of macro prudential stress tests they are still unable to provide all the required information for policy response(Galati and Moessner 2013,Haldane 2009 and Čihák 2007). The inability to provide a concrete framework necessary for carrying out and enhancing the prudential policies framework can also be seen on further attempts towards this direction.

To this point, a stress test exercise developed by Buncic and Melecky (2013), examines the effect of macroeconomic scenarios over banks assets' portfolios in order to measure the credit risk exposure of Southern European Banks. Through a Vector Autoregressive Approach (VAR), they draw conclusions about banks' capital level and risk concentration without fully capturing the complexity of the financial system and providing further analysis for other types of risks existing in the system under investigation.

The aim of capital regulation incorporated in stress test exercises led credit risk to hold a significant position when counting for prudential policies. The reason behind this is mainly that credit risk is linked with traditional bank operations, such as providing loans and holding/ investing capital. However, the complete assessment and the information that policy makers require from stress test approaches cannot only be provided from one type of financial risks. In order to sustain the soundness of FIs, the prudential policy framework should be fully incorporated in stress tests simulation by including and other types of risks, specifically when these are a regulatory prerequisite, and quantifying the interrelationships arising within the economic and the financial system, in order to capture all the systemic effects might arise within the system under examination.

3.2.3 Systemic Liquidity Risk and its role in Stress Testing

Despite the rise of stress test analysis under different methods and applications (see for example Boss et al. 2006a, Čihák 2007, Quagliariello 2009, Foglia 2009 and Demekas 2015), and the crucial role they hold for sustaining the financial stability (Dees et al., 2017), stress tests are still unable to act as standalone tools and to address the complexity of the financial system (Borio et al., 2014). These limitations stem from stress tests' inability to fully incorporate the prudential reforms combined with the regulatory regime at both micro and macro level. In parallel, the great focus on credit risk combined with the capital adequacy of FIs (Buncic and Melecky, 2013), led stress test exercises to disregard, other types of financial risks such as the Liquidity risk.

Liquidity risk comprises the risk that a bank becomes unable to meet its liquid needs (Drehmann and Nikolaou, 2013) and it is broken down into funding and market liquidity risk. The former is the inability of an FI to cope with its liabilities while the latter is the inability to trade an asset at its fair price (Hoggarth et al. 2001 and Ferguson et al. 2007). Even liquidity risk has been the subject of substantial academic interest (see for example Diamond and Dybvig 1983, Vento and La Ganga 2009 and Hesse et al. 2012, and Ong 2014), their role in stress test models has not been fully investigated. Current work in this area is primarily based on assessing liquidity risk by examining banks reserves, overdrafts, credit, interbank loans and the incoming payments from other banks (Čihák 2007) while the role of liquidity risk to the stability of the financial system under the prudential regime has not been fully assessed.

A recent attempt developed by Van Den End (2009) who endogenizes liquidity risk for Dutch banks while considering first and second round effects. The Monte Carlo simulation results suggest that liquidity risk is non-linear and liquidity buffers should increase under stress events. Van Den End (2012) further develops this work and the author assesses the effect of adverse financial scenarios on the Basel III liquidity ratios (LCR, NSFR) in a stress test framework. Even this study acts from the micro prudential perspective combined with the regulatory reforms, the lack of a dynamic analysis for capturing the complexity of the financial system and the lack of an analysis from the macro side of the economy by incorporating systemic liquidity risk, led this analysis to omit the effects of liquidity risk, its behaviour over the time as well as the role of macro prudential framework within a stress tests application.

Systemic Liquidity Risk (SLR) is the probability that multiple financial institutions will face liquidity shortages at the same time (Schumacher and Barnhill, 2011). In order to measure SLR, both practitioners and researchers have developed systemic liquidity indices. For instance Brunnermeier et al. (2012) develop a maturity index based on the cash flow approach while Jobst (2014) generates a probabilistic measure of the frequency and severity of multiple entities experiencing a joint stressed market liquidity event. In the same context of probabilistic measures and market liquidity risk, the IMF has also developed SLR measures. For example, Jobst (2014) combines option pricing with market information and balance sheet data to generate a probabilistic measure of the frequency and severity of multiple entities experiencing a joint stressed liquidity event.

In spite the rise of measures for systemic liquidity risk, these measures are built up on probabilistic approaches rather than the quantification of the systemic risk. In parallel, the focus of these studies to market liquidity risk leads the measurement of funding liquidity risk systemic aspects to emerge. The macro prudential assessment combined with liquidity requirements when counting for Systemic Liquidity Risk comprises a significant omission.

On the other side, the systemic treatment of funding liquidity risk still remain at an early stage. Severo (2012) constructs a systemic liquidity risk index (SLRI). The main purpose is to calculate a liquidity premium in case of funding from public authorities. With SLRI he examines equity return exposures while deriving a positive association between SLRI and Net Stable Funding Ratio (NSFR) from Basel III. In a similar context to funding liquidity risk, End and Tabbae (2012) aim to reveal the systemic aspects arising from Dutch banks' balance sheets. Specifically, through the evolution of assets and liabilities they calculate the correlation of balance sheet changes across the banks. However, the analysis is carried out at a micro rather than a macro prudential assessment while the quantification of systemic risk would provide further information for banks' reactions.

Although there is lack of systemic liquidity risk from the funding position of the banks in a macro prudential stress test framework, there are a few studies developed which shed light on liquidity risk and contagion effects through interbank lending with the use of network analysis. Cifuentes et al. (2005), assess FIs' liquidity risk interconnection when these institutions are subject to regulatory solvency constraints and market's demand trigger assets' prices. In addition, Ladley (2013) focuses on liquidity risk through an interbank computational model, in order to assess the contagion risk arising from liquidity shortages. Furthermore, Krause and Giansante (2018) model liquidity and solvency shocks, in order to investigate the ability of banks to amplify systemic risk. Therefore, these computational methods such as network analysis and dynamic agent-based models (ABM) allow to deal with non linear dynamic environments and quantify the interaction of financial systems with the real economy (Hommes, 2006), however in stress test applications computational models remain at an infant stage.

In the next section (3.3), we provide the analytical framework for developing a macro prudential liquidity stress test which with the use of the newly implemented LCR, links the funding position of banks with the macroeconomic fluctuations through the main transactions with other agents acting under the same economy. In addition this model specifies the existence of systemic liquidity risk by quantifying simultaneous liquidity shortages Banks' face when acting under stress.

3.3 Model

The analysis is carried out with the use of an Agent Based Model, which is able to capture the complexity of the financial system. Agent Based models fall into the category of computational economics and their use in stress tests remains limited (Demekas 2015 and Bookstaber et al. 2018). Agent based modelling comprises a forward looking approach, where parts of a system are modelled as autonomous decision making agents who are interrelated (Darley and Outkin 2007).

Agent based models simulate aspects of real world conditions. Agents are bundled data or behavioural methods under a dynamic, complex and adaptive system. Through the use of agent based models we simulate the interrelation between the macroeconomic and financial side of the economy in order to produce adverse but plausible scenarios. An agent based model is an appropriate way to do this, as it comprises not only forward looking models but also they can produce large dataset of extreme events which can be rarely modelled with the traditional stress test tools due to lack of real data (Tesfatsion and Judd 2006). The use of agent based modelling in the area of stress testing overcome the limitations of the traditional methods have been developed so far, such as the structural and reduced form approaches which proved unable to capture the complexity of the financial system, to provide robust forecasting and to act as standalone tools. The assumption of linearity and normality of these traditional models led these tools under perform in times of market distortion (Bookstaber 2012).

The main objectives of macro prudential policy are to be fulfilled with the global liquidity requirements as introduced by the Basel Committee (Cooke et al. 2015, Calomiris et al. 2015, De Nicoló et al. 2012). This model studies the ability of the LCR to capture the systemic liquidity risk due to economic cycle fluctuations in a macroprudential framework for the Southern European economies populated by heterogeneous interacting agents.

The behaviour of these different agents who exist and interact in an open small economy, is assessed by also specifying their role in triggering simultaneous liquidity shortages for 30 systemically important banks from Cyprus, Greece, Italy, Portugal and Spain. The model closest antecedent is the process developed by Ladley (2013) and Leduc and Liu (2016) which we expand by providing a more detailed account of agents' decisions and banks' balance sheet and by exploring the existence of systemic risk in the vein of Basel III framework under a stress test application.

Through this stress test framework, we fill both theoretical and methodological gaps arising in the area of stress tests as their framework indicate substantial limitations, such as their inability to act as standalone tools (EBA wide stress tests, 2014-2016). We consider a model of a small open economy where, banks, (L_{ij}) interact with households (H_{ij}), firms (F_{ij}) and the government(G_{ij}) under a macro prudential environment (E_{ij}) as defined by the European Central Bank (2016).

In the model there are N agents (households and firms) and M Banks. The production possibilities contemplate a variety of homogeneous goods. Each firm and household is characterised by the coefficients ij where i denotes the economy they are producing their goods and j the Bank they set up their transactions through the deposit and lending activity.

The real sector is composed of $Firms$ which produce and sell the homogeneous consuming goods and form a relationship with the $Households$. A firm (F_{ij}) employs labour of type i to produce a good which will be sold in the economy/market. Each agent ($Household$) can be employed only in one firm. Employment and consumption of goods evolve endogenously over time. Firms produce using labour only and they denote their cost equal to the level of wages (w_{ij}) provided to the labour.

In the economy there is a fixed number of M banks indexed by m. Given that banking competition is binding by the Market rules implied by European Banking Authority (EBA) and the respective regime (Van Leuvensteijn et al., 2011), households and firms choose randomly the bank where they will set up their transactions. In other words I proceed with the assumption that the market competition leads banks to maintain similar levels for the interest rates they impose on offering and receiving funding respectively, leading households and firms to choose randomly the bank that they set up their lending and saving transactions.

The banking sector provides credit to households and firms through loans when the credibility of these agents is sufficient and their solvency based on their wealth denotes the ability to serve these obligations. Prudential regulation constrains the endogenous supply of credit in the economy. Beyond loans to households and firms, banks also hold cash and government securities. Banks are heterogeneous in terms of their balance sheets and may run out of liquidity if households and firms do not serve their loans, triggering substantial liquidity shortages.

The government comprises the economy where all the agents interact and is represented by the Gross Domestic Product (GDP_{ij}) which denotes the advancements in the economy, the gross of the production in the economy through the Exports and Imports, the Investments and the total Consumption as well as the financial support to the banking sector through the securities offered to banks, namely the government securities. Beyond these resources, the government has a gross debt from other resources receiving in order to finance its activities, which should be served in order to maintain the level of GDP and in turn the prosperity in the economy. All the agents interact under this economy.

3.3.1 Macroprudential Framework

The Macroprudential Framework is based on a set of the main macroeconomic parameters as denoted by the ECB (2016) . The economy where all the different types of agents interact is represented by the respective government where banks, firms and households are located.

The government (G_{ij}), is modelled as a function of National Income namely the Gross Domestic Product (GDP_{i}). Government's decision making is characterised through its main transactions which aim to specify the price stability, the economic activity and the indebtedness of the respective economy.

$$GDP_{\text{i}} = CPI_{\text{i}} + INV_{\text{i}} + X_{\text{i}} - M_{\text{i}} - Debt_{\text{i}} \tag{3.1}$$

For the price stability we use the level of inflation, estimated by the Consumer Price index (CPI_{i}). Through the CPI we identify whether the price changes incentivise households to increase or decrease the level of the consumption which constitutes the main constraint when they have to decide between expenditure and saving as well as between expenditure for consumption and loan payment. In addition, the price stability is also used for quantifying the increase on firms' production and in turn their value.

$$CPI_{\rm i} = \frac{Consumption_{\rm i}}{Inflation_{\rm i}} \tag{3.2}$$

Furthermore, the level of investments ($INV_{\rm i}$) combined with the volume of exports($X_{\rm i}$) and imports ($M_{\rm i}$) define the economic activity of the respective government and in turn the ability of firms to maximise or not their net value. As long as the level of investments and exports increase, firms' net value also increases.

$$INV_{\rm i} = \frac{Investments_{\rm i}}{GDP_{\rm i}} \tag{3.3}$$

$$AccountBalance_{\rm i} = \frac{X_{\rm i} - M_{\rm i}}{GDP_{\rm i}} \tag{3.4}$$

Another component which specifies the Economy's reaction function is the gross debt ($Debt_{\rm i}$) (3.5) which includes both the external, and the internal debt of an economy such as the government bonds and other government securities.

$$Debt_{\rm i} = \frac{GrossDebt_{\rm i}}{GDP_{\rm i}} \tag{3.5}$$

3.3.2 Firms

Firms use their $profits_{\rm ij}$ as funds to the banks through current and term deposits ($d_{\rm ij}$) and they receive a return equal to the deposit rate ($r_{\rm deposit}$). Each Firm ($F_{\rm ij}$) is a non-bank entity, which has a loan contract with entity Bank ($L_{\rm ij}$) at an interest rate settled by Banks ($r_{\rm loan}$). Firms receive funds from the banks through commercial and corporate loans at an interest rate $r_{\rm loan}$ at time T.

In this economy firms produce homogeneous goods and they receive inflows from the trade of these through consumption, investments and exports. These cash inflows comprise the main source of funding for the firm while combined with the amount of loan received from the Bank, denotes the ability of firms to meet their liabilities such as the cost of production and the loan interests. To this point, the cost of production ($c_{\rm ij}$), is the sum of wages ($\sum_{N=1}^{N} w_{ij}$) provided to the labour.

Firms maintain rationality and aim to maximise their net value ($NV_{\rm ij}$) at each time step T and under the different economic conditions (3.6). The ability of firms to repay or not the loan interest ($loan_{\text{interest}}$) and meet the level of cost, depends on the level of the firms' net value at each time step. When the economic state is good firms repay the loan interest to the banks as well as the wages to the households.

When acting under stress economic conditions, firms are not able to repay the loan as they prefer to place their inflows either for increasing their profits or covering the cost of production. When firms inability to repay their loan obligations is for multiple periods (not necessary sequential), it is then captured by the banks' system specification namely the non-performing loans ($NPLs$). In parallel, when firms' inflows are not enough for also covering the cost of production and firms change their strategy and place their inflows as deposits only while the the wages to the households are getting equal to zero.

Firms' reaction function is specified by the level of the Net Value while at each time step the aim to maximise this value is constrained by the different levels of cost they face under the different economic conditions.

$$arg\ maxNV_{\text{ij}} \quad (cash_{\text{ij}} + (1 + r_{\text{deposit}})^t * d_{\text{ij}} - c_{\text{ij}} - loan_{\text{interest}}) \tag{3.6}$$

where the $loan_{\text{interest}}$ is calculated as follow:

$$loan_{\text{interest}} = Loan_{\text{principal}} * D^i{}_{\text{f}}, \quad D^i{}_{\text{f}} = \frac{[i(1+i)^T]}{[(1+i)^T - 1]} \quad and \quad i = \frac{r_{\text{loan}}}{T} \tag{3.7}$$

3.3.3 Households

Households (H_{ij}) are non-bank entities, which aim to maximise their income (I_{ij}) at any time step. Households receive wages (w_{ij}) for offering their homogeneous good which is labour to firms (F_{ij}). Households, use this wage as the main source of income for saving and consumption. At each time step T households given the level of wage they receive from firms, aim to maximise their disposable income (Y_{ij}).

Households are also related to banks through deposits for which they receive a return equal to the deposit rate (r_{deposit}) and through loan contracts at a rate which is set by banks (r_{loan}). Loan contracts include consumer and other loans. Being constrained from their expectations, households at each time step have choose between saving and consuming.

Households aim to maximise their income (Y_{ij}) at each time step T under the different economic conditions (3.8). The ability of households to repay or not the loan interest ($loan_{\text{interest}}$) and meet the level of consumption which satisfies them, depends on their disposable income and its level at the different states. When the economic state is good households repay the loan interest to the banks while the consumption in the economy increases and in turn the performance of the economic activity also rises (GDP_{i}).

Under stress events, households should decide between their need to consume and the obligation to pay back the loan interest. In these constrained states, households decisions are driven by the firms' actions, in other words the level of wages the latter provide. Households' financial constraints enhance their difficulty to serve their loans to banks. When households cannot repay their loan obligations for more than three periods (not necessary sequential) which turns loans with unpaid instalments into non performing loans, and banks' non-performing loans mechanism is activated. This action leads banks decisions to other strategies in order to maintain their funding position and being able to meet their liquid needs. Moreover, when households' level of wage is not sufficient to fulfil the optimal level of consumption (cs_{ij}), they make use of their savings which in turn lead banks to face substantial outflows.

The households' reaction function (3.8) is denoted by the maximum level of the disposable income they have at each period of time under the consumption and lending obligations constraints.

$$arg\ maxY_{\text{ij}} \quad (w_{\text{ij}} + (1 + r_{\text{deposit}})^t * d_{\text{ij}} - cs_{\text{ij}} - loan_{\text{interest}}) \tag{3.8}$$

where the $loan_{\text{interest}}$ is calculated as follow:

$$loan_{\text{interest}} = Loan_{\text{principal}} * D^{i}{}_{\text{h}}, \quad D^{i}{}_{\text{h}} = \frac{[i(1+i)^{T}]}{[(1+i)^{T}-1]} \quad and \quad i = \frac{r_{\text{loan}}}{T} \tag{3.9}$$

3.3.4 Banks

In order to address the lack of a liquidity macro prudential stress test, banks' (L_{ij}) position and reaction is assessed with the use of the Liquidity Coverage Ratio (LCR)(3.10). The LCR assesses the funding position of Banks on monthly basis, in other words the ability of banks to use their inflows such as liquid assets in order to fund substantial outflows such as deposits withdrawals. The LCR calculates the amount of liquid assets over the net outflows for a period of one month. The LCR is defined as follow [1]

$$LCR(ij) = \frac{LiquidAssets_{\text{ij}}}{NetOutflows_{\text{ij}}} \geq 1 \tag{3.10}$$

The assets of Banks (L_{ij}) consist of short term loans to households, firms and to other banks, the cash and equivalent and the government securities. The liabilities of banks are constituted by deposits to households, firms and other banks and other contingent liabilities. We follow a stylised balance sheet approach in order to represent the relationship and the mismatch between the liquid assets and the potential outflows the Bank will face under stress conditions. The LCR follows a stylised balance sheet and requires that the assets side should be equal to the liabilities, in other words, the sum of the liquid assets should be equal or greater to the short-term liabilities, so in case of substantial bank runs the bank should be prepared to meet its obligations.

At each time step banks aim to maximise the expected return arising from the transactions with the other agents subject to the LCR $E(LCR_{\text{ij}})$ constraint (3.11). The LCR for banks is calculated at each period T in order to capture the dynamic treatment of the banks' funding position and the evolution over the time, under the

[1] Basel Accord indicates LCR thresholds for the banks, which have not yet implemented this Regulatory ratio, which varies between 60% and 80% (BIS, 2014b)

different economic conditions and the decisions developed by the agents interacting in the economy.

$$arg\ maxLCR_{\text{ij}} \quad (la_{\text{ij}} - lb_{\text{ij}}) \tag{3.11}$$

where, la_{ij} are the liquid assets and lb_{ij} the net outflows

At $T = 0$ the bank offers its funds to the respective agents by increasing the liquid assets side, namely the consumer, corporate loans, loans to banks and government securities. In the next periods, the bank is expecting to decrease the remaining loan outstanding amounts while in order satisfy its expectations ($E(LCR_{\text{ij}})$) the cash and equivalent should raise by the amount of loan interests provided by the other agents in the economy which include both loan capital and interest.

In parallel by setting up lending transactions with the economy's other agents, the bank receives deposits d_{ij} and generates an amount of liabilities which in order to satisfy the LCR constraint, the volume of liabilities should not exceed this of the assets. Under stress conditions, these obligations which comprise a substantial source of funding for commercial banks turn into claims and banks are obliged to cover these outflows.

3.3.5 Model Calibration

In this section, we present the summary statistics of the parameters used as input in the model. We perform our analysis on commercial banks in the banking systems of Cyprus, Greece, Italy, Portugal and Spain. We focus on the Southern European banking sector because , even during the crisis, these banks were considered well capitalised but still were unable to prevent significant losses on their balance sheets and at the same time many of the banks were found to be illiquid. Additionally, we are making use of the same group of banks as in Chapter 2 in order to provide further information regarding the performance and the ability of the Basel III liquidity measures, LCR and NSFR, to capture the economic vulnerabilities and assess the key macrofinancial linkages even under different computational approaches. In particular in Chapter 2 we investigate the effects of macroeconomic indicators to the banks' NSFR through a copula estimation, while now we are developing a computational approach for assessing the LCR. By definition the LCR investigates whether banks are able to cover outflows on a period of 30 days, therefore the use of a model capturing the time evolution is a prerequisite for estimating banks coverage ratio.

Similarly to Chapter 2, we use individual banks balance sheet and income statements information. The analysis focuses on systemically important banks located in Greece, Cyprus, Italy, Portugal and Spain, are collected. This gives 30 banks in total for 2014. Although the initial search provided results for more than 41 Financial Institutions (FIs), 11 were eliminated to ensure the panel was well defined. We consider only banks, which are rated by one or more of the rating agencies Moody's Standard & Poor's and Fitch and which are used in European system-wide stress tests. In addition to avoid double counting of banks we consider only banks with consolidated statements and therefore exclude subsidiaries and branches as separate financial entities. Thirdly, we consider only large banks where book value of assets exceeds 1000 Euro millions for all years examined. Finally, any bank whose data is incomplete of not qualified under the International Reporting Standards is excluded. The bank level data are collected from Bankscope and Bloomberg databases. Table 3.1, presents the descriptive statistics used for the LCR parameterisation and the model set up. The LCR structure is the fraction of banks' liquid assets over potential outflows. For defining banks liquid assets we make use of consumer and corporate loans, loans to other banks and the amount of cash banks' hold as well as government securities which comprise high liquid safe assets banks' invest in. For modelling the potential outflows, we model banks' funding through the deposits channel as well as other liabilities.

Table 3.2 displays the descriptive statistics for the macroeconomic indicators as well as demographic information regarding households and firms data on income, consumption and financial turnover respectively. Regarding the macroeconomic environment, we focus on five macroprudential indicators; Gross Domestic Product, Consumption, Inflation, Gross Debt, Account Balance (amount of imports and exports) and Foreign Direct Investment based on the report developed by the

ECB(2016) which provides the main macroprudential indicators . Each of these variables is collected for each country in our sample. The macro level data come from World Bank, the European Central Bank datawarehouse and the OECD databases. In parallel, for modelling the behaviour of households and firms we collected data for households income, level of wages (in terms of basic salary) as well as financial turnover of corporates for 2014.These data were also collected from Datawarehouse and World Bank.

Table 3.1: LCR Summary Statistics of Banking Parameters

Assets in th. million €	**Min.**	**Max.**	**Mean**	**Std.**
Consumer Loans	232.90	143609	5856.36	37725.67
Corporate Loans	193	45825.20	10015	13698.92
Loans to Banks	25.4	68730.13	1982.11	13648.18
Government Securities	83.1	132219	8512.7	34234.51
Cash & Equivalent	33.8	69428	1072.99	13497.49
Liquid Assets	59.2	239430	4566.25	52751.26
Liabilities in th. million €	**Min.**	**Max.**	**Mean**	**Std.**
Current Deposits	110	271220.4	13180.75	63054.11
Term Deposits	138.2	222756	10104.85	45297.91
Deposits from Banks	30	106036.91	5918.58	23703.15
Other Liabilities	5.4	2063891	2469.35	388955.03

Table 3.1 provides the summary statistics of the banking variables used as parameters input for Chapters 2 & 3 for the model calibration. The data are balance sheet items collected for 2014 on annual span, from Bankscope database.

Table 3.2: Economy Summary Statistics of Macroeconomic Parameters

Macroeconomic Data in th.million €	Min.	Max.	Mean	Std.
Gross Domestic Product	17,605.9	1,621,827.2	178,656.5	695453.77
Consumption Expenditure	12,234.95	985,995.30	125,440.56	415,248.80
Gross Debt	1,540.8	61,942	12,402.3	27,358.74
Foreign Direct Investment	-65,140	113809	-8,049	71,080.91
Exports	10,597.8	449,943.8	66,408.6	194,436.31
Imports	10,564.90	429,026.10	69,033.20	183,655.70
Economic Indicators in th. €	**Min.**	**Max.**	**Mean**	**Std.**
Annual Household Income	14,972	20,703	16,813	2,171.15
Annual Household wage (basic salary)	13,579.92	18,068.4	16,019.52	1,612.90
Annual Corporate Sector Turnover	3,038.16	748,389.51	43,546.19	32,8785.99

Table 3.2 provides the summary statistics of the macroeconomic activity and economic indicators used as parameters input for the model calibration. The data are collected on country level 2014 on annual span, from DataWarehouse and World Bank database.

3.3.6 Model Operation

This section details the order of events within each time period. At $T = 0$, the models starts operating under the baseline scenario which means the current state of the economy before introducing the macroeconomic shocks. In the baseline state, households and firms choose the respective bank to receive credit and place their savings through the deposits account.

Banks grant loans to households and firms according to their creditworthiness by classifying debtors into resilient and not resilient based on households level of income and firms' net value. The model process acts under two different conditions: (a) the Baseline 3.3.6 and (b) the Stress case 3.3.6.

In this section we first discuss the model process under the baseline case which means the current state of the economy while in turn we analyse the economy's state under stress, how this stress is defined and incorporated in the models as well as whether the agents' decisions change and affect the Banks' funding position. Furthermore, the assessment and quantification of systemic liquidity risk is also discussed.

Baseline Scenario process

Banks credit assessment is specified by the borrowers' income and net value respectively as they determine the financial and economic situation of the loan applicants and their potential future revenues (see for example Jiang 2007).The classification of good and bad debtors (3.12 and 3.13) is to provide a positive answer to the following questions about a borrower demanding a loan:(i)Can the borrower pay the loan?(ii)Does the borrower have enough revenues to pay the loan if a period of adversity arises? Does the borrower demonstrates the ability to make wise decisions?

Furthermore, each bank commits to a lending rate prior to being approached by borrowers with loan opportunities. Under this assumption, the market competition leads banks to keep similar levels of the interest rates while households and firms choose randomly the Bank that they set up their lending and saving transactions.

Therefore Banks set the interest rate on new loans ($loan_{ij}$) as well as on deposits (d_{ij}) held at the end of the previous period. The interest rate on loans is common across all banks and it is fixed.

$$Firm_{ij} = \begin{cases} good \quad debtor, & \text{if } NV_{ij} > f(NV_{ij}) \\ bad \quad debtor, & \text{otherwise} \end{cases} \tag{3.12}$$

$$Household_{ij} = \begin{cases} good \quad debtor, & \text{if } Y_{ij} > g(Y_{ij}) \\ bad \quad debtor, & \text{otherwise} \end{cases} \tag{3.13}$$

In parallel with the loan supply process, banks accept firms' and households' savings through deposits account for funding their activities. Firms and households constrained by the level of labour costs (c_{ij}) and consumption (cs_{ij}) respectively, place their savings through deposits and receive a return equals to deposit rate ($r_{deposit}$).

$$Firm_{ij} \rightarrow Bank_{ij} \begin{cases} cash\&equivalent_{ij_T} = cash\&equivalent_{ij_{T-1}} + loan_{\text{installment}}, & \text{if } cash_{ij} > c_{ij} \\ cash\&equivalent_{ij_T} = cash\&equivalent_{ij_{T-1}} + loan_{\text{installment}}, & \text{if } cash_{ij} = c_{ij} \\ cash\&equivalent_{ij_T} = cash\&equivalent_{ij_{T-1}} + 0, & \text{if } cash_{ij} < c_{ij} \end{cases} \tag{3.14}$$

$$Household_{ij} \rightarrow Bank_{ij} \begin{cases} cash\&equivalent_{ij_T} = cash\&equivalent_{ij_{T-1}} + loan_{\text{installment}}, & \text{if } w_{ij} > cs \\ cash\&equivalent_{ij_T} = cash\&equivalent_{ij_{T-1}} + loan_{\text{installment}}, & \text{if } w_{ij} = cs \\ cash\&equivalent_{ij_T} = cash\&equivalent_{ij_{T-1}} + 0, & \text{if } w_{ij} < cs_{ij} \end{cases} \tag{3.15}$$

Banks' funding position is adjusted by the above statements (3.14) and (3.15) and the economy's performance. The ability of firms and households to serve the loan payments, increases banks' cash and equivalent account and in turn the liquid assets.

When firms and households are unable to serve their loan obligations for multiple periods (not necessary sequential), then banks activate the $NPLs$ account for recording the non-performing payments ($\text{loan}_{\text{interest}}$) which are subtracted from the initial value of the loan ($\text{Loan}_{\text{principal}}$). In case of non-performing payments, the liquid assets of the bank change as described in equation 3.16.

$$la_{\text{ij}T} = la_{\text{ij}T-1} - \sum_{n=3}^{N} LossValue_{\text{ij}} \tag{3.16}$$

Where la_{ij} is the current period (T) banks' liquid assets and n is the amount of periods, firms and households do not provide the loan payments, which comprise the $LossValue_{\text{ij}}$.

Firms' and households' level of expenditure in labour and consumption respectively, not only bind banks liquid assets position but also the amount of inflows banks receive through deposits. Equations 3.17 and 3.18, explain firms' and households' decisions for saving or not, where banks' should be able to react accordingly and maintain the LCR_{ij} above the critical value of 70%.

$$Firm_{\text{ij}} \rightarrow Bank_{\text{ij}} \begin{cases} {d^f}_{\text{ij}T} = {d^f}_{\text{ij}inflows} * (1 - r_{deposit}), & \text{if } cash_{\text{ij}} > c_{\text{ij}} \\ {d^f}_{\text{ij}T} = {d^f}_{\text{ij}T-1} - {d^f}_{\text{ij}outflows}, & \text{if } cash_{\text{ij}} = c_{\text{ij}} \\ {d^f}_{\text{ij}T} \rightarrow 0, & \text{if } cash_{\text{ij}} < c_{\text{ij}} \end{cases} \tag{3.17}$$

$$Household_{\text{ij}} \rightarrow Bank_{\text{ij}} \begin{cases} {d^h}_{\text{ij}T} = {d^h}_{\text{ij}inflows} * (1 - r_{deposit}), & \text{if } w_{\text{ij}} > cs_{\text{ij}} \\ {d^h}_{\text{ij}T} = {d^h}_{\text{ij}T-1} - {d^h}_{\text{ij}outflows}, & \text{if } w_{\text{ij}} = cs_{\text{ij}} \\ {d^h}_{\text{ij}T} \rightarrow 0, & \text{if } w_{\text{ij}} < cs_{\text{ij}} \end{cases} \tag{3.18}$$

Stress Scenarios process

The processes described above indicates the system's state under the current economic situation (baseline scenario). In order to develop the stress case, we specify the shocks based on the main components which describe the Economy's behaviour. These components are the consumption (CPI_{i}), the investments (INV_{i}), the exports (X_{i}) and imports (M_{i}) and the gross debt ($Debt_{\text{i}}$). In order to define the stress scenario, we assume the largest percentage change of these components and apply a Monte Carlo simulation to these for producing the θ parameters which describe the volume of the shocks.

These θ parameters follow a stochastic process in order to address the dynamic specification our model. Let θ be a Θ-valued stochastic process. For every finite sequence $T^{'} = T_1, ..., T_{\text{K}} \in T^K$ a random variable taking values Θ^K. To each outcome θ_{TK}, there corresponds a function of T_{K}. This function is called a realization, or sample function of the stochastic process. In our case Θ^K represents the set of macro prudential variables, and θ comprises the specific shock which corresponds to time $T = 2$ and follows the random motion the macroeconomic shocks follow over the steps the model acts. This process allows us to capture both the good and the bad periods of the macroeconomic environment interrelated to the banking sector.

Given that the agents in the economy constitute the structure of this, they comprise part of the economy's performance. The implementation of the stochastic shocks will not only change the economy's behaviour but it will also affect the respective transactions with the banks, firms and households, namely through the government securities, the net value and the income value respectively. By assuming this, we firstly calculate the weight of $Bank_{ij}$ (3.19), $Firm_{ij}$ (3.20) and $Household_{ij}$ (3.21) and use these weights in order to calculate the new states of these agents.

$$w_{\text{GovernmentSecurities}} = \frac{\sum_{M=1}^{M} (GovernmentSecurities_{ij})}{GDP_i} \tag{3.19}$$

$$w_{\text{NetValue}} = \frac{\sum_{N=1}^{N}(NV_{ij})}{GDP_i} \tag{3.20}$$

$$w_{\text{Income}} = \frac{\sum_{N=1}^{N}(Y_{ij})}{GDP_i} \tag{3.21}$$

The new state of the banks' government securities, firms' net value and households' income, assist on investigating whether stress economic conditions are able to change the agents' behaviour (3.22).

$$Agent_{ij_{NewState}} = weight_{Agent_{ij}} * (1.0 - (\theta_{shock_i} * GDP_{component}/GDP_i)) \tag{3.22}$$

The above equation (3.22), specifies the new state of banks, firms and households and assists on defining these agents' decisions and actions when acting under the economic stress. Based on the agents' rationality to maximise their return given the economic state,we set up the process discussed in section 3.3.6, in order to see whether agents' transactions are changing or not when the economic conditions change.

The scope of this analysis is to quantify the Banks' LCR_{ij}, and see whether this is under the critical value of 70%. In addition, as this model process is dynamic we benefit from this and capture the systemic risk as this defined by Severo (2012). Specifically, the model process run for a finite number of steps which allow for shedding light on the LCR performance and the system's simultaneous LCR shortfalls.

3.3.6.1 Scenario Analysis Parameters

Table 3.3 shows the θ parameters used for the specification of the macroeconomic scenarios. These parameters are extracted from the historical macroeconomic indicators largest percentage changes, for Cyprus, Greece, Italy Portugal and Spain. The θ parameters arise from a Monte Carlo simulation for different percentiles, namely 5%, 25%, 75% and 95%. These parameters indicate the changes of the macroeconomic variables when counting for tail events, therefore for our analysis we use the

95% percentile counting for extreme but plausible events.

By comparing across the parameters, it is possible to identify common linkages among the different economies. Across all countries there is a similarity of these parameters which indicate that the group of these different economies face similar macroeconomic changes. The change in Investments and Gross debt further enhance this, as the group of these counties is still subject of the debt crisis (Stracca, 2013) which leads their creditworthiness to decrease.

The illiquid profile banks have since the recent financial turmoil made these countries unable to attract investors' interest while the economic condition is still under-performing (World Bank, 2010). In order to avoid, liquidity risk overestimation, we used the marginal change of these parameters and we assess our system sensitivity under these plausible conditions as described in section 3.3.6.

In the following section, we discuss the findings of the above model process by providing an analysis on the Banks' reaction and the level of the LCR under the different economic states. In addition, the systemic liquidity risk and how this arises from banks' main transactions is also provided.

Table 3.3: θ Parameters of the Macroeconomic Variables for the different Economies

1980-2017			Volume of Shocks for Scenario design			
Country	No.Banks	Consumption	Investments	Exports	Imports	Gross Debt
Cyprus	2	0.060	0.299	0.038	0.064	0.120
Greece	6	0.029	0.644	0.048	0.049	0.277
Italy	13	0.011	0.099	0.017	0.055	0.056
Portugal	3	0.035	0.021	0.059	0.056	0.136
Spain	6	0.039	0.63	0.017	0.054	0.113

Table 3.3 provides the θ parameters of the macroeconomic variables which constitute the respective economy of each country. These parameters arise from a Monte Carlo simulation using the 95% macroeconomic changes to define the level of shock and specify the agents behaviour under the stress case scenario.

3.4 Results

In this section we present the key findings of our analysis and model process described above. The agent-based model investigates the existence of systemic liquidity risk led by a series macroeconomic shocks. The macroprudential stress test framework we develop, reveals the existence of systemic liquidity risk arising from the interrelation of the macro and the financial side of the economy. Also, our framework uncovers the importance to incorporate funding liquidity risk when counting for macroprudential stress tests and the systemic dimension triggered from the main transactions of banks with other agents in the economy.

At each time step agents' behaviour and their interactions with other market participants, highlight the key macro-financial linkages which lead to simultaneous liquidity shortages. Also, this analysis displays the ability of the LCR to capture the existence of systemic liquidity risk which increases the probability of systemically important banks being unable to meet their liquid needs, simultaneously. In addition, we show the levels and the degree to which households and firms trigger substantial outflows considering at each time step the updated banks' liquidity demands.

The model is calibrated with banks' balance sheet data and macroeconomic indicators, while the analysis is applied on 30 systemically important banks located in Cyprus, Greece, Italy, Portugal and Spain. This system, the economy and the agents, initially operates under the baseline scenario. At $T = 2$, a series of shocks arise endogenously and evolve through a stochastic process. From $T = 2$ and onwards our system operates under stress. The shocks are modelled through a stochastic process which allow us to observe the evolution of the LCR based on the transactions between banks and the other agents such as households and firms. Both baseline and stressed states capture the economy's heterogeneity, as the different states count for effects arising in each country's macroeconomic environment.

The LCR behaviour under the different economic states (baseline and stressed), reveals that this regulatory liquidity measure is able to capture systemic effects, while our findings uncover valuable information for banks' contingency planning when systemic shocks arise. Specifically, further analysis for banks' asset liability allocation is provided, as the behaviour and the reaction of firms and households at the different economic states, are assessed. Firms and households' contribution to systemic risk, through the Transactions of borrowing and saving (i.e. loan repayments, deposits savings and withdrawals), is estimated.

3.4.1 LCR under Baseline and Stress Scenario

Table 3.4 provides the expected value of the LCR, on country level, under the baseline and the stressed scenario. Our process operates for a finite number of steps ($T = 1, ..., 10$) and the stress scenario is implemented from $T = 2$ and onwards, where the shocks are applied and evolve for the next periods ($T = 2, ...10$).

From Table 3.4, we initially observe that under the baseline state, all banks in our sample have sufficient liquid assets to cover potential outflows.[2] An exemption to this, is Portugal. Even under the baseline state, Portuguese banks indicate LCR below the critical value of 70%. Portugal has been facing several occurrences of a banking crisis, leading to "boom-bust" and "capital-flow bonanza" cycles (Borio and Zhu, 2012; Reinhart and Rogoff, 2009). In other words, during the pre financial crisis period,"the main Portuguese banks began borrowing money intensively from financial institutions abroad and started pumping enormous liquidity into the Portuguese economy, leading to a dramatic bust, when the banks were no longer able to meet their obligations" (Cardao-Pito and Baptista, 2017).

Moving to the stressed state of the economy, the results display that for all countries, except Italy, LCR under stress, is below the 70% threshold. Italian banking system has a strong presence in our sample as the number of Italian banks is almost double of Greece and Spain (13 in total). By following a series of experiments regarding the size of the Italian banking system (changes to the number of banks and

[2]LCR on country level is the average of individual banks' LCR located in the respective country

Table 3.4: Expected Value of the LCR under baseline and stressed scenarios

Country	**Banks**	**Baseline**	**Stressed**
Cyprus	2	225.50	69.90
Greece	6	160.39	52.96
Italy	13	124.27	70.41
Portugal	3	58.75	28.77
Spain	6	123.86	45.35

Table 3.4 provides the expected value of the LCR under the baseline and the stressed scenarios. The LCR is shown in percentage points and is displayed on a country level - calculated as the mean of the values for all banks in each country. The medians were also calculated, not shown, and follow a similar pattern.

sub categorise banks into small and large), we observe that LCR indicates a positive correlation with the size and the volume of the respective system. This sensitivity and variability of the LCR highlights that by increasing the number of banks, we eliminate the risk concentration in the financial system. The risk concentration can amplify stress in the economy, such as the propagation of systemic risk. By including in our analysis all the Italian systemically important banks (in total 13 banks), the liquidity performance of the respective banking system improves and the expected value of the LCR just meets the lower bound of the threshold, namely 70.4%.

Under the stressed economic conditions, the greatest reduction of the LCR is for Cyprus. Whilst Cypriot banks have on average LCR equal to 225.5% during the baseline state, under the stressed scenario, the LCR for these banks reduces by 155.5%. The magnitude of this reduction explains the strong nexus between the macroeconomic environment and the funding liquidity risk. Similar albeit great reductions are observed for Greece, Spain and Portugal. In particular, the interconnectedness between the macroeconomic environment with liquidity risk, lead banks in Greece, Spain and Portugal to face substantial liquidity shortfalls up to 110%. Greek and Spanish banks during the baseline state are above the 70% threshold and seem to be able to meet substantial outflows, however the vulnerable macroeconomic conditions propagate substantial shortages in the funding position of these banks.

Taken together these results, it is evident the need for macro prudential analysis of liquidity provision and in particular within a system wide macroprudential stress test. In particular, the use of computational agent-based model underlines the dynamic treatment capability of these models, which captures the key characteristics of an economy and provides the interconnectedness of dynamic systems such as this of banking and the economic one. The expected value of the LCR is sensitive and strongly linked to the macroeconomic fluctuations as well as to the preferences and decisions of the agents interacting in the same Economy. Changes in the macroeconomic environment are very capable of pushing financial institutions into a state whereby they are unable to meet their liquidity needs. The use of different macro scenarios evolving endogenously in our model, highlights the degree of sensitivity in banks' funding position. Banks in Southern European region seem to be highly liquid under the baseline state but are currently in a position whereby they fail the tests as the interconnectedness between the macro environment and the funding position of banks, measured by the LCR, is significant. The decrease of the LCR even for highly liquid systems of banks during the stressed scenario, explain that for a marginal change in the macro environment, banks face substantial liquidity constraints and their LCR drops dramatically.

In the following subsection we examine whether the strong nexus between the macro and the financial side of the economy leads to simultaneous liquidity shortages in the funding position of banks. We also provide the key findings highlighting our contribution on revealing and capturing systemic liquidity risk.

3.4.2 LCR and Systemic Liquidity Risk

Systemic risk differs from the contagion one. Whilst the latter measures the connectivity among the illiquid entities and counts for domino effects (Iori et al., 2006; Ahnert and Georg, 2018), the former estimates the probability that multiple financial entities will face simultaneous effects due to adverse market or economic conditions (Schumacher and Barnhill, 2011).

Figure 3.1: LCR expected value evolution from the baseline state to the stressed periods

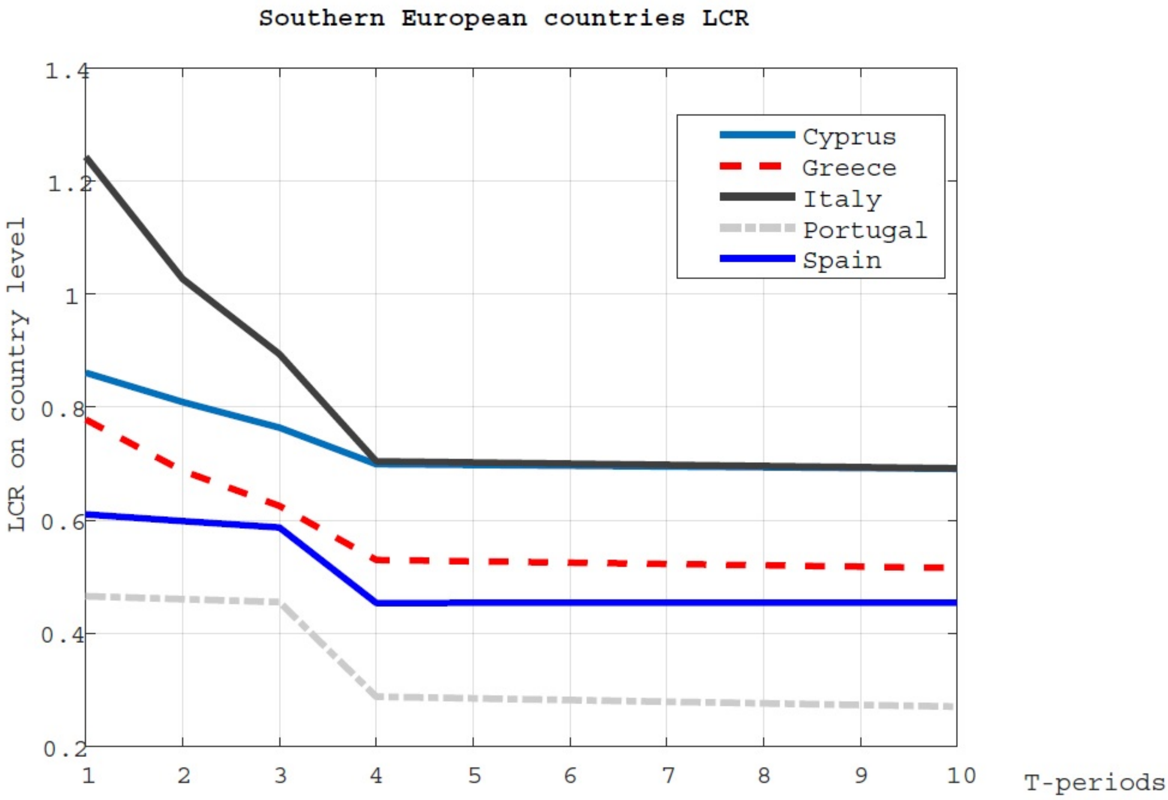


Figure 3.1 illustrates the existence of systemic liquidity risk and highlights the dynamics our model captures. This figure provides the LCR evolution from $T = 1$ to $T = 10$. We observe country level LCR for Southern European banks starting with the baseline state at $T = 1$, following the macro economic shocks' implementation at $T = 2$ and continuing with the stress conditions from $T = 3$ to $T = 10$.

At $T = 1$, the value of the LCR is banks' funding position at the current economic state. The baseline state has as input the current values of banks, firms, households and the government as these specified from our dataset.[3] At the baseline state, Southern European banks indicate sufficient liquidity levels. In particular, comparing across countries, the level of LCR expected value varies from 125.0% to 50.0%. At $T = 1$ Cyprus, Greece and Italy meet the liquidity requirements imposed by Basel III regulatory framework, as the LCR expected value equals to 85%, 80% and 125% respectively. However, as discussed in section 3.4.1 an exemption to this

[3]see Section 3.3.5 which provides details on the data used for the model calibration and the baseline state of agents

is Portugal and Spain. Portugal and Spain are not binding from the liquidity regulatory requirements and LCR (on country level) is close to the critical threshold of 60.0% and 70.0%. This behaviour can be explained by the risk profile Portuguese and Spanish banks indicate in the pre-crisis period.

As stated by Veloz and Benou de Gómez (2007) and Baselga-Pascual et al. (2015), Portugal and Spain display high levels of credit risk which has a positive correlation with the liquidity one. Particularly, banks with higher levels of liquidity are less likely to experience an increase in the default rate and vice versa. In addition, the correlation between credit and liquidity risk is further examined by Gómez-Fernández-Aguado et al. (2018) who estimate the credit profile of commercial banks in Spain and concludes that stronger liquidity position for commercial banks is associated with lower probability of default.

At $T = 2$, the macroeconomic shocks are introduced. Figure 3.1 displays that LCR expected value decreases for all banks across the countries. Whilst our model counts for agents and economies heterogeneity, the introduction of the macroeconomic shocks indicates a similar reaction of Southern European banks to these shocks. Specifically, we observe simultaneous shortfalls of the LCR expected value leading up to 20% decrease. This behaviour not only explains the strong nexus between the macro and the funding position of banks but also this simultaneous banks' reaction reveals the existence of systemic liquidity risk in Southern European banks.

Despite, banks' reaction when macroeconomic shocks are applied ($T = 2$) resulting a sharp decrease on the LCR expected value, at $T = 3$ banks LCR expected value continues to decrease but at a slower pace. This behaviour explains that banks do not proceed to any mitigation policy and continue their operation through the key transactions they have with economy's agents, namely households, firms and the government. However, at $T = 4$ we observe that all banks in our system face substantial liquidity shortfalls. LCR expected value goes below the threshold of 70% and all banks in our system face substantial liquidity shortages as an outcome of the vulnerable economic conditions.

At $T = 4$, Portugal displays the greatest shortfall compared to the rest of the sample, where the LCR expected value for the Portuguese banking system reaches at 29% indicating a liquidity shortfall equal to 36.79%. Similarly to Portugal, Spain faces a great recession as LCR expected value goes under the critical threshold of 70% and reaches 45%.

Apart from Spain and Portugal, Cyprus, Greece and Italy indicate substantial liquidity shortfalls. At $T = 4$, Italian banks are almost below the critical value of 70% facing a shortfall equal to 21.21%. The liquidity shortfall Italian banks face, highlights the nexus with the economic activity (Klusak et al. 2017 and Balassone et al. 2018) but it also reveals that the size of the banking system can limit the exposure to illiquidity as the risk concentration eliminates (Cerrone et al., 2017).

When $T = 4$, similarly to the rest of the Southern European countries, Cyprus indicates its greatest liquidity reduction equal to 15%. During this stress period the LCR expected value of Cypriot banks is slightly lower than the critical value of 70% though. The reason why the LCR expected value of Cypriot banks just only meets the threshold of 70%, is the implementation of the bailout program. The bailout program refers to a set of restrictions to Cypriot banks in order to limit the amount of outflows they face (Xiouros, 2013). In particular, the bailout program sets capital control requirements which enable Cypriot banks to avoid substantial outflows through the firms and households deposits withdrawals. However, banks in Cyprus face a substantial decrease on the LCR value. This decrease arises not from the outflows side which have been limited due to the capital controls, but from the amount of liquid assets Cypriot banks hold. The reduction of liquid assets consists on firms and households inability to serve their loans and provide loan payments to banks. The deposits haircut combined with deposits withdrawals limits, do not allow households and firms to serve their obligations as the savings channel of these agents has been diminished.

Furthermore, at $T = 4$ it is evident that all banks face simultaneously their largest liquidity shortfalls due to macroeconomic shocks propagation leading to systemic liquidity risk. Whilst T represents an 1-month period of time and the macroeconomic shocks are applied when $T = 2$, we observe that banks face their largest liquidity shortages at $T = 4$. This time lag highlights that LCR assessment under the Basel III Pillar II supervisory engagement through the Internal Liquidity Adequacy Process (ILAAP), should be extended to more than 30-days stressed period. Whilst, Basel III recommendations on the regulatory liquidity measures (BCBS, 2014) suggest LCR estimation in 1-month time horizon, the evidence of our analysis is valuable for the macroprudential surveillance, as systemic liquidity risk appears in 2-month time horizon.

Moving to the next periods we observe that all banks' LCR expected value indicates a persistent behaviour during the distressed period ($T = 5$ to $T = 10$). Once banks faced the largest liquidity shortfalls, the expected value of the LCR remains at the same level. This behaviour uncovers two key points which should be taken into consideration when dealing with macro prudential surveillance and supervisory engagement. On the one side, macro-prudential stress test developed so far, deal with shortages banks' face without taken into consideration further mitigation steps banks should take, in order to deal with these substantial losses (Bouveret, 2017). On the other side, the LCR expected value persistence during the distressed period has to reveal further information regarding the nexus between the macro economy and banks' funding position. In particular, this LCR constant level flags that funding liquidity risk evolution over the business cycle and the macroeconomic fluctuations should be further examined.

Complementary to the above findings, we present the LCR expected shortfall for the largest banks located in Cyprus, Greece, Italy and Spain.[4] We start analysing the LCR expected shortfall, in other words the percentage change of the LCR, starting from the baseline state and reaching to the distress period $T = 6$.

Table 3.5 provides the percentage change of the LCR for the largest banks of our sample, from $T = 1$ to $T = 6$.[5] We focus on the largest banks of our sample, as these

[4]The size of banks is in terms of the amount of assets they hold

[5]Table 3.5 presents the key events captured in our model. Specifically the 1st event refers to the period between the baseline state and T=2 which is the macroeconomic shock implementation. The 1st period of stress refers to the transmission from T=2 to T=3, while the 2nd period of stress which is the period systemic liquidity risk appears, is the transmission from $T = 3$ to $T = 4$. The 3rd and 4th period refers to the distress periods, from T=4 to T=5 and from T=5 to T=6 respectively

Table 3.5: Expected Shortfall of largest banks LCR

Events			LCR expected shortfall		
T-periods	Bank of Cyprus	National Bank of Greece	Credito Emiliano	Banco Commercial Portuguese	Banco Santader
Baseline to Shock implementation	-0.060	-0.117	-0.174	-0.011	-0.158
1st period of stress	-0.056	-0.090	-0.130	-0.011	-0.019
2nd period of stress($T = 4$)	-0.085	-0.153	-0.212	-0.368	-0.227
3rd period of stress	-0.002	-0.005	-0.003	-0.010	0.000
4th period of stress	-0.002	-0.005	-0.003	-0.010	0.000

Table 3.3 provides the Southern EU largest banks' expected shortfall during the baseline and stressed periods. The size of the Banks is defined by their total assets.

banks indicate greater exposures in terms of lending and deposits activity compared to the smaller commercial banks. These large banks indicate significant presence in the domestic and international markets, thus their contribution to systemic risk is of upmost significance to be further analysed (Begenau et al., 2015).

Comparing across individual banks' funding position and the expected value of LCR on country level, the findings specify that Individual banks' funding position has the same as the country level LCR reaction when macroeconomic shocks are applied. Specifically, as displayed in Table 3.5, from the baseline state to the shock implementation, the largest southern European banks indicate a significant reaction and a shortfall in their funding position reaching up to 17.4%. Credito Emiliano, Banco Santader and National bank of Greece face a decrease of the LCR expected value equal to 17.4%, 15.8% and 11.7% respectively. However, when moving to the next period (1st period of stress, from $T = 2$ to $T = 3$), these banks continue facing a deterioration in their funding position but the LCR expected shortfall is significantly smaller reaching up to 13% decrease. Similar albeit applies to the rest of banks.

In the 2nd period of stress (from $T = 3$ to $T = 4$), all the banks reflect the same reaction as the LCR on country level. In particular, the largest banks included in our analysis indicate substantial outflows while the largest shortfall is for Banco Commercial Portuguese. This bank's LCR expected value when the macroeconomic shocks are applied, equals to 45.5% while during the 2nd period of stress the LCR drops by 36.8% and reaches the 28.8%. A similar behaviour is observed to the rest of the banks for which LCR shortfalls vary between 8.5% (Bank of Cyprus) and 22.7% (Banco Santader). Individual banks' liquidity performance further support our key findings which reveal the existence of systemic liquidity risk when the financial system face adverse economic conditions.

Our findings highlight the existence of systemic liquidity risk. Also these results emphasize our analysis' contribution to perform macro-prudential liquidity stress tests able to capture the interconnectedness between the macroeconomic environment and the funding liquidity risk of banks, which nexus can turn into systemic affecting multiple financial entries simultaneously. In parallel, the evidence provided, not only underlines the interconnectedness between the real sector and banks' funding position, but also the macro shocks propagation to banks' liquidity position which leads to systemic liquidity risk in the Southern European banks.

The analysis of the LCR evolution combined with the key dynamics of our model captures such as agents' heterogeneity and financial system complexity, underlines that LCR regulatory measure is able to catch the adverse economic conditions. However the LCR in order to reveal the existence of systemic risk and reflect successfully the different economic states (periods), should be examined for more than 30-days period. The extension of the LCR assessment from 1-month period to 2-months assessment is of upmost significance as the key dynamics of funding liquidity risk lagged the economic shocks.

Lastly, the economic shocks' evolution through a stochastic process combined with households and firms transactions, notify agents' ability to serve loan obligations and savings to banks at each time step as a reaction to the respective economic state. This premise is further enhanced by assessing the amount of loan payments and deposits from the transactions with the households and firms which will be further discussed in the next subsection (3.4.3), where we will focus on the decisions of households and firms when acting under stress as well as on their contribution to the banks' liquidity shortages.

3.4.3 Agents Behaviour

This section discusses the volume of liquid assets and outflows the banks face during the baseline and the stress periods. We analyse the amount of liquid assets arise from the transactions with the households and firms respectively, as well as the proportion of outflows due to firms' and households' deposits withdrawals. These findings draw conclusions on agents' behaviour and transactions when they are binding from the consumption and the cost of production constraints under the different states of the Economy. Also these results assist on banks' contingency planning, in particular the asset and liability allocation, when adverse economic conditions arise.

Figure 3.2 indicates the volume of liquid assets provided from households and firms to banks through the cash&equivalent account. These liquid assets refer to the loan payments provided by households and firms loan payments. The blue area of Figure 3.2 corresponds to the average amount of payments coming from households to all banks in our system while the grey one is the amount of cash provided by firms. The evolution of the liquid assets illustrate that during the baseline period ($T = 1$), the volume of cash&equivalent banks receive from households is €5.25 bn while the amount coming from the transactions with firms is almost double. When the macroeconomic shocks are introduced ($T = 2$) and during the first period of stress ($T = 3$) both households and firms continue to serve their loan obligations while in the second period of stress in the economy ($T = 4$) there is a simultaneous sharp drop of these liquid assets. Specifically the amount of cash&equivalent provided by households drops up to €3.5 bn while almost half of loans provided to firms are not regularly served. Thus the amount of cash&equivalent banks receive from the transactions with firms decreases by €3bn.[6]

The economic situation affects households' and firms' decisions regarding the level of consumption and financial turnover as well as the labour costs (amount of wages). Particularly, households and firms are forced to reallocate their disposal

[6]Under the baseline state banks receive almost €8.25 bn in total from the transactions with firms while at $T = 4$ this amount equals €5.25 bn

income and net value respectively, due to adverse economic conditions . Thus as rational agents, households and firms relocate their expenses given the new state of their revenues, wages and cash respectively. The reaction of these agents and the decrease in banks cash&equivalent account signals how real sector triggers simultaneous shortages to banks' funding position leading to systemic liquidity risk.

Complementary to these findings, Table 3.6 provides details on the liquid assets shortfalls banks face at each time step focusing mainly on $T = 4$, which is the time period, systemic liquidity risk arises. we provide these findings in order to see which time step T banks' liquid assets indicate their greatest shortages. These result explain households and firms contribution to banks' funding position deterioration. To this point, agents' decisions and actions to serve their loan payments combined with the development of the non-performing loans mechanism, we conclude that banks face liquidity shortages and we estimate whether banks should change or not their preferences regarding the type of customer (agent) they choose to provide their funds.

Table 3.6 highlights that the percentage change of liquid assets from both households and firms is the same by the time the macroeconomic shocks take place (from $T = 1$ to $T = 2$). These are relatively small values (ranging from -1.2% to -1.96%) as the shock has not yet fully affected the agents' actions. The magnitude of the shock becomes apparent from the first period ($T = 3$) of stress where banks' liquid assets coming from firms' transactions indicates a stronger negative effect than households do. At $T = 4$ a steep decrease of banks liquid assets coming from the transactions with households and firms, is displayed. However, households indicate a greater than firms inability to provide loan payments to banks. The reason why banks' cash&equivalent account face substantial drops due to households inability to provide loan payment, is because of the decrease in the level of wages. The adverse economic conditions, lead firms to cut labour costs in order to maintain and maximise the level of net value.

In Portugal, where the banking system has been shrinking (Greenwood et al. 2015) households lead banks' cash&equivalent account to a decrease equal to 79.55%

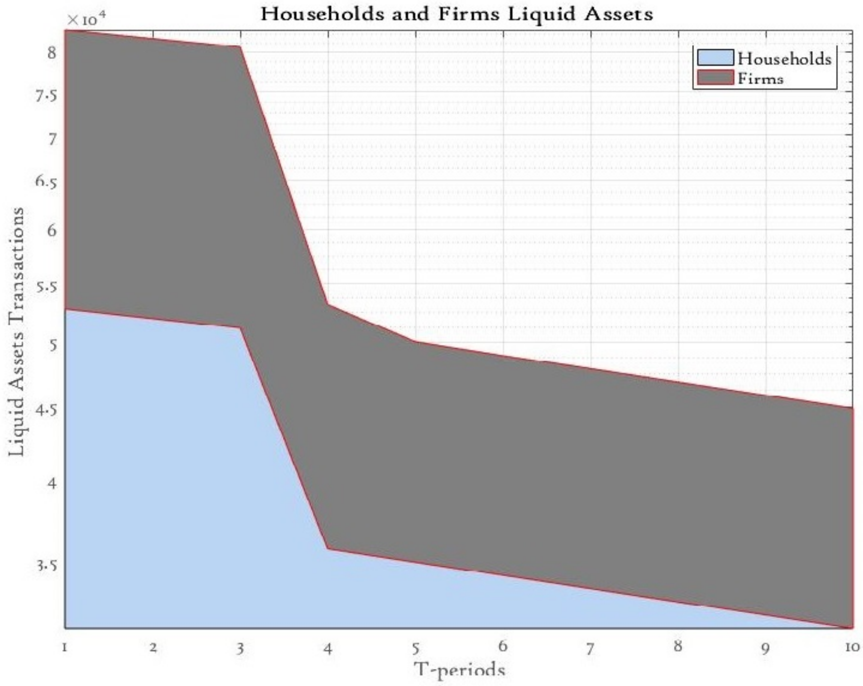
. This is the largest decrease compared to the rest of commercial banks for the second period of stress ($T = 4$), with Greece and Spain lagging behind. In contrast, Italian banks have the smallest decrease in cash&equivalent account. To this point, the size of the Italian banking system as also highlighted in the previous subsections plays a key role, as the liquidity risk concentration risk concentration is split among the banks.

Firms on the other hand, demonstrate milder decrease in the funding position of banks, compared to households. However, also in the case of firms, Portugal displays the largest decrease in banks' cash&equivalent account. Portuguese firms' activity leads to a 45.71% decrease in banks' cash&equivalent, resulting a respective decrease in the expected value of the LCR.[7] This reduction is due to Portuguese firms' size and activity, which is shrinking dramatically. The deterioration in Portuguese firms size and activity is an outcome the economic activity which does not allow firms to meet their maximum value (Braguinsky et al., 2011).

Cyprus has the smallest shortfall in cash&equivalent account. During the stressed event, Cypriot firms contribute to the LCR shortfall by -9.95%. Even during the macroeconomic crisis, Cypriot firms were able to overcome market vulnerabilities and financial constraints, as these firms indicate significant international presence through their corporate activities. Cypriot firms resist the crisis from the levy imposed on banks' deposits, leading these firms to lose only 5% of their pre-crisis net value (Hardouvelis et al., 2016).

[7] See Section 3.4.2, which provide details on the LCR expected value evolution and shortfalls at each time step

Figure 3.2: Liquid Assets behaviour during baseline and stress period



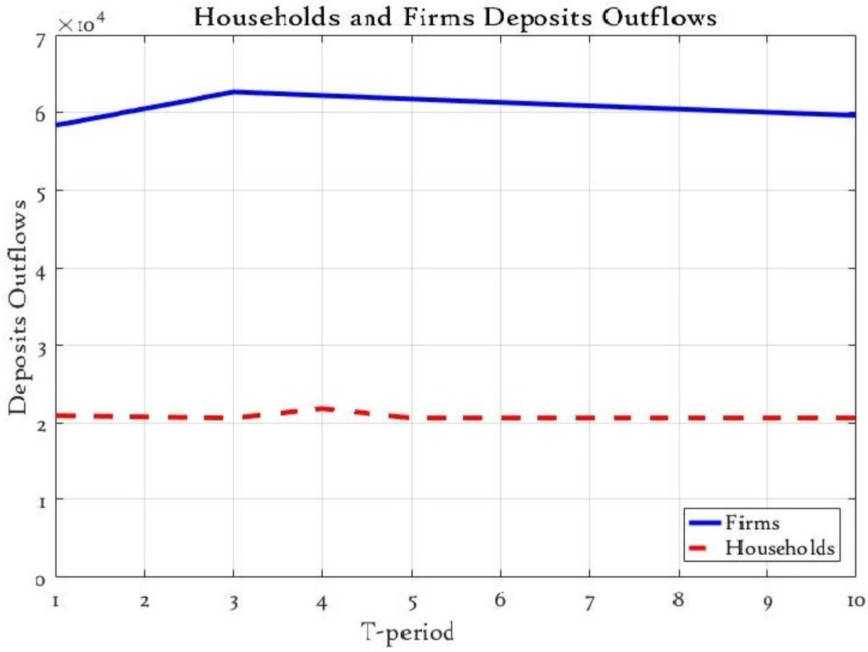
In order to fully capture households and firms' contribution to LCR substantial shortfalls leading to systemic liquidity risk, we analyse the amount of outflows banks face from the transactions with households and firms over the time (from $T = 1$ to $T = 10$). Whilst the outflows banks' face seem to be stable over the time, which means that agents to do not proceed to substantial deposits outflows, at $T = 4$ where systemic liquidity risk appears we observe that the amount of outflows from households and firms increase by €0.25 bn and €0.8 bn respectively. To this point, LCR counts for the amount of outflows and the ability of banks to cover these outflows through their liquid assets. However, households and firms reaction related to their savings and in turn deposits withdrawals, indicates that the LCR shortfall relies more on agents inability to provide loan payments rather than to withdraw deposits and increase the amount of outflows banks face.

Table 3.6: Liquid Assets Percentage change from Households and Firms Transactions

T-period	Liquid Assets percentage change from Households				
T-periods	Cyprus	Greece	Italy	Portugal	Spain
Baseline to Shock Implementation	-1.96%	-1.80%	-1.71%	-1.20%	-1.25%
1st period of Stress	-1.45%	-1.03%	-1.16%	-0.45%	-1.17%
2nd period of Stress	-33.89%	-53.26%	-27.18%	-79.55%	-46.63%
3rd period of Stress	-2.12%	-2.12%	-26.49%	-2.12%	-2.12%
4th period of Stress	-2.10%	-2.00%	-2.88%	-2.15%	-2.02%
T-period	Liquid Assets percentage change from Firms				
T-periods	Cyprus	Greece	Italy	Portugal	Spain
Baseline to Shock Implementation	-1.96%	-1.80%	-1.71%	-1.20%	-1.25%
1st period of Stress	-1.96%	-1.79%	-1.70%	-1.19%	-1.24%
2nd period of Stress	-9.95%	-17.84%	-22.10%	-45.71%	-43.40%
3rd period of Stress	-2.02%	-2.13%	-2.37%	-2.19%	-2.24%
4th period of Stress	-2.02%	-2.12%	-2.39%	-2.16%	-2.22%

Table 3.6 provides the percentage change of the liquid assets as these provided by households and firms through the cash and equivalent account during baseline and stressed periods.

Figure 3.3: Deposits Outflows arising from transactions with households and firms



The red dotted line displays the deposits from households and highlights that these agents, even during the distress period, do not proceed to substantial withdrawals. This behaviour is explained by the amount of loan payments (liquid assets) provided to banks which decrease significantly over the time, highlighting that households prefer not to serve the loan obligations rather to withdraw deposits in order to finance their activities.

Figure 3.3, shows the evolution of households and firms' deposits on average, for all the banks in our sample, from $T = 1$ to $T = 10$. The blue line shows the deposits from firms, hese indicate a a greater decrease than this of households. Firms during the stressed period withdraw almost €1bn from their deposits. Despite, this increase in banks' outflows, firms in order to sustain the level of their net value, they proceed to substantial delays of the loan payments (see Figure 3.2) reduce labour costs reduction, which force households to make use of their savings.

To this point, in Figure 3.3, the red dotted line displays the deposits from households and highlights that these agents, even during the distress period, do not proceed to substantial withdrawals. This behaviour is explained by the amount of loan payments (see Figure 3.2) provided to banks which decrease significantly over the time, highlighting that households binding from the decrease their wage due to firms' decision to reduce labour costs, decide not to serve the loan obligations rather to withdraw deposits. As rational agents, the decrease of their income through the wages channel, create further insecurity, which prevent households from making use of their savings in order to finance their activities and obligations.

Furthermore, another reason which explains the evolution of banks' outflows is the global financial crisis of 2007-2008. As a consequence of this financial turmoil, countries such as Cyprus and Greece of countries faced structural changes in the Financial and Fiscal policy. These reforms enable Banks to set a threshold amount of deposits withdrawals (Hardouvelis et al., 2016). in particular, in Cyprus and in Greece, capital control and deposits haircuts were applied for preventing further liquidity drainage to the banking system (Monokroussos et al., 2015).

The break down of the LCR liquid assets and outflows, combined with further information on households and firms contribution to systemic liquidity risk, should be the focus of banks' management. This analysis contributes to banks' contingency planning, not only banks to identify the sources of systemic risk (i.e. macroeconomic fluctuations) but also to draw outcomes about the contribution of real sector agents to substantial liquidity shortages, these banks face during periods of stress. This process is of upmost significance, in order banks to enhance and build up efficient business models during distress periods. Banks need to cope with liquidity risk fast in periods of crisis as their capital base is already at a critical stage. Thus, the estimation of the volume of liquid assets, cash&equivalent, non-performing loans and deposits outflows is necessary for banks to withstand shocks.

3.5 Concluding Remarks

In this paper, we examine the role of funding liquidity risk and its systemic dimension with the use of the regulatory LCR liquidity ratio, under a macro prudential stress test framework. Through this analysis, we assess the levels of the LCR under both a baseline and a stressed scenario. We measure the changes of the banks' liquid assets and outflows based on households' and firms' decisions led by the disposable income and net value constraints respectively. We conduct the analysis in an environment where the macroeconomic fluctuations affect households and firms decisions under both the baseline and the stressed scenarios.

We derive the LCR expected shortfall for all banks acting under the same economy. Our analysis reveal that LCR experiences its greatest reduction during the second period after the shock implementation. Our results indicate that LCR should be treated for a more than 30 days period in order to capture the time lag between the economic and the financial stress. Therefore the LCR assessment over 30 days is not able to capture the whole aspect of the stress. As banks' funding position is defined by the transactions with households, firms and the government, this means that the financial system cannot immediately react to the economic stress.

We find evidence that banks' business model and transactions contribute more to the LCR deterioration. The cash inflows and the outflows of banks coming from households and firms respectively, imply that banks' contingency planning and model should be continuously monitored, during periods of economic stress. The use of ABM in our study reveals the need of analytical frameworks instead of the traditional econometric and statistical approaches when dealing with scenario analysis. Hence, ABM assess the position of banks as well as other agents' behaviour when acting under the same economic environment.

A key result of our study is highlighting the need to complement the macro prudential framework with the assessment of systemic liquidity risk. This need seem to be amplified when dealing with different banking systems. The examination of liquidity risk arising from the funding position of banks with the use of the Basel III LCR, provides further insight on the financial stability framework. In addition, this study contributes to prudential framework from the micro aspect of this regime as it reveals information regarding banks business model. The behaviour of households, firms and the government illustrates that banks should reconsider their business models and act in a more prudent way in intermediation activities .

The sensitivity of the LCR over the marginal fluctuations of the macroeconomic environment combined with existence of systemic liquidity risk illustrate the strong linkage between the macro side of the economy with the funding position of banks. This study shows the importance of considering liquidity risk when conducting stress tests as well as the validity of the regulatory framework in liquidity risk as assessed through the LCR. The model and the dynamics captured from our analysis comprise a useful tool and substantial evidence for macroeconomic surveillance and supervisory engagement.

However, this framework can be further expanded and count for feedback processes. The application of multiple feedback process will provide evidence on financial risks behaviour such as funding liquidity risk, and will reveal banks' ability to withstand systemic risk effects and recover their funding position. For this scope, the following Chapter extends the current macroprudential stress test framework by incorporating a series of multiple feedback responses and assess whether banks' liquidity position recovers.

Lastly, given that most of the stress test analysis are lacking contingency plans when assessing the financial position of banks, the agent based process provides a guide to the volume of fund flows that banks should hold in order to cope with severe liquidity shortages. Our results are rather appealing to regulators and policy makers alike. Hence, we provide ample evidence that helps in designing robust and forward looking frameworks for establishing and maintaining financial stability and prudential policies.

Chapter 4

When liquidity risk becomes procyclical: A multi agent feedback process

Abstract

This study presents a macro prudential stress test model including for second round effects. With the use of a multi agent stress test approach, we investigate liquidity risk's evolution when banks operate under adverse but plausible macroeconomic shocks. In this paper, the interaction of banks with firms, households and the economy, reveals funding risk's pro cyclical behaviour, when systemic risk appears. Simultaneously, banks develop a series of responses for facing the economy's vulnerabilities. These responses uncover the second round effects which arise in banks' funding position, and provide evidence about funding liquidity risk behaviour. The results of this process show that, the development of adjusted liquidity channels supports banks to resist to economic recession. However the pro cyclical behaviour, liquidity risk indicates, leads banks to face substantial shortages in the balance sheet. By addressing the adjusted channels and counting for banks' responses, we contribute to the area of second round effects, that banks should consider to set up their funding planning.

JEL classification: C63; G01; G17; G18; G21

Keywords: Macroprudential Policy; Stress Test; Liquidity Risk; Procyclicality; Agent Based Model;

4.1 Introduction

Post the financial crisis of 2007-2008, policy makers and regulators revised the required reforms, for promoting and sustaining the safety in the financial system. One of the primary objectives they focused on, was the design of new regulatory reforms, the amendment of existing ones and the development of tools which act as early warning indicators and reveal system vulnerabilities (BCBS, 2017).

The financial soundness indicators developed by IMF (2006) and Drehmann and Juselius (2014) proved mechanical than analytical tools for monitoring financial institutions performance. Therefore, policy makers and regulators proposed advance risk management methods for financial resilience assessment. Stress test models comprise these risk monitoring methods, in order to examine the resistance of FIs to financial and economic vulnerabilities.

Stress test models attracted academics' and policy makers' interest, who provided substantial advancements in such core area (Foglia, 2009). Despite these advancements and the rapid rise of the stress test models, a series of limitations led these applications to still emerge. These limitations refer to the the great focus on asset quality review, by omitting other financial risks, such as the funding liquidity, combined with traditional econometric applications, which are unable to capture the complexity of the financial system (see for details Borio et al. 2014).

Whilst the scope of stress tests is to provide financial and economic information required for policy makers' decision making, these applications proved unable to address this scope (Haldane, 2009). This financial and economic information consist on the development of feedback mechanism, in order to capture second round effects. By developing banks' responses to economic and financial shocks, the implementation of a feedback mechanism in a stress test process captures the evolution of financial risks under long periods of stress, especially when these risks comprise an outcome of systemic or contagious effects. However, the stress tests models developed so far lack these mechanisms because of the reliance on rather econometric than analytical computational approaches (e.g. agent based models).

By incorporating feedback assessments when carrying out stress test models, the evolution and pro cyclical behaviour of financial risks reveal that policy makers can draw outcomes about financial risks and economic cycle fluctuations (Landau, 2009). Even second round effects are not fully addressed by the stress test models developed so far. The academic literature on financial risks' pro-cyclical behaviour displays significant evidence of credit risk and its cyclical patterns to business cycle fluctuations (see for example Bikker and Metzemakers 2005; Bouvatier and Lepetit 2008; Repullo and Suarez 2012; Bertay et al. 2012). Besides these attempts, funding liquidity risk pro-cyclical behaviour remains at an early stage (Kim et al. 2013 and Athanasoglou et al. 2014) and combined with liquidity stress tests' inability to count for second round effects, it leaves ample space for further research.

Our analysis contributes and provides evidence to the very limited studies on funding risk and its pro-cyclical behaviour, by implementing novel multiple feedback mechanisms which assess and quantify cyclical patterns arising from the main macro financial linkages. The use of a data driven agent based model comprises another significant contribution in the area of stress test methods as it acts as a unified process. In particular we extend the model developed in Chapter 3 and we perform novel multiple feedback processes. The implementation of multiple feedback processes accommodates for complex financial systems such as the banking one. Our analysis counts for banks' responses through the development of multiple feedback process which investigate funding liquidity risk's pro-cyclical behaviour. This study is the first to consider the implication of multiple feedback mechanisms on Basel III liquidity measure (LCR) under a state of economic stress.

We carry out the analysis by setting up a system where banks, households, firms and the government interact. Our framework counts for both baseline and stressed periods, where the transactions of banks with other agents are modelled to react to the development of LCR through banks' balance sheet. In addition, in order to count for multiple feedback processes we incorporate second round assessments through banks' responses to systemic liquidity shortages. Banks' responses comprise the adjusted liquidity channels which focus on the loan supply restriction, the increase on high quality liquid assets, i.e. government securities and the fire sales when banks are unable to meet their liquid needs.

The model operates on a finite number of steps where all the agents aim to maximise their returns under their constraints. This process goes beyond the traditional stress test approaches as it provides a unified stress test method, able to act as standalone tool. To this point, the development of the feedback mechanism reveals the LCR evolution and funding risk pro cyclical behaviour to adverse economic changes.

Our results illustrate the pro-cyclical behaviour of funding liquidity risk, under the examination of adverse macroeconomic scenarios. Specifically, the LCR, under stressed economic conditions, displays simultaneous shortfalls for all the banks in our system, while the largest shortfall reaches 40% on average for the whole system. Another characteristic is that the size of banks (in terms of assets) combined with the adjusted liquidity channels, assist on maintaining the LCR above or close to 70% threshold. Large banks' LCR drops as the economic recession unfolds. However, it takes longer for these banks to fail below this threshold. With regards to small banks, these go below the 70% LCR threshold and even when adjusted responses are activated, these banks are unable to recover or maintain their funding position. In addition, the decisions and rationality of firms and households lead to further investigation of the LCR behaviour, as households' contribution to the LCR deterioration is greater than that of firms'. Households indicate substantial amount of deposits outflows and combined with banks' responses to systemic risk and the increase in lending rates, underline the LCR continuous reduction.

Overall, our results highlight the substantial role of macro prudential policy in the area of financial stability and points out to the need for developing analytical unified stress test models, counting for second round effects. We provide clear evidence that the linkage for prudential policy and macro level transactions, as well as the implementation of feedback mechanism reveal further information for banks' business model and assist in banks' funding planning.

The remainder of this paper is structured as follows. Section 4.2 reviews the relevant literature. The methodology and model specification is presented in Section 4.3, while results are given in Section 4.4. Section 4.5 concludes.

4.2 Related Literature

This section discusses the relevant literature within liquidity risk and pro cyclical behaviour as well as stress tests and their ability to capture second round effects. This section denotes whether funding liquidity risk is pro-cyclical and reveals the need to investigate liquidity risk evolution when systemic aspects arise. In addition, a discussion and analysis for the stress test models and their ability to count for second round aspects is also provided.

4.2.1 Funding Risk and Pro cyclical behaviour

The inability of banks to meet their liquid needs, directly relates to their liquidity profile and signals the existence of liquidity risk, namely the funding risk (Drehmann and Nikolaou, 2013). Funding liquidity risk comprises a forward looking type of risk, measured for a specific time horizon (Brunnermeier and Pedersen, 2008). Funding liquidity focuses on banks balance sheet evolution and the cash flow mismatch arising from banks main financial activities through assets and liabilities (Bryant, 1980; Allen and Gale, 2004, 2009).

Besides funding liquidity risk, the financial crisis of 2007-2008 underlined the existence of market liquidity risk. The rise of sub-prime loans and securities led to substantial drops to assets' prices (Blanchard, 2009), which revealed the existence of liquidity risk in the market and the lack of trust in the financial transactions. According to Ferguson et al. (2007), market liquidity risk is the inability to trade an asset at the fair price. In addition, the financial policy committee in Bank of England defines market liquidity risk exists when "the demand for liquidity exceeds the supply" (BoE, 2017a).

Whilst, the existing literature attempts to provide evidence regarding liquidity risk, at both funding and market aspect, this type of risk still emerges. Bai et al.

(2012) uncover the importance of market liquidity risk through an in depth assessment of this risk behaviour, but the assessment of funding risk and its evolution over the time highlights the need to investigate funding liquidity risk pro-cyclical behaviour.

As stated by Landau (2009), pro cyclicality is "the tendency of financial variables to fluctuate around a trend during the economic cycle". For the banking system, the term pro cyclicality is explained as the behaviour of financial risks and their relationship with the economic activity (Athanasoglou et al., 2014). The assessment of funding risk and the its evolution over the time, highlights the need to examine this risk's behaviour.

Studies developed so far regarding banks' procyclical behaviour (Bikker and Metzemakers 2005, Bouvatier and Lepetit 2008, Repullo and Suarez 2012 and Bertay et al. 2012), tend to focus on banks' credit risk and capital requirements rather than liquidity risk. In particular, Bikker and Metzemakers (2005) assess banks' portfolios and the relation with the economy's performance, through an econometric estimation, they reveal the inter-linkage between credit risk and the economy's behaviour. Results show when banks act under economic recession, credit portfolios' riskiness increases. In the same direction Jesus and Gabriel (2006) assess the evolution of credit risk and its interrelation to the business cycle fluctuations based on macro prudential tools for measuring credit risk, such as the loan loss provisions. Also a recent study provided by Tasca and Battiston (2016) focuses on credit risk procyclicality. The authors carry out a network model that captures credit risk dynamics and the contagion counting for pro cyclicality between asset prices and financial leverage.

Pro cyclicality in banking risks has been assessed under different perspectives. Whilst the current literature indicates a great focus on credit risk procyclicality (Shin, 2013), current studies also reveal the need to investigate leverage and liquidity risk pro cyclical behaviour. As suggested in a policy paper by Bank of England, leverage pro cyclicality, is the association between leverage and the business cycle (Saporta, 2009). To this point, Acharya and Ryan (2016) and Rauter (2016) recommend to capture leverage pro cyclicality by looking at the association between leverage growth and the business cycle. Particularly, Rauter (2016) documents strong pro cyclicality of leverage and show that fair value accounting contributes to the positive relation between the GDP growth and leverage growth during expansionary periods. In the same direction, Olszak et al. (2016) underline that during the non-crisis periods, leverage is not pro cyclical, while leverage pro cyclicality is visible during crisis period.

Beyond credit and other banking risks, other types of risks have also been found to be pro cyclical. According to an IMF study (Andritzky et al., 2009), funding risk is pro cyclical to market changes while a recent analysis developed by Kim et al. (2013), identifies banks' cyclical patterns between monetary aggregates, such as core and non-core funding, and financial vulnerability. Also, Olszak et al. (2016) show that liquidity risk is pro cyclical during non-crisis period while during crisis period this risk becomes countercyclical. However, there is not enough evidence revealing funding liquidity risk pro cyclicality as the current literature partially addresses the funding risk behaviour. A series of studies highlight the need to move from traditional credit risk assessment to other types of financial risks such as the market and the funding liquidity. Specifically, Athanasoglou et al. (2014) in their paper on banks' behaviour and policies to mitigate pro cyclicality underline the need to incorporate into risk management tools, such as stress tests, the assessment of funding liquidity risk and its evolution over the economic cycle, in order to identify potential cyclical patterns.

Despite the need for funding risk pro cyclical behaviour to be investigated, recent developments in financial and prudential policy tools indicate rather mechanical than analytical processes (Andritzky et al., 2009), which cannot fully incorporate in depth liquidity risk examination, which is required for banks' contingency planning. Stress test processes fall to the category of financial resilience assessment, however the models developed so far and the way they treat liquidity risk omits funding risk and its relation to pro cyclical behaviour.

4.2.2 Stress tests and second round effects

Stress test models comprise an indispensable part of the financial stability assessment framework. In order to promote the resilience of FIs, academics and practitioners reinforced their efforts to provide stress test techniques able to capture financial and economic stress and draw outcomes regarding banks' financial performance.

Despite the rise of stress tests (see for example Boss et al. 2006a, Čihák 2007, Quagliariello 2009, Foglia 2009 and Demekas 2015), and their crucial role they hold for sustaining financial stability (Dees et al., 2017), these models are still unable to act as standalone tools. In addition, stress tests are still unable to address the complexity of the financial system (Borio et al., 2014) and to be informative for policy response (Galati and Moessner 2013,Haldane 2009 and Čihák 2007).

These limitations stem from stress tests' inability to fully provide all the required information for a complete assessment of both micro and macro prudential framework, necessary for banks' contingency planning and policy makers and regulators' decisions. In particular, the stress test models which have been developed so far do not present a concrete framework for a feedback mechanism which can incorporate the main macro financial linkages and underline banks' responses when acting under stress. Additionally, by neglecting financial risks such as the funding liquidity, required for banks' funding planning, stress tests models do not fully address and contribute to the new prudential reforms, while the behaviour financial risks under economic recession is also omitted.

Liquidity risk has been the subject of academic interest (see for example Diamond and Dybvig 1983, Vento and La Ganga 2009 and Hesse et al. 2012, and Ong 2014), while studies in the area of stress tests and funding liquidity risk assess banks reserves, overdrafts, interbank loans and funds from other banks (Čihák 2007). However, the investigation of liquidity risk within stress tests scenario analysis, the evolution and association of liquidity risk to macroeconomic changes (procyclical behaviour), as well as banks' responses to substantial funding shortages for revealing liquidity second round effects on banks balance sheets, are still at an infant stage.

To this end a study developed by Van Den End (2012) investigates the effect of adverse financial scenarios on the Basel III liquidity ratios (LCR, NSFR) in a stress test framework. This analysis attempts to take into account liquidity second round effects. However, the lack of a dynamic treatment for capturing the complexity of the financial system and the lack of an analysis from the macro side of the economy, leaves ample space for further investigation of the main inter-linkages between liquidity risk and the economy's performance. Additionally, the behaviour of liquidity risk to economic recession as well as banks' responses to substantial liquidity shortages, are needed for a complete evidence to both macro and micro prudential reforms.

Second round effects comprise the changes in financial variables, when banks and other FIs respond endogenously to financial and economic shocks (Martínez-Jaramillo et al., 2010). Whilst policy makers and regulators highlight the need to incorporate second round effects when applying stress test simulations (Haldane, 2009), only a few stress test studies address these effects while the great focus is on credit risk, capital requirements and bank losses (Martínez-Jaramillo et al., 2010).

In particular, a recent attempt focusing on second round effects mechanism, has been developed by Martinez-Jaramillo et al. (2014). With the use of network analysis, the authors estimate the distribution of banks' losses after the detection of contagion risk in the system of banks. While this approach comprises a step forward to the traditional stress test applications, the evolution of risk factors' after the second round effects implementation is needed for a concrete risk analysis.

Another study which contributes in the area of second round effects by providing banks' responses channels is this of Cohen and Scatigna (2016). In their analysis, the authors design adjustment capital channels for modelling banks' responses to financial and economic shocks. With the use of econometric estimation, they conclude that banks, after the responsive channels application, indicate a prudent behaviour with an increase in safe assets while sustaining their profitability and capital levels. Despite, the analytical banks' responses provided in this paper, the use of econometric estimation and the lack of banking factors evolution, for capturing potential pro-cyclical behaviour, is required.

Second round effects are also addressed in the wide stress test analysis carried out by central banks. The European Central Bank (ECB), under the framework of asset quality review, carries out a series of responses in order to draw outcomes about the evolution of capital shortfalls, loan supply and banks' probability to macroeconomic changes. With the use of Global Vector Autoregressive Models (G-VAR), they count for credit risk procyclicality to potential economic recession. However, the great focus on credit risk combined with the reliance to econometric applications, such as reduced form models, not only omit other types of financial risks but also cannot provide a detailed analysis due to econometric techniques limitations.[1]

In the same direction of asset quality review, the Bank of England stress test model overcomes the limitations of econometric estimations when counting for second round effects and applies a network analysis, which assists in investigating credit market risk evolution through assets' prices depreciation followed by fire sales (BoE, 2017b). This process provides a great insight to the built up of second round effects. However a further analysis on the evolution of funding risk combined with banks responses would be required.

The current literature indicates a field on the rise through attempts to account for banks' second round effects, when operating under stress. These highlight the need to provide a detailed framework for capturing second round effects. In addition, the inability of including, substantial risk factors and monitor their evolution for measuring potential pro-cyclical behaviours, underline that this area emerges.

4.3 Model

This model develops a mechanism for assessing the evolution of funding liquidity risk after the detection of systemic behaviour led by macroeconomic fluctuations. In other words, based on the model developed in Chapter 3, we extend the process and

[1] See Acharya et al. 2014 for a full description of reduced form models limitations, such as the assumption of linearity

count for second round effects in banks' funding position. Particularly we develop multiple feedback processes, filling both theoretical and methodological limitations in the area of wide stress tests. The use of the Agent-based model allows to perform simultaneous feedback channels in order to provide a unified stress test process acting as standalone tools (Borio et al. 2014).

The purpose of this analysis is to investigate whether banks' reaction, with the activation of multiple feedback processes to tackle systemic liquidity risk, improves banks' LCR expected value. Through this process and the banks' actions to overcome systemic liquidity risk, we provide evidence on funding liquidity risk evolution. In particular we investigate whether funding liquidity risk becomes procyclical to the macroeconomic fluctuations. Also, we assess the contribution of households' and firms' indebtedness to funding liquidity risk, and we estimate whether banks need to develop further requirements to cover their liquid needs when adverse economic conditions are applied.

The multiple feedback processes start with two main channels which describe banks' reaction when adverse economic conditions appear and systemic liquidity risk arises in the system of banks. The development of these key strategies is an extension of Cohen and Scatigna (2016) study who build up adjustment channels for banks in order to recover their capital requirements. We follow these strands for assessing banks' ability to meet their liquid needs by focusing on the restrictions in loan supply and on banks' inflows, which can increase through the asset fire sales mechanism and the investment to safer assets such as the government securities.

Similarly to Chapter 3 process, an Agent Based Model is carried out, which is able to capture dynamic and complex systems such as the financial one (Tesfatsion and Judd 2006). Through this process we simulate aspects of real world conditions such as the interrelation between the macroeconomic and financial side of the economy in order to identify the second round effects in Banks' expected return arising to their funding position.

An agent based model is the right method to be used for performing macro-prudential stress tests. ABM is a forward looking method which can produce large dataset of extreme events which can be rarely modelled with the traditional stress test tools due to lack of real data. Also, ABM can model and iterate the parallel actions agents proceed. Additionally, these parallel actions which can be modelled and run simultaneously can incorporate multiple feedback processes necessary for banks' resilience and contingency planning. The use of agent based modelling overcomes the limitations of other approaches developed and applied for second round effects such as the Dynamic Stochastic General Equilibrium (DSGE) models which "lack of flexibility for generalisations based on unrealistic economic assumptions" (Fagiolo and Roventini, 2016).

The model is applied to 30 systemically important banks from Cyprus, Greece, Italy, Portugal and Spain, populated by heterogeneous agents, who exist and interact in an open small economy.[2] This model closest antecedent is the process developed by Hałaj (2018) which we expand and adjust in detailed analysis of agents' decisions and banks' balance sheet evolution by exploring the behaviour of systemic liquidity risk on banks' liquidity performance, after the implementation of multiple feedback action, namely the adjusted liquidity channels in the vein of Basel III framework.

4.3.1 Agents: Economy, Firms, Households and Banks

We make use of the small open economy model developed in Chapter 3 for the baseline state and we extend this model by developing multiple feedback processes during the stressed economic states, analysed in Section 4.3.2.1.

Economy

Our model operates for a finite number of steps T.[3] All the agents interact under this economy, which comprises the real sector composed by firms and households, and the banks. Firms produce and sell the homogeneous consuming goods and form a relationship with the households[4] Also, the economy includes M banks indexed by j,

[2]See Chapter 3, Section 3.3.5 which provides details on model calibration and the data used to set up the process before running the multiple iterations

[3]T represents 1-month period and our model operates for 10 periods

[4]As denoted in Chapter 3, each household can be employed only in one firm. Employment and consumption of goods evolve endogenously over time. Firms produce using labour only and they

(L_{i}), which interact with N households (H_{ij}) and firms (F_{ij}),and the government(G_{i}). Thus the macro prudential framework represents the respective economy (G_{i}), where all the agents interact, and it is modelled as a function of the national income through the Gross Domestic Product (4.1).[5]

$$GDP_{\mathrm{i}} = CPI_{\mathrm{i}} + INV_{\mathrm{i}} + X_{\mathrm{i}} - M_{\mathrm{i}} - Debt_{\mathrm{i}} \tag{4.1}$$

Firms and households

Firms and households borrow funds from banks through corporate and commercial loans respectively at an interest rate r_{loan}. In parallel, they place their savings as funds to banks, through deposits (d_{ij}) and they receive a return equal to the deposit rate (r_{deposit})[6]. In parallel, at each time step firms and households aim to maximise the net value 4.2 and the disposable income 4.3 respectively, under the different economic conditions.

$$arg\ max \quad NV_{\mathrm{ij}} \quad (cash_{\mathrm{ij}} + (1 + r_{\mathrm{deposit}})^t d_{\mathrm{ij}} - c_{\mathrm{ij}} - loan_{\mathrm{installment}}) \tag{4.2}$$

$$arg\ max \quad Y_{\mathrm{ij}} \quad (w_{\mathrm{ij}} + (1 + r_{\mathrm{deposit}})^t d_{\mathrm{ij}} - cs_{\mathrm{ij}} - loan_{\mathrm{installment}}) \tag{4.3}$$

where the $loan_{\mathrm{interest}}$ is calculated as follow:

$$loan_{\mathrm{installment}} = Loan_{\mathrm{principal}} * D^i{}_{\mathrm{j}}, \quad D^i{}_{\mathrm{j}} = \frac{[i(1+i)^T]}{[(1+i)^T - 1]} \quad and \quad i = \frac{r_{\mathrm{loan}}}{T} \tag{4.4}$$

When stress events apply to the system, firms and households constrained from their preferences to increase the net value and the disposable income respectively, are assessed by our model operation whether they are able to serve their loan obligations. Once firms and households are unable to provide loan payments for multiple periods

denote their cost equal to the level of wages

[5]See Chapter 3, for the detailed model specification of the government's (G_{i}) main transactions, which denote the price stability, the economic activity and the indebtedness of the economy

[6]Firms use their $profits_{\mathrm{ij}}$ for offering funds to the bank and households, use the wage as the main source of income for consumption and saving through a deposit account.

(not necessary sequential), it is then captured by the banks' system specification namely the non-performing loans ($NPLs$).[7]

Banks

Banks offer credit to households and firms through loans when the solvency of these agents is sufficient based on the wealth denoted by the net value and disposable income respectively (see for example Jiang 2007). Beyond loans to households and firms, banks also hold cash and government securities while they receive deposits. Banks are heterogeneous in terms of their balance sheets and may run out of liquidity if firms and households do not serve their loans, or subtract substantial amounts of deposits which comprise one of the main sources of funding banks receive. Banks' (L_{ij}) funding position is assessed with the use of the LCR (4.5), which illustrates the ability of banks to use their inflows in order to back and fund potential outflows such as deposits withdrawals over a period of 30-days.[8]

$$LCR(ij) = \frac{LiquidAssets_{\mathrm{ij}}}{NetOutflows_{\mathrm{ij}}} \geq 1 \tag{4.5}$$

For the scope of our analysis, we follow a stylised balance sheet format that requires the assets side to be greater or equal to the liabilities, so in case of substantial bank runs, banks should be prepared to meet their obligations and losses. This stylised balance sheet analysis does not make use of banks' equity as Basel III LCR measure, does not entail equity on its specification, while the Regulatory framework does not count for liquidity risk capital requirements.

4.3.2 Model Operation

The model acts for a finite number of periods. At $T = 0$, the models starts operating under the baseline scenario which means the current state of the economy before

[7] NPLs mechanism is analytically presented in Chapter 3 Section 3.3.6 Baseline Scenario process

[8] As also defined in Chapter 3, the regulatory framework requires banks' LCR to be greater or equal to 1, however we follow the most recent LCR technical summary which indicates a threshold varying between 60% and 80% for those banks which have not yet fully implemented this liquidity measure (BIS, 2013a)

introducing the macroeconomic shocks. In the baseline state, households and firms choose the respective bank to receive credit and place their savings through the deposits account.[9] Banks assess agents' credibility and proceed with the loan supply. Under adverse economic conditions, banks react to these conditions, which also affect the other agents' decisions, by developing adjusted liquidity channels.[10]

According to (4.6) and (4.7), firms and households are eligible borrowers if the net value and the disposable income are greater than or equal to zero. In other words, in order to set up a loan contract with banks, firms' and households' total revenues should be greater or equal to the total expenses these agents face at each time step.

$$Firm_{\text{ij}} = \begin{cases} good \quad debtor, & \text{if } NV_{\text{ij}} \geq f(NV_{\text{ij}}) \\ bad \quad debtor, & \text{otherwise} \end{cases} \tag{4.6}$$

$$Household_{\text{ij}} = \begin{cases} good \quad debtor, & \text{if } Y_{\text{ij}} \geq g(Y_{\text{ij}}) \\ bad \quad debtor, & \text{otherwise} \end{cases} \tag{4.7}$$

in turn banks' funding position is adjusted by 4.8 and 4.9 actions and the economy's performance. The ability of firms and households to serve the loan payments, increases banks' cash and equivalent account and in turn the liquid assets. When firms and households are unable to serve their loan obligations for multiple periods (not necessary sequential), then banks activate the $NPLs$ account for recording the non-performing payments ($\text{loan}_{\text{interest}}$) which are subtracted from the initial value of the loan ($\text{loan}_{\text{principal}}$).[11]

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[9] Based on the market competition assumption, banks maintain similar levels for the interest rates they offer. This leads households and firms to select randomly a bank for setting up lending and saving transactions.

[10] See Chapter 3, Stress Scenario section, which explains how the stress events and shocks have been specified.

[11] For further details on the NPLS mechanism and how banks' losses are estimated due to firms and households inability to serve their loans, see Chapter 3, Section 3.3.6

$$Firm_{\text{ij}} \rightarrow Bank_{\text{ij}} \begin{cases} cash\&equivalent_{\text{ij}T} = cash\&equivalent_{\text{ij}T-1} + loan_{\text{installment}}, & \text{if } cash_{\text{ij}} > c_{\text{ij}} \\ cash\&equivalent_{\text{ij}T} = cash\&equivalent_{\text{ij}T-1} + loan_{\text{installment}}, & \text{if } cash_{\text{ij}} = c_{\text{ij}} \\ cash\&equivalent_{\text{ij}T} = cash\&equivalent_{\text{ij}T-1} + 0, & \text{if } cash_{\text{ij}} < c_{\text{ij}} \end{cases} \tag{4.8}$$

$$Household_{\text{ij}} \rightarrow Bank_{\text{ij}} \begin{cases} cash\&equivalent_{\text{ij}T} = cash\&equivalent_{\text{ij}T-1} + loan_{\text{installment}}, & \text{if } w_{\text{ij}} > cs \\ cash\&equivalent_{\text{ij}T} = cash\&equivalent_{\text{ij}T-1} + loan_{\text{installment}}, & \text{if } w_{\text{ij}} = cs \\ cash\&equivalent_{\text{ij}T} = cash\&equivalent_{\text{ij}T-1} + 0, & \text{if } w_{\text{ij}} < cs_{\text{ij}} \end{cases} \tag{4.9}$$

In parallel with the loan supply process, banks accept firms' and households' savings through deposits account, which comprise the key source of funding for banks. Firms and households constrained by the level of labour costs (c_{ij}) and consumption (cs_{ij}) respectively, place their savings through deposits and receive a return equals to deposit rate (r_{deposit}). Firms' and households' level of expenditure in labour and consumption respectively, not only bind banks liquid assets account but also the amount of inflows banks receive through deposits. Equations 4.10 and 4.11, explain firms' and households' decisions for saving or not, where banks' should be able to react accordingly and maintain the LCR_{ij} above the critical value of 70%.

$$Firm_{\text{ij}} \rightarrow Bank_{\text{ij}} \begin{cases} {d^f}_{\text{ij}T} = {d^f}_{\text{ij}inflows} * (1 - r_{deposit}), & \text{if } cash_{\text{ij}} > c_{\text{ij}} \\ {d^f}_{\text{ij}T} = {d^f}_{\text{ij}T-1} - {d^f}_{\text{ij}outflows}, & \text{if } cash_{\text{ij}} = c_{\text{ij}} \\ {d^f}_{\text{ij}T} \rightarrow 0, & \text{if } cash_{\text{ij}} < c_{\text{ij}} \end{cases} \tag{4.10}$$

$$Household_{\text{ij}} \rightarrow Bank_{\text{ij}} \begin{cases} {d^h}_{\text{ij}T} = {d^h}_{\text{ij}inflows} * (1 - r_{deposit}), & \text{if } w_{\text{ij}} > cs_{\text{ij}} \\ {d^h}_{\text{ij}T} = {d^h}_{\text{ij}T-1} - {d^h}_{\text{ij}outflows}, & \text{if } w_{\text{ij}} = cs_{\text{ij}} \\ {d^h}_{\text{ij}T} \rightarrow 0, & \text{if } w_{\text{ij}} < cs_{\text{ij}} \end{cases} \tag{4.11}$$

In the next section (4.3.2.1) we will discuss banks' response to firms and households decisions as well as to the adverse economic conditions which restrict the agents activity and in turn shrink banks' funding position.

4.3.2.1 Banks Feedback Actions through Adjusted Liquidity Channels

At each time step banks aim to maximise the expected return arising from the transactions with other agents subject to $E(LCR_{\text{ij}})$ constraint. The LCR for banks is calculated at each period T in order to capture the dynamic evolution of banks' funding position and the ability of adjusted channels to recover liquidity and the decisions developed, binding by firms and households decisions and actions when adverse economic conditions are applied. When shocks are applied, banks activate the adjusted liquidity channels, through multiple feedback processes which are iterated simultaneously.

In response to macroeconomic fluctuations and agents' decisions to serve their loan obligations and provide their funds through deposit inflows, banks develop two main adjusted channels in order to meet their liquid needs. The purpose of these two channels, is to provide multiple feedback processes and assess whether these recovery plans, lead banks to meet their initial funding state.[12]

Compared to Chapter 3 model process, we now develop a novel mechanism which through the development of parallel feedback processes, investigates whether banks' recovery responses assist banks to sustain the expected return of the LCR_{ij} close to

[12]In order to develop the stress scenario, we assume the largest percentage change of the macro prudential components and apply a Monte Carlo simulation to these for producing the parameters which describe the volume of the shocks. For further details on the Monte Carlo simulation and the volume of shocks, see Chapter 3, Section 3.3.6.1

70% threshold as required by regulatory authorities. This mechanism reveals banks' ability to absorb outflows through liquidity buffers and to recover the liquid assets through the increase of high liquid assets and the restriction of lending supply. Also, this analysis provides a great insight on banks' business model.

For this scope we initially classify banks into liquid and illiquid. Banks are classified as liquid when they are able to back the amount of inflows they receive through the deposits funds and cover outflows arising from firms and households deposits withdrawals. Banks' flows (4.12) are calculated as the difference of the deposits inflows between current and previous period $T-1$, arising from the transactions with N firms and households.

$$Bank_{\mathrm{ij}_{netflows}} = \sum_{N=1}^{N} ({d^f}_{\mathrm{ij}_T} + {d^h}_{\mathrm{ij}_T}) - \sum_{N=1}^{N} ({d^f}_{\mathrm{ij}_{T-1}} + {d^h}_{\mathrm{ij}_{T-1}}) \tag{4.12}$$

Once the amount of net-flows is calculated, banks are then classified into liquid and illiquid based on the total amount of cash they hold and the amount of flows they receive at each time step (4.13). Banks constrained by the insurance they should provide to firms and households deposits (Anginer et al. 2012), are in turn forced to maintain an adequate amount of cash and funds for covering potential outflows, when facing bank runs. For this scope banks create buffers for covering potential outflows.

$$Bank_{\mathrm{ij}} \begin{cases} Liquid, & \text{if } cash\&equivalent_{\mathrm{ij}_T} + inflows_{\mathrm{ij}_T} > 0 \\ Illiquid, & otherwise \end{cases} \tag{4.13}$$

Liquid Banks Feedback Actions

For liquid banks, we then assess the amount of inflows or outflows they face, at each time step T (4.14). When $netflows_{\mathrm{ij}_T} > 0$, banks subtract an amount of these flows for creating liquidity buffers in order to cover potential bank runs. Banks hold a proportion of the total flows they hold based on the deposit coverage rate (Demirgüç-

Kunt et al. 2014).[13] When net-flows become negative ($netflows_{ij_T} < 0$), banks add these liquidity buffer to cover further outflows arising from the transactions with firms and households.

$$LiquidBank_{ij_T} \begin{cases} cash\&equivalent_{ij_T} - d_{coverage} * buffer_{ij_T}, & \text{if } netflows_{ij_T} > 0 \\ cash\&equivalent_{ij_T} + d_{coverage} * buffer_{ij_T}, & \text{if } netflows_{ij_T} < 0 \end{cases} \tag{4.14}$$

In parallel, liquid banks constrained by the regulation which requires LCR to be above a 70% threshold, decide to invest in safe and high liquid assets to increase LCR return. For this scope, banks invest in government securities (GS_{ij}) which comprise high quality liquid assets (HQLA). When banks debit their assets with government debt securities a cost is arising which equals to the risk free rate (r_f). Based on the amount of flows banks receive at each time step ($netflows_{ij_T}$), in order to meet the LCR threshold, they decide the amount of government securities they need to add to their HQLA account (4.15).

$$GS_{ij_T} = GS_{ij_{T-1}} + \mid netflows_{ij_{T-1}} \mid \tag{4.15}$$

Illiquid Banks Feedback Actions

When banks are classified as illiquid, they proceed to other strategies, in order to avoid further deterioration of their funding position. The first strategy consists on the restriction in lending policy by increasing the credit spread in the transactions with firms and households. Banks apply a higher interest rate ($r_{loan_{new}} > r_{loan}$) to firms and households loans while in parallel a slight increase on the deposit rate is also set, $r_{deposit_{new}} > r_{deposit}$.[14]

Simultaneously to the credit spreads increase, in order banks to ensure that the amount of available funding is able to cover substantial outflows, they proceed to

[13] The proportion of flows, banks hold is specified by $d_{coverage}$ as this developed in Demirgüç-Kunt et al. (2014) study.

[14] The transactions with firms and households follow the same process as discussed above

asset sales. Banks sell-off the more liquid assets they hold, such as the government securities. When proceeding to these asset sales, the price impact is also calculated based on the value of the assets sold. In particular, the value banks receive from selling-off government securities (GS_{ij}), is the market value of these securities when a haircut is applied. Banks receive through their cash&equivalent account, the amount arising from the asset sales process. For evaluating the amount banks receive from asset sales action, we also incorporate the respective Government credit profile for applying a more realistic haircut and price impact. The estimation of each government credit profile arises from each country's GDP_{i} performance at each time step.

$$cash\&equivalent_{\text{ij}T} \begin{cases} cash\&equivalent_{\text{ij}T-1} + (GS_{\text{ij}} * alpha * (1 - PD_{\text{Low}})), \text{ if } GDP^i_T > GDP^i_{T-1} \\ cash\&equivalent_{\text{ij}T-1} + (GS_{\text{ij}} * alpha * (1 - PD_{\text{High}})), \text{ if } GDP^i_T < GDP^i_{T-1} \end{cases} \tag{4.16}$$

The above equation (4.16) illustrates banks available funds change when proceeding to assets monetisation. Through this adjusted liquidity channel, banks cash & equivalent account increases, in order to face and cover substantial outflows. The price impact from these asset sales, is a function of the government securities initial value when subtracting the amount of haircut ($1 - alpha$). In parallel, in order to incorporate the economy's conditions (see for example Duffie et al. 2007) a risk premium is also considered. the risk premium is based on the respective government performance. Once the GDP_{ij} of the respective Government increases, the risk premium decreases as a low probability of default is applied.

In the following section, we discuss the findings of the above process by providing an analysis on the LCR expected value under the baseline and stressed conditions, when the multiple feedback processes are applied. A comparative analysis between the findings of this model operation and this developed in Chapter 3. The LCR evolution during the different economic states. Also, banks' responses to firms and households decisions as well as a comparison between large and small banks business models when acting under adverse economic conditions.

4.4 Results

In this section we present the results of the model process described above. The agent based process develops multiple feedback mechanisms and investigates whether adjusted liquidity channels assist banks to recover their funding position. In particular we examine the ability of adjusted liquidity channels to mitigate the liquidity shortages arising from systemic liquidity risk. Also, our findings indicate whether banks are able to sustain the expected value of the LCR close to the 70% threshold even under adverse economic conditions. Our unified stress test comprises a useful tool for macroprudential surveillance and supervisory engagement, as it includes banks' responses through multiple feedback processes for capturing second round effects arising in the funding position of these banks.

This framework sheds light on the interrelation between the macro and the micro side of the economy and the importance to incorporate second round effects analysis when counting for system wide stress tests. Specifically, our findings provide evidence on banks' reactions under stress conditions with the LCR evolution over the time as well as banks' business models when trying to recover from substantial liquidity shortages they face at each time step.

Complementary to the above findings we compare our results with these of Chapter 3 in order to investigate the LCR expected value and its evolution under the baseline and the stressed scenarios. This comparative analysis uncovers significant evidence for the current stress test regime, as it investigates the system dynamics' changes, when multiple feedback processes are applied. Furthermore, we observe how real sector agents' interrelations reveal the key macro-financial linkages which lead funding liquidity risk to transform from systemic to pro-cyclical risk. In particular, we investigate whether banks through the adjusted liquidity channels, are able to improve their funding position and meet the LCR 70% threshold even under adverse economic conditions .

Whilst banks in parallel with the loans supply restrictions, try to act prudently and increase their liquid assets by investing in low risk securities, their actions and business models continue uncovering excessive risk taking. Specifically, an analysis we provide below between the large and the small banks included in our sample, highlights that small banks tend to accept funds through deposit inflows. These banks are unable to cover these inflows when turning into outflows and their funding position further deteriorates in the distress period.

We also estimate real sector agents contribution to liquidity risk pro-cyclicality. We quantify the volume of loan payments arising from the transactions with households and firms. Additionally, the volume of inflows and outflows through the deposits transactions, is also estimated at each time step.

The existence of systemic liquidity risk leads to funding risk pro-cyclicality, while the size of banks, contributes to prevent from further liquidity deterioration. In parallel, by developing the adjusted liquidity channels and restrict the loan supply, banks affect real sector agents' behaviour. Households and firms under adverse conditions are unable to serve their loan obligations and provide loan payments to banks due to the increase on credit spreads.

Our model is calibrated with banks' balance sheet data and macroeconomic indicators, while the analysis is applied on 30 systemically important banks located in Cyprus, Greece, Italy, Portugal and Spain.[15]

4.4.1 LCR under baseline and stressed scenarios when feedback processes are activated

Table 4.1 provides the expected value of the LCR, on country level, under the baseline and the stressed scenario. Similarly to Chapter 3 our process operates for a finite number of steps ($T = 1, ..., 10$) and the stress scenario is implemented from $T = 2$ and onwards, where the shocks are applied and evolve for the next periods

[15]The dataset used for the model calibration is this also used and discussed in Chapter 3. The economy and the agents initially operate under the baseline scenario, while at $T = 2$, a series of shocks arise endogenously and evolve through a stochastic process. From $T = 2$ and onwards our system operates under stress

Table 4.1: Expected Value of the LCR under baseline and stressed scenarios

Country	**Banks**	**Baseline**	**Stressed**
Cyprus	2	79.00	59.00
Greece	6	86.10	65.60
Italy	13	102.50	68.00
Portugal	3	57.00	56.00
Spain	6	128.40	85.30

Table 4.1 provides the expected value of the LCR under the baseline and the stressed scenarios. The LCR is shown in percentage points and is displayed on a country level - calculated as the mean of the values for all banks in each country. The medians were also calculated, not shown, and follow a similar pattern.

$(T = 2, ...10)$.[16]

From Table 4.1, we initially observe that under the baseline state, all banks in our sample have sufficient liquid assets to cover potential outflows.[17] Similarly, to our findings in Chapter 3, an exemption to this, is Portugal. Even under the baseline state, Portuguese banks indicate LCR below the critical value of 70%. Portugal has been facing several occurrences of a banking crisis, leading to "boom-bust" and "capital-flow bonanza" cycles (Borio and Zhu, 2012; Reinhart and Rogoff, 2009). Beyond this banking crisis, the activation of the multiple feedback processes also indicates that Portuguese banks do not act prudently. Particularly, Portuguese banks continue accepting funding through households and firms deposits, without being able to back the volume of these inflows. These banks, where their behaviour and actions are discussed in details in Section 4.4.3, are not able to create liquidity buffers for covering potential outflows. Thus, even under the baseline state Portuguese banking system indicates LCR expected value equal to 57%, in other words 13% below the required threshold.

Moving to the stressed state of the economy, the results display that for all

[16] In order to define the scenarios for the macroeconomic variables, we use annual historical observation from 1980-2017 and we apply a Monte Carlo simulation to calculate the volume of shocks. During the 1980-2017 period we observe that the peaks of the economy are stronger and more persistent compared to the crisis periods, such as the financial crisis period of 2008-2010.

[17] LCR on country level is the average of individual banks' LCR located in the respective country

countries LCR expected value during the stress period, is below 70% threshold, confirming the former analysis performed (see Chapter 3)which indicates a strong nexus between the macroeconomy and the funding position of banks. As it has been also highlighted in Chapter 3, the expected value of LCR measure is sensitive and strongly linked to the macroeconomic fluctuations.

Despite the sensitivity of the LCR to adverse economic events, the activation of multiple feedback processes with the use of adjusted liquidity channels assist in maintaining sufficient levels of liquidity. In Chapter 3, Spanish banks under the stress scenario, indicate that LCR expected value equals 45.35%. By incorporating the feedback mechanism application, our findings display that LCR expected value for Spain is 85.3%. Spanish banking system incorporates banks with strong participation in the international markets (Trujillo-Ponce, 2013) . This strong market presence of Spanish banks combined with the adjusted liquidity channels, sustains LCR expected value above the threshold even under adverse economic conditions. Thus, the multiple feedback process mitigates the economic fluctuations and allows banks to sustain sufficient levels of funding liquidity.

Furthermore, Table 4.1 provides evidence on the adjusted liquidity channels ability to decrease LCR expected value variation between the baseline and the stress scenario. Particularly, in Chapter 3 key findings, we observe that Cyprus and Greece display substantial differences in the LCR expected value between the baseline and stressed conditions. Cypriot banks face shortfall equal to 155.5% when they move from the baseline to the stress economic state, while Greek banks' LCR expected value decrease reaches up to 110%. However, when the multiple feedback process is applied and the adjusted liquidity channels are activated we observe that LCR shortfall for Cypriot and Greek banks is 20% and 20.5% respectively.

These findings indicate the need to incorporate multiple feedback processes in macro prudential liquidity stress tests. The activation of banks responses through these multiple feedback mechanisms and the use of adjusted liquidity channels, indicate that banks face significant shortfalls in their funding position when adverse economic conditions are applied. However, the dispersion of the LCR expected value between the baseline and the stressed scenario has decreased compared to the results arising from our stress test model developed in Chapter 3.

The adjusted liquidity channels assist banks to prevent their funding position from deterioration. Nevertheless, as most banks are not able to meet the LCR 70% threshold, in the next section we will analyse the evolution of banks' funding position to assess whether pro-cyclical behaviour arises. The use of computational agent-based model underlines the dynamic treatment capability of these models, which captures the key characteristics of an economy and provides the interconnectedness of dynamic systems such as this of banking and the economic one. Also, the ability of ABM to carry out and iterate parallel actions captures the complexity of the financial system and uncovers valuable information on banks' characteristics and business models, necessary for macro prudential surveillance and supervisory engagement.

4.4.2 LCR evolution and Pro-cyclical behaviour

This section analyses the evolution of the LCR on country level at each time period T and the banks' decision to activate the adjusted liquidity channels. At $T = 1$, the LCR indicates the funding position of banks when acting under the baseline scenario, while at $T = 2$, banks react to the macroeconomic shocks implemented in the economy. The baseline scenario has as input the current values of banks, firms, households and the government as these specified from our dataset.

Our analysis differs from this of Chapter 3. Apart from firms and household decisions and transactions, which led by the macroeconomic fluctuations affect the expected value of the LCR at each time step, we now take into account banks' responses. In particular, by developing a multiple feedback process we also incorporate banks' reactions which also define the ability to serve their liquid needs under adverse economic conditions.

Figure 4.1: Liquidity Coverage Ratio procyclical behaviour under adverse economic scenarios

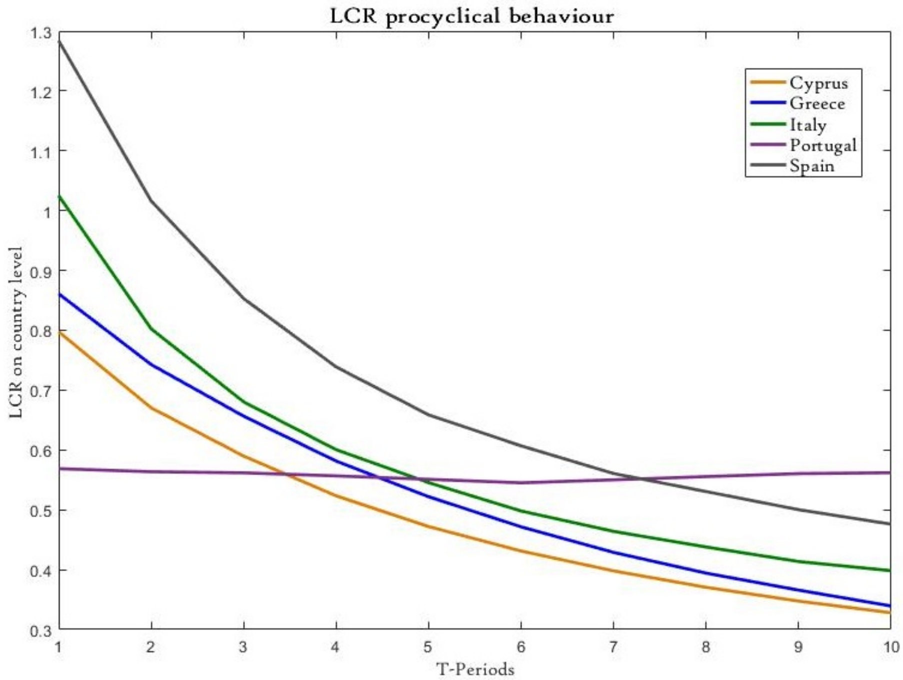


Figure 4.1 illustrates the LCR evolution and the procyclical behaviour funding liquidity risk develops in the distress period. This figure provides the LCR evolution from $T = 1$ to $T = 10$. We observe country level LCR for Southern European banks starting with the baseline state at $T = 1$, following the macro economic shocks' implementation at $T = 2$ and continuing with the stress conditions from $T = 3$ to $T = 10$.

A comparison across banks' liquidity performance highlights that during the baseline scenario ($T = 1$) the LCR varies from 130.0% to 57.0%. Southern European banks indicate sufficient liquidity levels. In particular, at $T = 1$ Cyprus, Greece Italy and Spain meet the liquidity requirements imposed by Basel III regulatory framework, as the LCR expected value equals to 79%, 86.1%, 102.5% and 128.4% respectively. However, as discussed in section 4.4.1 an exemption to this is Portugal. Portugal is not binding from the liquidity regulatory requirements as the LCR expected value is below the critical threshold and equals 57%. As stated in Chapter 3, this behaviour can be explained by the risk profile Portuguese banks indicate in the pre-crisis period. In addition, LCR expected value for Portuguese banks, consists on the limited size of the banking system which leads to risk concentration. As long as the amount of banks located in an economy decreases, risk concentration increases (Boyd and De Nicolo, 2005; Boyd et al., 2009).

At $T = 2$ macroeconomic shocks are applied and indicate the immediate reaction in the expected value of the LCR across all countries. Similarly to Chapter 3 findings, when the macroeconomic shocks are applied, we observe simultaneous shortfalls of the LCR expected value, which highlight the strong nexus between the macro and the funding position of banks as well as the existence of systemic liquidity risk. However, the current analysis indicate that LCR expected value decrease is greater than this of the previous Chapter. In particular, in Chapter 3 the LCR shortfall at $T = 2$ reaches up to 20%. However, the application of multiple feedback processes, flags larger decrease up to 40%. The difference between Chapter 3 and the current analysis findings, explains the ability of feedback mechanism to act as early warning process and Southern European banks to be responsive to the macroeconomic fluctuations. Banks immediate reaction, uncovers the need to incorporate banks' responses under a dynamic stress test framework, in order stress tests to address their scope and act as early warning models.

Figure 4.1 also displays the evolution of the LCR expected value over the time, from $T = 1$ to $T = 10$. Compared to the respective figure provided in Chapter 3 (Figure 3.1), we now observe that the evolution of the LCR expected value is non linear. In Chapter 3, a steep decrease of the LCR at $T = 4$ signals the existence of systemic liquidity risk as all banks in our system face substantial liquidity shortfalls at the same time, however the current analysis results differentiates. Despite all banks face their greatest shortfalls at $T = 4$, the behaviour of the LCR over the time indicates a smoother non-linear decrease. This behaviour explains that the implementation of the feedback processes incorporating banks' responses, improves the LCR expected value even during the distressed period.

Specifically, our results show that at $T = 4$, all banks in our system go below the 70% threshold. However, in the current process at $T = 4$, banks withstand to macroeconomic shocks and the expected value of LCR is close to 60%, 10p.p. below the threshold. For instance, in Chapter 3, at $T = 4$, Portugal LCR expected value is 29% indicating a liquidity shortfall equal to 36.79%, in the current analysis Portuguese banks' LCR expected value is 56%. This difference is explained by the application of the adjustment liquidity channels, banks activate in order to tackle the systemic aspects of liquidity risk. Similar albeit applies to the rest of countries included in our analysis.

Whilst at $T = 4$, Chapter 3 key findings indicate that all banks are unable to meet their liquid needs due to systemic liquidity risk, the current process captures the effect of systemic liquidity risk but also indicates the ability of the adjusted liquidity channels to face these systemic shortages. Our model results, indicate that when $T = 4$, Spain faces its greatest liquidity reduction equal to 40%. During this stress period the LCR expected value for Spanish banks just meets the threshold of 70%. The reason why the LCR expected value for Spain is close to 70%, is the activation of the adjusted liquidity channels. Banks responses with the use of adjusted liquidity channels combined with a banking system with strong participation in the international markets (Trujillo-Ponce, 2013), indicate the ability of these banks to leverage funding and monitor their activities in order to meet the liquidity requirements. In parallel the application of the feedback processes and banks' classification between liquid and illiquid can reveal which banks are able to continue financing their activities without facing liquidity constrains. However, the significant decrease of the LCR is evident in the nexus between funding liquidity risk and macroeconomic environment.

Moving to the next periods (from $T = 5$ to $T = 10$) we observe that all banks' LCR expected value continues to decrease. This behaviour explains that the existence of systemic liquidity risk leads to funding risk procyclicality. The adjusted liquidity channels assist banks to sustain their funding position but the stochastic evolution of the macroeconomic fluctuations combined with the existence of systemic liquidity risk, uncovers funding liquidity risk procyclical behaviour. LCR expected value displays a continuous decreasing behaviour which does not allow banks to recover and meet the liquidity requirements. Thus, banks' simultaneous liquidity shortages combined with the continuous decrease of the LCR, highlights that funding risk is procyclical to macroeconomic fluctuations and under these adverse economic conditions, banks are unable to meet the regulatory liquidity threshold.

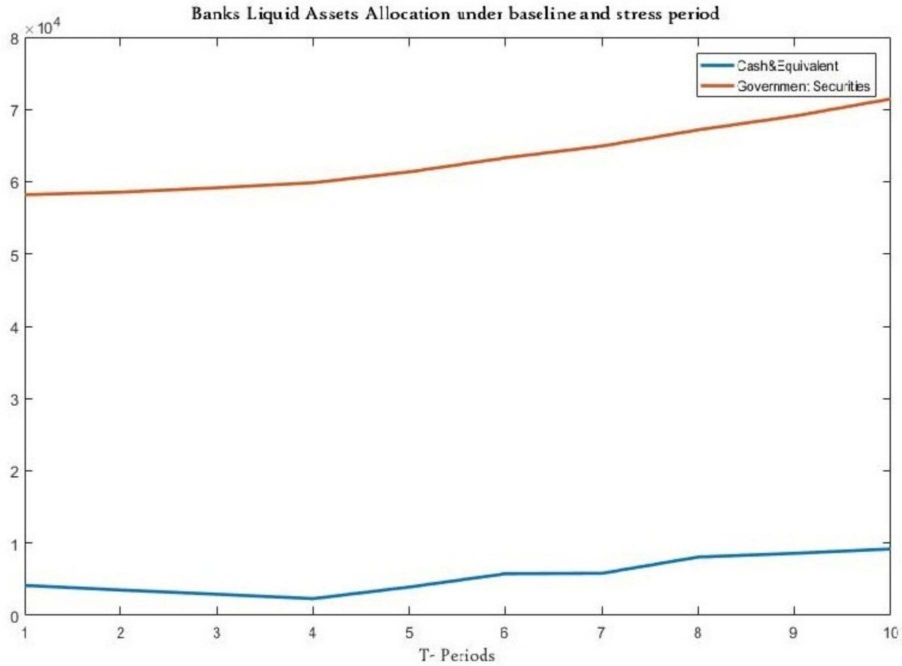
The LCR pro-cyclical behaviour can be further explained from the findings in Chapter 3. Specifically, Figure 3.1 in Chapter 3 indicates a persistent behaviour of the LCR during the distressed period ($T = 5$ to $T = 10$). Once banks faced the largest liquidity shortfalls, the expected value of the LCR remains at the same level, which flags that funding liquidity risk evolution over the business cycle and the macroeconomic fluctuations should be further examined. Therefore, the application of banks' responses through the multiple feedback processes, explains this LCR persistence and reveals the pro-cyclical behaviour funding liquidity risk develops in the distress period.

Whilst, banks try to sustain their funding position and in turn the expected return of the LCR with the activation of the adjusted liquidity channels, the existence of systemic liquidity risk effect reveals funding risk pro-cyclicality. Banks' simultaneous liquidity shortages combined with the continuous decrease of the LCR, highlights that funding risk is pro cyclical to macroeconomic fluctuations and under these adverse economic conditions, banks are unable to recover their positions. However, LCR evolution explains banks' efforts to maintain their funding position above or close to the regulatory liquidity requirements, for longer than one period of stress. To this point, the adjusted liquidity channels and the application of the multiple feedback processes, assist banks to improve their liquid assets position either by increasing the amount of cash they hold or by adapting to the "fly to quality" behaviour (Caballero and Krishnamurthy, 2008) and invest in high liquid assets, such as the government securities.

To this point Figure 4.2, provides further evidence to the above analysis, as we present banks actions to sustain their liquid assets and be able to meet potential outflows. Figure 4.2 displays banks liquid assets' allocation and their evolution over the time including the distress period (from $T = 2$ to $T = 10$). We initially observe that Southern European banks hold a substantial amount of government securities compared to the amount of cash&equivalent. On the one side the assets allocation explain that banks act prudently and invest in safe assets which can be quickly monetised when fire sales process is activated. Thus, we see that banks invest in government securities which are considered to be safe assets which can be easily liquidate at the minimum price impact (Gorton and Ordonez, 2013).

On the other side, the low volume of cash&equivalent, explains firms and households inability to serve the loan payments. Real sector agents, binding from their constraints to maximise their net value and income respectively, do not serve their loan obligations. As also highlighted in Chapter 3, firms and households inability to repay their loans lead to substantial liquidity shortfalls in banks' funding position.[18]

Figure 4.2: Banks' cash & equivalent and government securities evolution under baseline and stress scenario measured across all banks included in our sample



The evolution of banks assets indicate a slight decrease during the first periods of stress, from $T = 2$ to $T = 4$, flagging the existence of systemic liquidity risk and

[18]Section 4.4.4, discusses in details the effects on banks' liquid assets arising from the transaction with firms and households

explaining the increased volume of LCR shortfalls. In the distress period, from $T = 5$ to $T = 10$, there is a small rise for both government securities and cash&equivalent, though. Particularly, cash&equivalent governments securities banks hold, increase by 2.52% and 28.2% respectively. This increase uncovers that despite the adverse economic conditions and the effects of systemic liquidity risk, the adjusted liquidity channels activation even slightly assist banks to increase their liquid assets. However, as banks funding position does not recover and continuous decreases, it is evident that funding liquidity risk is pro-cyclical to the macroeconomic fluctuations. Thus, funding liquidity risk pro-cyclical behaviour does not allow banks to reach in their initial state even they develop strong responses towards economic stress.

These findings highlight the importance of implementing feedback processes and investigating banks' reaction as they reveal valuable information on financial risks' behaviour. in particular, by developing a dynamic model where banks interact with firms and households and activate adjusted liquidity channels as responses to macroeconomic stress, we contribute to the scenario analysis stress tests. We develop an analytical top down framework which counts for dynamic wide stress test. Our model captures the dynamic of the model process developed in Chapter 3, but it also uncovers more dynamics as the multiple feedback processes provide evidence beyond the existence of systemic liquidity risk. The LCR continues decrease at a non-linear pace explains LCR pro cyclical behaviour.

4.4.3 Large and Small banks LCR expected value and Liquid Assets holdings under the baseline and stressed scenarios

This section provides a comparative analysis between the largest and smallest banks[19] for Cyprus, Greece, Italy, Portugal and Spain. This analysis sheds light on banks' behaviour and ability to continue meeting the LCR requirement even under adverse

[19] The size of banks is specified by the total assets holding during the baseline periodas well as their liquidity profile

macroeconomic events. Additionally, a scrutiny on banks' responses through the adjusted liquidity channels and their business models specification is also discussed. Banks with substantial amounts of liquid assets resist economic recessions as they are able to continue meeting the LCR requirement even they face reductions in their funding position, while banks with weak liquidity profile cannot serve their liquid needs and continue acting below the threshold.

Table 4.2 displays individual banks' LCR under both the baseline and the stressed scenario. Banks funding position is led by the macroeconomic shocks and indicate a strong inter linkage between the economy and the liquidity risk. These results display that LCR has a decreasing trend since the macroeconomic shocks are applied. The percentage change of the LCR ranges from 0.14% to 40% , while Italian banks face the largest shortfall during the stress scenario (from 189.5% to 118.2% for Iccrea Bank and from 58.2% to 34.4% for Banca Carige). The drop of Italian banks funding position, reveals the sensitivity to macroeconomic fluctuations (Klusak et al. 2017 and Balassone et al. 2018). However, the size of the bank combined with the size of the system of banks in Italy (13 banks in total), assists large banks to keep the LCR above the threshold, as the liquidity risk concentration reduces (Cerrone et al., 2017) .

Additionally, from the LCR results we observe that small banks face greater liquidity shortages comparing to the large ones. Large banks which hold a greater amount of liquid assets are able to sustain the LCR requirement even after the implementation of macroeconomic shocks. Large banks liquidity adjusted channels, support their ability to serve their liquid needs while these banks based on the substantial amount of assets they hold, they handle the inflows and outflows facing at each time step.

Small banks in contrast, are below the 70% LCR threshold and even when adjusted responses are activated, these banks are unable to recover or maintain their funding position. In Greece and Portugal, where the banking system has been shrinking (Greenwood et al. 2015), Attica bank and Caixa level of LCR does not meet the regulatory requirements even during the baseline scenario. To this point,

Table 4.2: Large vs Small Banks Liquidity Coverage Ratio

T-period	Large Banks Liquidity Coverage Ratio				
T-periods	Bank of Cyprus	National Bank Greece	Iccrea	Banco BPI	Santader
Baseline to Shock Implementation	100.7	131.4	189.5	102.0	381.6
1st period of Stress	87.5	116.6	118.2	99.8	267.0
2nd period of Stress	78.2	103.3	90.8	99.5	205.0
3rd period of Stress	70.0	89.3	81.7	98.88	166.0
4th period of Stress	63.5	78.0	71.5	98.09	146.9
5th period of Stress	58.07	68.95	59.61	97.17	133.78
T-period	Small Banks Liquidity Coverage Ratio				
T-periods	Hellenic Public Cyrus	Attica Bank	Banca Carige	Caixa	MPCA
Baseline to Shock Implementation	58.9	32.9	58.2	16.2	12.6
1st period of Stress	46.5	18.4	34.4	15.0	10.8
2nd period of Stress	39.7	12.4	24.1	14.9	9.8
3rd period of Stress	34.6	9.2	18.5	14.0	9.2
4th period of Stress	30.9	7.3	15.0	13.1	8.8
5th period of Stress	28.2	6.1	12.6	12.2	8.5

Table 4.2 provides the funding position of the largest and smallest banks for each country during baseline and stressed periods.

the limited economic activity, these countries face , is shrinking dramatically the corporate performance (Braguinsky et al., 2011), which leads the small size banks to under perform (Mercieca et al., 2007).

The LCR findings for large and small banks, highlight that liquidity adjusted channels contribute to large banks responses for meeting the regulatory liquidity requirements, as even under stress macroeconomic conditions, LCR of large banks is above the 70% threshold. In parallel, the LCR behaviour for small banks, highlight that by continuing accepting flows, these banks increase the probability to become unable for covering flows when these are on demand.

In response to the above findings, Tables 4.3 and 4.4, provide further evidence on LCR behaviour, through banks' actions for recovering cash & equivalent as well as investing in HQLA such as the government securities. In addition, these findings assist on drawing remarks for banks' size and how affects their decisions and in turn their business models for sustaining or recovering their funding position.

From Table 4.3, we observe the percentage change of cash & equivalent for the large and small banks, for each country included in our sample. Cash & equivalent evolution, highlight the ability of large banks to make use of the adjusted liquidity channels and be able to slightly increase the amount of cash even under adverse economic situations. To this point small banks continue facing substantial reductions in their cash position, which they are unable to recover.

Despite, the ability of large banks to increase their cash & equivalent, National bank of Greece (NBG) comprises an exception to this. NBG even holds a satisfying amount of liquid assets and meets the regulatory requirements, displays a decrease on the amount of cash as long as the economic recession continues. The inability of NBG to increase the amount of cash is an outcome of the bailout programmes imposed and the failure to apply the required structural reforms which led to suboptimal banks behaviour (Christodoulakis 2016 and Ardagna and Caselli 2014).

As oppose to NBG, Attica bank during $T = 2$ seems that recovers a small amount of cash and combined with the government securities continuous decrease, this bank

Table 4.3: Large vs Small Banks Cash & Equivalent

T-period	Large Banks Cash & Equivalent changes during baseline and stressed period				
T-periods	Bank of Cyprus	National Bank Greece	Iccrea	Banco BPI	Santader
Baseline to Shock Implementation	-3.42	-18.58	1.82	-20.39	-39.37
1st period of Stress	-0.39	-16.54	-3.39	-27.97	-66.01
2nd period of Stress	2.10	-21.48	-47.81	-41.82	-195.81
3rd period of Stress	4.35	-17.95	35.24	-76.56	-100.82
4th period of Stress	6.22	-12.42	2.86	-344.91	130.42
5th period of Stress	7.66	-5.23	7.76	147.19	-156.96
T-period	Small Banks Cash & Equivalent changes during baseline and stressed period				
T-periods	Hellenic Public Cyrus	Attica Bank	Banca Carige	Caixa	MPCA
Baseline to Shock Implementation	-18.63	-613.11	-6.47	-5.98	-4.48
1st period of Stress	-23.62	85.35	-4.27	-6.38	-5.04
2nd period of Stress	-31.35	30.15	-2.06	-6.84	-5.58
3rd period of Stress	-46.26	12.59	0.08	-7.37	-6.19
4th period of Stress	-87.10	3.02	2.03	-7.98	-6.85
5th period of Stress	-682.59	-3.97	3.71	-8.70	7.60

Table 4.3 provides the percentage change of the cash & equivalent account, of the largest and smallest banks in each country during baseline and stressed periods.

proceeds to fire sales (Table 4.4), which means that it is classified as insolvent[20]. However, this rise of cash & equivalent at a reduced rate, also displays the country's indigent performance (Meghir et al., 2017).

Santader on the contrary, is an example of how a bank with a strong market presence can handle substantial drops arising in the cash & equivalent account, while the increase in government securities, illustrates the prudent behaviour an international bank should have in order to enhance its liquid position (Cardone-Riportella et al. 2010) by adding substantial amounts of HQLA. During $T = 3$, whilst Santader's cash & equivalent presents a substantial decrease, at the same time this bank rises by 5.55%, the amount of government securities (Table 4.4) and continues to meet the liquidity requirements.

Table 4.4, supplements the evolution of banks cash & equivalent and provides further analysis, regarding banks' profile and the decisions for their business model in order to satisfy the liquidity regulatory constrain. The main findings arising from the government securities behaviour underline that both large and small banks are binding by the regulatory constraints and increase their investment in HQLA. To this point, small banks display greater government securities percentage changes compared to the large ones, namely 7% and 2% respectively.

Despite, the periods both large and small banks indicate decrease in government securities and are classified as insolvent, these findings show the need to implement second round effects and investigate banks responses when acting under stress. Banks are binding by the regulatory constraints and combined with the adjusted liquidity channels, their ability to react and adapt a prudent behaviour comprise an added value for regulators and policy makers. Counting for second round effects and banks responses when designing wide stress test, assists on banks' contingency planning and the structure of their business model, evaluation.

[20]See section 4.3.2 for the solvent and insolvent banks definition

Table 4.4: Large vs Small Banks Government Securities

T-period	Large Banks Government Securities changes during baseline and stressed period				
T-periods	Bank of Cyprus	National Bank Greece	Iccrea	Banco BPI	Santader
Baseline to Shock Implementation	-0.41	-4.35	0.63	2.79	-0.08
1st period of Stress	1.11	-3.29	4.28	3.00	0.03
2nd period of Stress	0.24	-3.69	10.10	3.10	0.11
3rd period of Stress	0.51	-2.52	5.43	3.20	5.55
4th period of Stress	0.76	-1.46	0.57	3.28	5.57
5th period of Stress	0.98	-0.55	1.57	3.32	1.94
T-period	Small Banks Government Securities changes during baseline and stressed period				
T-periods	Hellenic Public Cyrus	Attica Bank	Banca Carige	Caixa	MPCA
Baseline to Shock Implementation	-0.41	-4.35	0.63	2.79	-0.08
1st period of Stress	6.64	-4.72	-1.41	19.49	15.61
2nd period of Stress	4.80	-3.25	-0.66	7.16	14.27
3rd period of Stress	4.64	-1.83	0.03	2.48	13.08
4th period of Stress	4.49	-0.50	0.65	14.91	12.02
5th period of Stress	4.34	0.68	1.20	5.79	11.09

Table 4.4 provides the percentage change of the government securities account, of the largest and smallest banks in each country during baseline and stressed periods.

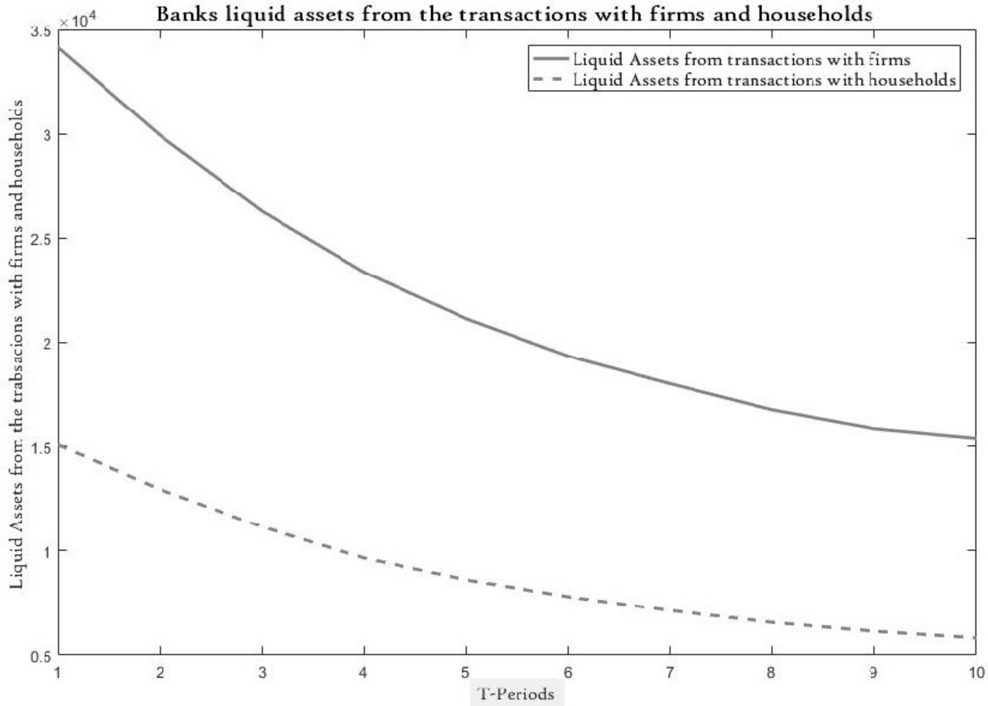
4.4.4 Firm and Household transactions

This section discusses the evolution of liquid assets and netflows banks receive from the transactions with firms and households, under the baseline and the stress periods. We analyse the amount of liquid assets arise from the transactions with the households and firms as well as the proportion of inflows and outflows arising from these agents' decisions for saving or withdrawing deposits. This analysis draws remarks regarding the agents' behaviour and actions when they are constrained by consumption and the cost of production as well as the restriction in loan supply under the different states of the economy.

Figure 4.3 indicates the evolution of liquid assets provided from households and firms to banks through loan instalments. The dotted line of figure 4.3 corresponds to the average amount of loan instalments coming from households acting in the system under examination while the black one is the amount of instalments provided from firms. The evolution of the firms' and households' liquid assets display that during the baseline period ($T = 1$), the volume of loan instalments banks receive from households equals €1.5 bn while the amount coming from the firms' transactions is almost double (€3.5 bn).

During the economic recession, firms and households decrease the amount of payments provided to the banks. In particular, at $T = 2$ there is a simultaneous decrease of the liquid assets from both firms and households. Firms' loan payments decrease by 12.38%. For payments coming from transactions with households, banks face a reduction by 14.16%. The inability of firms and households to serve their loan obligations is a consequence of the adverse economic events as well as the banks' decision to restrict the loan supply by increasing the lending rates.

Figure 4.3: Banks' liquid assets on average from the transactions with firms and households



As a results of the economy's recession, firms' and households' ability to serve their loans obligations, changes. Firms and households are forced to reallocate their net value and disposal income, respectively. Being constrained by their preferences, firms and households prioritise their expenses given the new state of their revenues (cash and wages respectively)they get, at each time step T. The reaction of agents and the decrease in banks' liquid assets specifies how the economy's fluctuations prompt banks' funding position, which becomes procyclical to these vulnerabilities.

In parallel to the above lending transactions, banks receive flows from firms and households through deposits. Banks adjust their funding position and respond to the net flows arising from the deposits. Constrained by the deposit insurance should be provided to firms and households (Anginer et al. 2012), banks develop buffers for covering any potential deposit outflow stems from firms and households withdrawals. In parallel, the net flows behaviour is bound by a set of structural changes in the Financial and Fiscal policy which led Cyprus and Greece to allow only for a threshold amount of deposits withdrawals (Hardouvelis et al. 2016 and

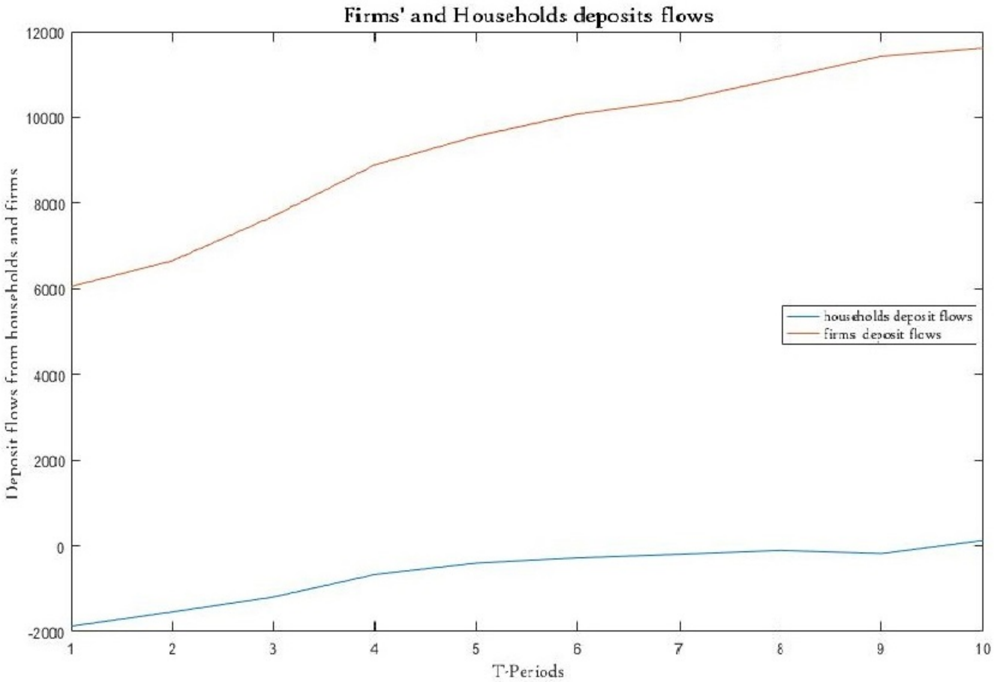
Monokroussos et al. 2015).

Figure 4.4, shows the evolution of retail and corporate deposit flows on average, for all banks in our sample, under the baseline and stressed time events. The dotted line presents the deposit flows from households, while the blue line the deposit flows from firms. Whilst, households indicate a substantial amount of outflows starting from the baseline period, firms acting in our system, display an increase in the amount of inflows provided to banks. Starting from €6 bn, the amount of corporate inflows slightly increases over the time and reaches €11 bn during $T = 9$. Responsive to banks' credit spread increase, an increase in lending rate and a slight rise of deposit rate, firms' preferences [21] lead to inflows increase and to labour costs reduction, which force households to make use of their savings.

As opposed to firms, households' actions specify a substantial amount of outflows as an outcome of banks' credit spread increase and firms' decision to reduce wages (labour costs). Households face a substantial decrease in their income due to wages reduction, combined with the restriction in banks' loan supply and the increase in lending rate, which leads to significant deposits withdrawals. During the first periods of stress the amount of households' withdrawals reaches €2.2bn while from period $T = 4$ and on, the amount of outflows starts decreasing. This outflows evolution explains households rationality to benefit from deposit rate increase. Once households face changes to wages which is the main source of the households' income, they turn their preferences into saving and and take the advantage of the higher deposit return.

[21]Firms' objective is to maximise the net value according to equation 4.2 in section 4.3.1

Figure 4.4: Banks' deposits inflows and outflows from the transactions with firms and households



Banks' increase in inflows with the parallel evolution of significant amount of outflows, our system face, assists in highlighting the focus on banks management and contingency planning required to enhance their efficiency after significant liquidity shortages. As banks need to cope with liquidity risk fast in periods of crisis where their capital base is already at a critical stage, the increase in liquidity buffers volume for backing outflows under stressed macroeconomic events scenario is a prerequisite for banks to withstand shocks and reveal their weaknesses through a stress test assessment.

4.5 Concluding remarks

In this paper, we examine the role of funding liquidity risk and its pro-cyclical behaviour with the use of the Basel III measure (LCR), under unified macro prudential stress test framework. Through this analysis, we assess the changes and the evolution of the LCR over the time, when applying adverse economic conditions.

By developing a mechanism capturing for second round effects we assess the LCR changes and pro-cyclical behaviour, banks' responses to systemic risk and the reaction of firms' and households' when banks apply restrictions in loans supply. We assess the changes of the banks' liquid assets, through cash & equivalent account, investment on HQLA, assets fire sales and lending rates increase. In addition, we count for banks' liquidity buffers when facing inflows and outflows arising from the transactions with households and firms, under both the baseline and the stressed scenarios.

At each time step, we derive the LCR expected shortfall for all banks acting under the same economy. Our analysis reveals that all banks LCR faces simultaneously substantial shortfalls during the first period after the shock implementation, while for the next periods of stress all banks' LCR decreases. Our results indicate that banks' responses and the mechanism for capturing second round, uncover funding liquidity risk pro-cyclical behaviour. Whilst the system highlights that by applying the adjusted liquidity channels large banks, in terms of assets, can continue to meet the LCR 70% threshold, their funding position deteriorates over the time and indicates the LCR pro-cyclicality to adverse economic events. This evidence is of great significance and highlights the need to incorporate second round effects when applying system wide stress tests.

Furthermore, we find evidence about banks' responses to systemic risk when proceed to loans supply restrictions combined with the adverse economic conditions. The cash inflows and the outflows of banks coming from households and firms respectively, imply that banks' funding planning and model should be continuously monitored, during periods of economic stress. The development of an ABM model which captures the complexity of the financial system and counts for second round effects, reveals the need of a unified analytical stress test framework instead of the traditional econometric and statistical approaches when dealing with scenario analysis.

A key result of our study is highlighting the need that macro prudential stress tests should develop unified processes counting for multiple feedback processes. In addition, besides the focus on credit risk, macro prudential stress tests should also address funding liquidity risk. The examination of liquidity risk arising from the funding position of banks with the use of the Basel III LCR, provides further insight on the financial stability framework. Furthermore, this study contributes to prudential regulation framework from the micro aspect of this regime as it reveals information regarding individual banks' responses to systemic risk and structural changes on their business model during baseline and stress scenarios. When banks apply the adjusted liquidity channels combined with the reaction of firms and households, underline the need banks to adapt a more prudent business model.

The sensitivity of the LCR over the marginal fluctuations of the macroeconomic environment combined with the cyclical patterns illustrate the strong linkage between the macro side of the economy with the funding position of banks. This analysis shows the importance of considering multiple feedback process for providing evidence on financial risks behaviour. In particular, the application of multiple feedback processes reveals the procyclical behaviour of funding liquidity risk and underline the need to design and implement more informative stress tests acting as early warning systems.

Given that most of the stress test analysis which count for second round effects are lacking a unified process, the agent based model can act as a guide for standalone stress test tools and give significant insight for banks' funding plans regarding the volume of liquidity buffers, banks should hold in order to cope with unexpected liquidity shortages.

Our framework provide valuable information for future system-wide stress testing. However, further work requires the implementation of the interbank in order to examine contagion effects and banks interconnectdness as well as the introduction of more market participants (beyond firms and households) such as the non-bank financial sector.

Overall, our results present significant implications to regulators and policy makers alike, as we provide evidence that contributes substantially in designing robust and forward looking unified stress test frameworks for promoting and maintaining financial stability and prudential policies.

Chapter 5

Conclusion

5.1 Concluding Remarks

This thesis investigates the role of funding liquidity risk when macro prudential stress test models are applied. Specifically, through the dissertation chapters we reveal the importance of incorporating liquidity risk in macro prudential stress test models. A key question this thesis addresses, is which are the main liquidity risk drivers. By extending the traditional multivariate copula estimation in a stress test framework, we quantify the impact of the main macroeconomic indicators on banks' funding position. Also, the analysis uncovers whether the macroeconomic environment is linked to the funding position of commercial banks. Specifically, the macroeconomic environment when operating under stress, triggers simultaneous liquidity shortages on banks' balance sheets, which in turn signals the existence of systemic liquidity risk. Additionally, the pro-cyclical behaviour of liquidity risk is examined. Banks' funding risk demonstrates a pro cyclical behaviour to the macro economic fluctuations, as despite banks' responses to restore their liquidity profile, banks' liquidity position indicates a continuous decrease.

Chapter 2 is the development of a novel multivariate copula extension quantifies the main funding liquidity risk drivers. Specifically, this chapter examines the marginal effects of the main macroeconomic indicators over the Basel III liquidity measure, NSFR, under three scenarios, the good, the stressed and the baseline scenario. In parallel, this analysis provides an extension to Gaussian copula estimation through a novel assessment, this of marginal effects. The results reveal the strong and direct inter-linkages between the macroeconomy and funding liquidity risk. The sensitivity of the NSFR over the marginal fluctuations of the macroeconomic and interbank indicators illustrate that funding liquidity risk arise in periods of economic recession. The GDP, Unemployment, Account Balance, Foreign Direct Investment and the interbank interest rate are notified as the main liquidity risk drivers which lead the NSFR to substantial reduction reaching 50%. Additional, findings provide further insight on banks' business models as we also count for the volume of deposits and non-performing loans banks face when stress economic conditions are applied.

The results of this chapter provide significant evidence on the role of funding liquidity risk in a macro prudential stress testing. The direct links between the NSFR and the macroeconomic indicators comprise important findings that NSFR is a significant indicator which should be included when counting for liquidity stress tests.

In Chapter 3, the main findings highlight the strong effect of the macroeconomic fluctuations on banks funding position represented by the Basel III liquidity measure, namely the LCR. Economy's performance leads banks to face simultaneous liquidity shortages in their balance sheets. Specifically, the LCR for all banks, drops substantially and goes below the 70% threshold, as this threshold defined by the regulatory authorities. Another significant finding which also contributes to the need to incorporate funding risk in macro prudential stress tests is the time needed for SLR to appear. Whilst the regulatory guidelines, indicate the LCR assessment to cover a stress period of 30 days, this analysis findings indicate that LCR assessment period should be extended. Once the shocks are applied, banks' LCR drops, however the greatest shortage all banks face is after the 60-days stressed period.

To this point, this analysis highlights also outcomes regarding the size of the banking system (the amount of banks located in a respective economy). For systems having a large amount of banks operating, the risk concentration decreases and even banks' funding position deteriorates, the shortages indicated are smaller than these appear in shrinking banking systems. Additionally, significant outcomes for banks' business models can be drawn by the firms' and households' indebtedness. Specifically, households' transactions contribute more to the LCR decrease as they indicate greater amount of outflows compared to firms. Furthermore, due to the macroeconomic conditions, households inability to serve their loans is greater than this of firms. Finally, households payments to banks are almost three times less than the payments banks receive from firms, leading to substantial decrease on banks' asset side.

The outcomes of Chapter 3 reinforce the need to incorporate the funding risk in macro prudential stress tests. Additionally, the development of ABM as a scenario analysis stress test, assists on overcoming traditional econometric approaches. The ABM is able to quantify the systemic liquidity risk and detect the time needed for SLR to appear. In addition, by developing computational methods for stress test applications, we can also capture the dynamics of the financial system transactions, such as the transactions with other agents acting under the same economy.

Moving on to the final chapter of this thesis, we draw a better understanding about funding risk pro cyclical behaviour when banks operate under economic stress conditions. By assessing banks' funding position with the use of the LCR, this analysis provides banks' funding risk evolution. The findings of the analysis indicate that once SLR is detected, banks develop strategies for withstanding the substantial liquidity shortages on their balance sheets. Even these responses are designed for improving banks liquidity position, the economic recession does not allow for banks' funding position recovery and the LCR display a continuous decrease. Additional findings underline whether banks size, in terms of assets, contributes to the LCR behaviour.

Large banks even face decrease on their funding position, by developing the adjusted responses to macroeconomic fluctuations, they can maintain the LCR above or close to the critical value of 70%. However because of the economic recession, large banks are unable to recover their funding position and reach the pre stress LCR levels. With regards to small banks, these banks are notified by the system specification as illiquid while the fire sales and loan supply restriction channels, do not assist on small banks recovery. Findings also provide a great insight on banks' business model. To this point, the results indicate that small banks tend to accept substantial amounts of funds even these banks are unable to back the flows received, especially when these funds turn into claims, through households and firms deposit outflows.

The results of the final chapter, underline that banks' responses incorporated in a stress test analysis are of up most significance. They also highlight the need to have a unified process when counting for scenario analysis stress tests. To this end, currently the regulatory guidelines developed so far, for the LCR assessment do not count for banks' reaction. Combined with the limited literature on stress tests' second round effects mechanism, results suggest the importance of findings regarding funding risk pro-cyclical behaviour and evolution of banks.

5.1.1 Policy Implications

Overall, this thesis provides substantial evidence about the role of funding liquidity risk and the need to be incorporated in macro prudential wide stress tests. Funding risk indicates strong linkages with the macroeconomic environment. Macroeconomic indicators are substantial liquidity risk drivers with a direct effect on funding liquidity risk, as they can trigger and reveal funding liquidity risk systemic aspects and its pro-cyclical behaviour.

The results of this thesis provide substantial evidence for regulators and policy makers. Firstly, the development of macro financial linkages between the macroeconomic shocks and the funding liquidity risk, highlights the importance of liquidity risk and the need for it to be addressed in wide stress tests carried out by policy authorities. Complementary to asset quality review, the implementation of funding liquidity risk can reveal the ability of banks to meet their liquid needs under stress economic conditions.

In addition the sensitivity of the Basel III LCR and NSFR ratios over the marginal fluctuations of the macroeconomic environment establish a clear link between the goals of prudential regulation and liquidity risk. Furthermore, the existence of systemic liquidity risk when the system operates under economic recession, provides a substantial contribution to prudential regime and combined with the funding risk pro cyclical behaviour, offers a deep insight for both macro and micro prudential reforms under Basel III.

Lastly, given that most of the stress test analysis are lacking contingency planning when assessing the financial position of banks, the agent based model reveals the rising need to apply unified processes when counting for stress tests simulations which also include feedback mechanisms. The enforcement of the existing stress test applications is required in robust and forward looking frameworks to be developed for establishing and maintaining financial stability and prudential policies.

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