Technical University of Crete

A multicriteria decision framework for the assessment of banks' capital needs

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Dedicated to my wife

Katerina

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ABSTRACT

The global financial crisis affected significantly the soundness of individual banks and the health of the U.S. and the European banking system as a whole. Building on the outcomes of past regulatory exercises and decisions to capitalized weak banks, this thesis propose the development of an early-warning system that could serve in the future as an automated decision support system for the continuous monitoring and timely identification of weak banks, subsequently guiding regulatory decisions as for the capitalization needs of banking institutions. At the same time, bank managers could use the model to know in advance if their bank is developing a profile that is close to the one that would trigger supervisory actions.

Within this context, the proposed approach is based on a multicriteria decision aid (MCDA) technique, the UTADIS method (UTilitè Additive DIScriminantes), which enables the development of additive models for decision making and prediction purposes in a classification setting. The additive form of the models facilitates their interpretability, which is an important feature for their use in a regulatory context. For comparison purposes we benchmark the UTADIS models against logistic regression, as well as with two widely used measures the SRISK, and the Texas Ratio.

Using a sample of 76 large U.S. and European financial institutions and a set of 22 criteria across different dimensions related to bank-level risk factors, bank-level microeconomic criteria, and banking and financial market aggregate conditions we developed various multi-attribute models to distinguish between banks with capital needs and well-capitalized ones. This allows us to build a decision support framework that captures vulnerabilities from both a microprudential and a macroprudential perspective.

ΠΕΡΙΛΗΨΗ

(Extended Abstract in Greek)

Η παγκόσμια χρηματοπιστωτική κρίση επηρέασε σημαντικά την ευρωστία μεμονωμένων τραπεζών, καθώς και το τραπεζικό σύστημα των ΗΠΑ και της Ευρώπης συνολικά. Με βάση τα αποτελέσματα διενεργηθέντων εποπτικών ασκήσεων (προσομοιώσεων ακραίων καταστάσεων, ελέγχων ποιότητας στοιχείων ενεργητικού) και αποφάσεων για την ανακεφαλαιοποίηση αδύναμων τραπεζών, η παρούσα διατριβή προτείνει την ανάπτυξη ενός συστήματος έγκαιρης προειδοποίησης, το οποίο θα μπορούσε να χρησιμεύσει στο μέλλον ως ένα αυτοματοποιημένο σύστημα υποστήριξης αποφάσεων, για τη συνεχή παρακολούθηση και τον έγκαιρο εντοπισμό αδύναμων τραπεζών, υποβοηθώντας με τον τρόπο αυτό τη λήψη εποπτικών αποφάσεων που σχετίζονται με τις ανάγκες κεφαλαιοποίησης τραπεζικών ιδρυμάτων. Ταυτόχρονα, οι επικεφαλής των τραπεζών θα μπορούσαν να χρησιμοποιήσουν το υπόδειγμα αυτό για να γνωρίζουν εκ των προτέρων εάν η τράπεζά τους αναπτύσσει ένα προφίλ που είναι κοντά σε αυτό που θα ενεργοποιούσε εποπτικές δράσεις.

Στο πλαίσιο αυτό η προτεινόμενη προσέγγιση βασίζεται σε μια τεχνική από το χώρο της πολυκριτήριας ανάλυσης αποφάσεων, τη μέθοδο UTADIS (UTilitè Additive DIScriminantes), η οποία επιτρέπει την ανάπτυξη προσθετικών υποδειγμάτων για σκοπούς λήψης αποφάσεων και πρόβλεψης σε προβλήματα ταξινόμησης. Η προσθετική μορφή των υποδειγμάτων διευκολύνει την κατανόηση και ερμηνεία τους, κάτι που αποτελεί σημαντικό χαρακτηριστικό για τη χρήση τους σε ένα κανονιστικό πλαίσιο.

Για λόγους σύγκρισης, τα αποτελέσματα των υποδειγμάτων UTADIS που αναπτύχθηκαν αντιπαραβάλλονται με αντίστοιχα λογιστικής παλινδρόμησης, καθώς

και με δύο ευρέως χρησιμοποιούμενα μέτρα, το SRISK και το Texas Ratio. Τέλος, η προτεινόμενη προσέγγιση βασίζεται σε μια διατύπωση γραμμικού προγραμματισμού για την προσαρμογή του υποδείγματος, η οποία παρέχει ευελιξία στον υπεύθυνο λήψης αποφάσεων – εν προκειμένου τις εποπτικές αρχές των τραπεζών – να βαθμονομήσει το υπόδειγμα έτσι ώστε να περιγράφει όσο το δυνατόν ακριβέστερα όχι μόνο τα χαρακτηριστικά των δεδομένων, αλλά και τις γνώσεις και την τεχνογνωσία τους.

Χρησιμοποιώντας ένα δείγμα 76 μεγάλων αμερικανικών και ευρωπαϊκών τραπεζών και ένα σύνολο 22 κριτηρίων που καλύπτουν διαφορετικές διαστάσεις που σχετίζονται με: (α) παράγοντες κινδύνου σε επίπεδο τράπεζας, (β) μικροοικονομικά κριτήρια σε επίπεδο τράπεζας, και (γ) συγκεντρωτικές συνθήκες τραπεζικής και χρηματοπιστωτικής αγοράς, αναπτύξαμε διάφορα υποδείγματα πολλαπλών χαρακτηριστικών για τη διάκριση μεταξύ τραπεζών με κεφαλαιακές ανάγκες και καλά κεφαλαιοποιημένων. Αυτό μας επιτρέπει να δημιουργήσουμε ένα πλαίσιο υποστήριξης αποφάσεων που καταγράφει τις ευπάθειες τόσο από μικροπροληπτική όσο και από μακροπροληπτική σκοπιά.

Η διατριβή είναι οργανωμένη σε οκτώ κεφάλαια. Το πρώτο κεφάλαιο είναι η εισαγωγή. Στο δεύτερο κεφάλαιο παρουσιάζεται το κανονιστικό πλαίσιο των εποπτικών ασκήσεων τραπεζών στις ΗΠΑ και την Ευρωπαϊκή Ένωση. Στο τρίτο κεφάλαιο περιγράφονται οι επιπτώσεις της ελληνικής χρηματοπιστωτικής κρίσης στις εγχώριες τράπεζες. Στο τέταρτο κεφάλαιο γίνεται ανασκόπηση της βιβλιογραφίας. Στο πέμπτο και το έκτο κεφάλαιο αναπτύσσεται το εμπειρικό και το μεθοδολογικό πλαίσιο της ερευνάς μας. Στο έβδομο κεφάλαιο παρατίθενται τα αποτελέσματα της ανάλυσης. Τέλος, το όγδοο κεφάλαιο παραθέτει τα συμπεράσματα της διατριβής και ορισμένες κατευθύνσεις για μελλοντική έρευνα.

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ACRONYMS

ACA	Average Classification Accuracy
AQR	Asset Quality Review
ARRA	American Recovery and Reinvestment Act
AS	Actuarial Spread
AUROC	Area Under the Receiver Operating Characteristic
BHCs	Bank Holding Companies
CAMEL	Capital, Asset quality, Management, Earnings, Liquidity
CCAR	Comprehensive Capital Analysis and Review
CDS	Credit Default Swaps
CEBS	Committee of European Banking Supervisors
CLPs	Credit Loss Projections
CNR	Capital Needs Rate
DFAST	Dodd-Frank Act stress tests
Dodd-Frank Act	Dodd-Frank Wall Street Reform and Consumer Protection Act
DSS	Decision Support System
EBA	European Banking Authority
ECB	European Central Bank
EESA	Emergency Economic Stabilization Act
EFSF	European Financial Stability Facility
EFSM	European Financial Stability Mechanism
EIOPA	European Insurance and Occupational Pensions Authority
ELA	Emergency Liquidity Assistance
ESAs	European Supervisory Authorities
ESFS	European System of Financial Supervision
ESM	European Stability Mechanism
ESMA	European Securities and Markets Authority
ESRB	European Systemic Risk Board
EU	European Union
FDIC	Federal Deposit Insurance Corporation
FOMC	Federal Open Market Committee
FSOC	Financial Stability Oversight Council

GFC	Global Financial Crisis
GGBs	Greek Government Bonds
GLF	Greek Loan Facility
IHCs	Intermediate Holding Companies
IMF	International Monetary Fund
IRRBB	Interest Rate Risk in the Banking Book
JC	Joint Committee of the ESAs
KS	Kolmogorov–Smirnov distance
MCDA	Multicriteria Decision Aid
MES	Marginal Expected Shortfall
MoU	Memorandum of Understanding
MPE ST	Macroprudential Extension Stress Test
MTD ST	Top Down Macroprudential Stress Test
NPLs	Non-Performing Loans
OCA	Overall Classification Accuracy
PD	Probability of Default
PSI	Private Sector Involvement
SCAP	Supervisory Capital Assessment Program
SENS	Sensitivity
SES	Systemic Expected Shortfall
SIs	Significant Institutions
SPEC	Specificity
SRB	Single Resolution Board
SREP	Supervisory Review Evaluation Process
SRF	Single Resolution Fund
SRM	Single Resolution Mechanism
SSM	Single Supervisory Mechanism
ST	Stress Test
TARP	Troubled Asset Relief Program
UTADIS	UTilitè Additive DIScriminantes
V–Lab	The Volatility Laboratory – NYU Stern School of Business

1 Introduction

The global financial crisis affected significantly the soundness of individual banks and the health of the U.S. and the European banking system as a whole. According to the International Monetary Fund (IMF), during 2007-2010, the total write-downs and loan provisions by European banks reached $1,276 billion, and $885 billion in the U.S., increasing to a total of $2,276 billion on a global scale (IMF, 2010). Under the Troubled Asset Relief Program (TARP), the U.S. government authorized in 2008 expenditures of $700 billion to purchase toxic assets and equity from financial institutions to strengthen its financial sector after the subprime mortgage crisis. Along the same lines, to reduce the adverse effects of the European sovereign debt crisis and restore confidence on the financial sector, European Union (EU) governments approved €855 billion during 2008-2017 for the recapitalization of the European banks, in the form of state aid by the European Commission (European Commission, 2019).

Given the above costs, it is not surprising that potential ways to avoid similar events in the future attracted substantial attention from policy makers and academics. Within this context, there are at least two fundamental conclusions that emerged from the crisis. The first is that weak banks pose a challenge for all bank supervisors and regulatory authorities around the world. Therefore, bank supervisors should take actions to mitigate the failure risk of weak banks. The second is that the supervision and regulation of financial institutions had adopted an ineffective microprudential perspective, focusing mainly on the health of individual banks. In the aftermath of the financial crisis, regulators around the globe introduced macroprudential approaches looking at the health of the banking sector as a whole.

In this context, supervisors and regulators have intensified their actions towards strengthening the risk management and monitoring processes in the banking sector (see e.g. Basel Committee on Banking Supervision, 2015). To this end, the implementation of formal regulatory exercises (i.e., stress tests and capital exercises) has played an important role in simulating the soundness of financial institutions over a range of macroeconomic scenarios. However, due to their nature, these exercises are time consuming. Additionally, a survey of stress testing practices among selected national central banks and supervisory authorities, by Oura and Schumacher (2012) reveals that instead of relying on a systematic and comprehensive set of principles, such practices have been based on trial-and-error procedures, often reflecting constraints in human, technical, and data capabilities.

Building on the outcomes of past regulatory exercises and decisions to capitalized weak banks, we propose the development of an early-warning system that could serve in the future as an automated decision support system (DSS) for the continuous monitoring and timely identification of weak banks, subsequently guiding regulatory decisions as for the capitalization needs of banking institutions.

A report published by the Basel Committee on Banking Supervision (2018a), found that early supervisory actions taken by supervisors depend not only on the expert judgment of supervisors but also to an organisational infrastructure that sets in place: (i) supervisory reinforcement through vertical and horizontal risk assessments to maximise the early detection of risks, (ii) a clear framework for when actions should be taken, and (iii) internal governance processes and programs to support supervisory development and capacity-building.

The report also points out that "*The issue of accountability is particularly important in the context of early and effective intervention, where the supervisor will typically be acting on the basis of expert judgment"* (p. 10-11). Given that experts will typically employ heuristics in their judgment and decision making which is known to create certain judgment biases, the use of decision support systems can be useful in predicting what opinion other experts would issue in similar circumstances, in determining the scope of a specific bank's examination, as a quality control tool for the examination process, and as a means of defense should accountability issues arise.

Additionally, as mentioned in the Basel Committee on Banking Supervision report, early warning models that have been developed by various central banks can "*give indications that suggest the need for a deeper investigation by the bank and its supervisor. Early warning systems are particularly important for helping supervisors to direct limited resources towards banks or activities where weaknesses are most likely to be found*" (p. 12). At the same time, bank managers could use the model to know in advance if their bank is developing a profile that is close to the one that would trigger supervisory actions.

Within this context, the proposed approach is based on a multicriteria decision aid (MCDA) technique, the UTADIS method (Jacquet-Lagrèze, 1995; Zopounidis and Doumpos, 1999), which enables the development of additive models for decision making and prediction purposes in a classification setting. The additive form of the models, facilitates their interpretability, which is an important feature for their use in a regulatory context.

For comparison purposes we benchmark the UTADIS models against logistic regression, as well as with two widely used measures the SRISK, and the Texas Ratio.

We rely on logistic regression because it has been used either as the main method for comparison purposes in several occasions in a related strand of the literature that develops early warning systems to predict banking crises (Barrell et al., 2010; Caggiano et al., 2014; Filippopoulou et al., 2020) or the failure of individual banks (Martin, 1977; Kolari et al., 2002; Lanine and Vander Vennet, 2006).

One disadvantage of parametric approaches, like logit, is their dependence on distributional assumptions for the explanatory variables (Lanine and Vander Vennet, 2006). Also, Kolari et al. (2002) point out that there are potential drawbacks in interpreting the results from logit models as it concerns the contribution of the variables in discriminating between banks from different groups. In contrast, being non-parametric in nature, UTADIS is not restricted by statistical assumptions and it provides weights about the contribution of the criteria (variables) which are easy to understand and interpret.

Finally, the proposed approach is based on a linear programming formulation for model fitting, which provides flexibility to the decision maker (in our case bank regulator) to calibrate the model so that it describes as accurately as possible not only the characteristics of the data, but also his/her domain knowledge and expertise.

We use a sample of 76 large U.S. and European banks and a set of criteria across different dimensions related to: (i) bank-level risk factors, (ii) bank-level microeconomic criteria, and (iii) banking and financial market aggregate conditions. This allows us to build a decision support framework that captures vulnerabilities from both a microprudential and a macroprudential perspective. Thus, this study complements earlier studies that propose models for assessing the soundness and creditworthiness of individual banks from a microprudential perspective (Doumpos and

Zopounidis, 2010; Bellotti et al., 2011), predicting banking crises at the country–level (Beutel et al., 2019), modeling and analyzing scenarios in bank stress testing (Hu et al., 2014), and measuring systemic risk (Mezei and Sarlin, 2016).

More broadly, this study also relates to efforts to develop decision support systems that measure credit risk and predict the bankruptcy of non-financial firms (Chen et al., 2010; Figini et al., 2017; Li et al., 2011; Papouskova and Hajek, 2019; Saha et al., 2016; Serrano-Cinca and Gutiérrez-Nieto, 2013). The difference is that these models are used by banks to assess their clients, whereas the model that we propose could be used by regulators to assess the banking institutions themselves.

The dissertation is organized into eight chapters:

The first chapter is the introduction which describes the assessment of the soundness of banks in relation to regulatory exercises, and explains the innovation of this research.

The second chapter presents the regulatory framework of stress tests and capital exercises in the U.S. and the European Union. The aim is to describe the structure of the regulatory authorities along with the procedures for supervising the banks in each jurisdiction.

The third chapter, in a case study approach, presents the impact of the Greek financial crisis on banks. The causes of the Greek financial crisis, factors that influenced the Greek banking sector, as well as the recapitalisation and restructuring of the Greek banking sector are presented.

The fourth chapter provides a review of the literature. In the beginning, we examine studies related to regulatory stress tests and capital exercises, and then provide an extensive review of the literature on the prediction of bank failure or distress.

The fifth chapter is divided into different sections starting with the data collection, proceeding with the evaluation criteria, the sampling method used for models construction, and closing with the presentation and discussion of descriptive statistical analysis of the dataset.

The sixth chapter discusses the methodological framework used in the analysis. The first part of the chapter provides a comprehensive description of the multicriteria value-function model used for the classification of the banks. In the second part, the metrics used to assess the classification performance of the model are presented, along with empirical setting used in the analysis.

The seventh chapter presents the results of the analysis. The first part of the chapter presents the results achieved by testing procedures, across specifications, performance metrics, and prediction horizon. The second part provides a comparison of the obtained results with the ones of others widely known and used measures.

The eighth chapter concludes the thesis, summarizing the main findings and provide future research suggestions.

2 Regulatory framework of stress tests and capital exercises

This chapter presents the regulatory framework of stress tests and capital exercises in the U.S. and the European Union. The aim is to describe the structure of the regulatory authorities along with the procedures for supervising the banks in each jurisdiction.

2.1 Introduction[1]

In 2008-2009, big financial institutions in the U.S. and Europe were harshly hit by the global financial crisis. Amidst that crisis, regulatory bodies recognized that individual banks were not safe enough, nor robust enough to guarantee the stability of the financial system. Aiming at controlling systemic risk and preventing the spreading of the financial crises to the real economy, regulators in the U.S. and Europe carried out stress tests of large commercial banks.

Stress tests are forward-looking exercises, seeking to evaluate the impact of plausible severe shocks on the robustness of financial institutions. At first (early 1990s), those tests were designed for individual banks, but, in May 1999, the International Monetary Fund and the World Bank started to use them systematically, throughout the banking sector, as part of their Financial Sector Assessment Program.

As noted by Baudino et al. (2018), stress tests may have microprudential or macroprudential policy objectives. When the objective is microprudential, the stress test assesses the soundness of individual banks and informs the competent authorities

[1] This Section is based on the work of Baudino et al. (2018), which reviews capital exercises and analyses system-wide stress tests for banks in the euro area, Japan, Switzerland, and the United States.

about possible remedial actions to be taken by the banks (i.e., increasing regulatory capital, reducing risk exposures, improving capital planning processes). By contrast, when the objective is macroprudential, the stress test puts the emphasis on system-wide risks and their aggregate impacts. During systemic financial crises, stress tests can be a tool for providing information about recapitalisation needs for individual banks and the banking system as a whole. Furthermore, they can help to regain market confidence.

Additionally, a stress test may be top-down or bottom-up. Top-down stress tests are carried out by supervisory authorities through their own frameworks (i.e., models, scenarios, data, assumptions). The authorities may use bank-level or aggregated data, but always within the same, usually self-developed, pattern with consistent methodology and assumptions. Bottom-up stress tests are conducted by a bank using its own stress test framework as part of a wider exercise all over the banking system, or as part of a stress test where common scenarios and assumptions are provided to the banks by the supervisors.

As regards balance sheet forecasts, stress tests may be divided in static or dynamic. Static forecasts assume that the risk profile, the size or the composition of a bank's balance sheet remain unchanged throughout the entire duration of the stress test. On the other hand, dynamic forecasts assume that the risk profile, the size or the composition of a bank's balance sheet may differ during the stress test.

Stress tests scenarios can be divided in baseline or adverse. Baseline scenarios are following certain – generally stable – economic and financial conditions, with the projection of a probable path for future economic and financial conditions. Thus, usually, baseline scenarios does not lead to a stressed result. Adverse scenarios follow certain economic and financial conditions designed to put under pressure the

performance of the banking sector or an individual bank. An adverse scenario undoubtedly puts a greater pressure on the bank than a baseline scenario. Stress factors can be hypothetical, especially designed for the test, or real, having occurred in the past.

In the U.S. and Europe (euro area) several types of system-wide exercise are conducted by the central bank or the supervisory body. These stress tests are either macroprudential or microprudential, combining as defined earlier bottom-up and top-down approaches. Namely, for the U.S., (i) the Dodd-Frank Act stress test (DFAST), and (ii) the Comprehensive Capital Analysis and Review (CCAR); and for the euro area, (i) the European Central Bank Single Supervisory Mechanism stress test (SSM ST), (ii) the Top Down Macroprudential stress test (MTD ST), and (iii) the Macroprudential Extension stress test (MPE ST). Table 1 provides a deeper view on the components of the above mentioned exercises, while Sections 2.2 and 2.3 give a review for each of the examined regions

Table 1: Key aspects of system-wide stress test (ST) for banks in the U.S. and the Euro area

Unites States	Euro area
History	
Supervisory Capital Assessment Program (SCAP): first stress testing exercise in 2009, due to the global financial crisis. Dodd-Frank Act Stress Test (DFAST): the first round of exercise under the Dodd-Frank Act was carried out in 2013. Comprehensive Capital Analysis and Review (CCAR): started in 2011, in response to the global financial crisis and in accordance with the Federal Reserve's regulations.	Single Supervisory Mechanism (SSM) ST: following the inception of the ECB/SSM, STs were conducted starting from 2014, in parallel with the European Banking Authority (EBA) ST on larger EU banks. Before that, in 2009, the first EU-wide microprudential ST was conducted under the supervision of the Committee of European Banking Supervisors (CEBS). Macroprudential extension (MPE) ST: initiated in 2016 after the ECB was granted a macroprudential mandate and the first SSM system-wide stress testing exercise. Macroprudential top down (MTD) ST: developed as a systemic risk assessment tool in 2011, when the European Systemic Risk Board was created.
Overview	
DFAST: a top-down microprudential exercise based on bank and industry data to assess the impact of adverse economic and market conditions on the solvency of large banks. CCAR: a top-down microprudential exercise based on bank and industry data, consisting of (i) a quantitative assessment of the bank's capital adequacy and planned capital distributions, and (ii) a qualitative assessment of the reliability of the bank's capital planning procedures. Macroprudential perspectives are also considered such as the incorporation of countercyclical features in scenario design.	SSM ST: a bottom-up microprudential exercise based on bank data, focusing mainly on solvency risk assessment. Top-down models are used as benchmarks. MPE ST: a top-down macroprudential exercise based on microprudential ST results. The ST can control for banks' reactions, that may lead to further adverse effects on banks' capital. The ST can also consider cross-bank contagion. MTD ST: a top-down macroprudential exercise based on bank and aggregated data to assess the impact of specific scenarios and policy measures on the banking system and the economy.
Institutional setup	
DFAST: the Federal Reserve is responsible for conducting the supervisory ST for large banks. DFAST is a national supervisory programme that runs across the Federal Reserve System. CCAR: the Federal Reserve is responsible for conducting quantitative and qualitative assessments for large and complex banks, identified through various criteria such as bank size and operational complexity.	SSM ST: the ECB/SSM is responsible for the ST, covering all Significant Institutions (SIs) that are directly supervised by the ECB. SIs are defined through various criteria such as size and economic importance. Before being supervised by the ECB, such institutions undergo a comprehensive assessment. MPE ST / MTD ST: the ECB is responsible for the corresponding STs.
Objective	
DFAST: provides the public / banks / supervisors with forward-looking information to help address the effect of adverse conditions on the ability of banks to absorb losses, while continuing their operation as financial intermediaries.	SSM ST: (i) assesses capital/liquidity resilience to adverse conditions, (ii) provides input to Supervisory Review Evaluation Process (SREP), (iii) promotes transparency, and (iv) increases banks' awareness and preparedness.

Unites States	Euro area
Objective *(continued)*	
CCAR: (i) the quantitative assessment evaluates a bank's capital adequacy and planned capital distributions, and (ii) the qualitative assessment evaluates the reliability of each bank's analyses for capital planning, focusing on how a bank identifies, measures and determines capital needs, as well as a bank's controls and governance over those practices.	MPE ST: assesses the resilience of the banking system, considering the banks' reactions to shocks and spillover effects within the banking sector and to the rest of the economy. MTD ST: (i) provides an impact assessment of a systemic risk from a macroprudential point of view, considering the banks' reactions and spillover effects, and (ii) provides the ECB with information about macroprudential policy analyses at on topics such as systemic resilience and measure calibrations.
Relationship between ST exercises	
DFAST: a standalone exercise. CCAR: the quantitative assessment uses the same top-down models and assumptions as DFAST. They also share the same set of supervisory scenarios. However, the CCAR relies on the bank's planned capital actions and the bank's baseline scenario rather than the capital action assumptions required in the DFAST rules.	SSM ST: a standalone exercise. In the quality assurance process, various top-down risk models are employed to benchmark the banks' results. MPE ST: the MPE ST uses the SSM ST results as a starting point. The SSM ST's static balance-sheet (B/S) assumption is relaxed, to account for banks' reactions to macro and financial stress. MTD ST: a standalone exercise.
Scenario	
DFAST: one baseline and two adverse scenarios are considered (adverse and severely adverse). For the severely adverse scenario the Federal Reserve uses a recession approach, which reflect conditions that typically characterise historical post-war U.S. recessions. CCAR: compared to DFAST, two additional scenarios are included in CCAR: a baseline and a stress scenario, provided by the participants to the CCAR banks.	SSM ST: it incorporates an adverse and a common baseline scenario. MPE ST: it incorporates the same adverse scenario as the SSM ST, but includes credit dynamics and the impact on the macroeconomy of possible banks' capital shortfall. MTD ST: uses various scenarios, developed for financial stability purposes, and thus do not replicate macro-financial assumptions of the SSM ST. Furthermore, multiple scenarios are used for contagion and liquidity analysis.
Use of ST results	
DFAST: the ST results are used primarily to build and maintain high levels of capital for banks so that they can remain viable financial intermediaries. The disclosed information allows the public to make more informed judgements on the conditions of banks. CCAR: the Federal Reserve may object to a bank's capital plan on the basis of the ST outcomes. If a bank receives an objection to its capital plan, it may not make any capital distribution unless expressly permitted by the Federal Reserve.	SSM ST: the bottom-up microprudential ST is an input to SREP and Pillar II decisions, promoting a consistent and transparent disclosure on banks' risk exposures and increasing banks' awareness and preparedness. Other relevant elements may be a focus on specific risks, such as non-performing loans or the impact and implementation of IFRS 9. The results of the STs facilitate the formulation of policy decisions as part of the SREP. MPE ST / MTD ST: top-down macroprudential STs are used for the assessment of risk and policy impact.

Unites States	Euro area
Coverage of exercise	
DFAST: 35 banks were examined in 2018, representing about 80% of the US bank sector assets. CCAR: the coverage for the quantitative assessment is the same as for DFAST. The qualitative assessment includes only large and complex banks (18 were tested in 2018).	All SSM SIs represent about 80% of the total euro area bank assets. SSM ST: it covers approximately 100 banks, under the direct supervision of the ECB. MPE ST / MTD ST: has increased over time, aligned with the coverage of SSM ST since 2014.
Proportionality	
DFAST: in accordance with the Dodd-Frank Act, until 2017, banks with total assets of at least $50 billion were subject to top-down STs supervised by the Federal Reserve. In 2018, the Economic Growth, Regulatory Relief, and Consumer Protection Act raised the thresholds. CCAR: same as DFAST for the quantitative assessment. The qualitative assessment is tailored to large and complex banks and started in 2017.	SSM ST: limited to designated SIs. MPE ST / MTD ST: not relevant as they are TD exercises.
Data inputs	
DFAST/CCAR: it employs various regulatory reporting data.	SSM ST: bank-level supervisory data are used, similar to those employed in the EBA EU-wide exercises. MPE ST: incorporates bottom-up individual bank SSM ST results and underlying bank-level data, combined with data for macroeconomic and financial variables. MTD ST: macroeconomic and financial data are used, together with supervisory data.
Communication/disclosure of ST results	
Public and Banks: CCAR and DFAST post-stress capital ratios are publicly disclosed at the bank level. Moreover, the Federal Reserve provided information about its scenario design framework and major modeling changes. An annual symposium is also held in which supervisors and practitioners discuss the best practices in stress test modelling, model risk management and governance. Banks Only: for CCAR, the Federal Reserve provides each bank with the opportunity to adjust its planned capital distributions before the public disclosure of final post-stress capital ratios. A letter is sent to each bank after the completion of the exercise, noting areas where the bank must take action. A Questions and Answers is also prepared on an ongoing basis to assist with the interpretation of reporting instructions and related supervisory guidance.	SSM ST: banks have access to the SSM assessment. The final results are endorsed by the ECB/SSM and the results for banks in the EBA sample are made public. MPE ST / MTD ST: banks and the public get the same information (country-specific or bank-specific results are not announced).

Source: Adopted from Baudino et al. (2018).

2.2 The United States

2.2.1 US response to the crisis

During the financial crisis of 2008, the Troubled Asset Relief Program (TARP) was introduced to rehabilitate the liquidity and stability of the financial system. The Congress approved $700 billion through the Emergency Economic Stabilization Act (EESA) of 2008, which was overseen by the U.S. Department of the Treasury. EESA authorized the Secretary of the Treasury to establish TARP in order to *"purchase, and to make and fund commitments to purchase, troubled assets from any financial institution, on terms and conditions as are determined by the Secretary"*.[2]

The Dodd-Frank Wall Street Reform and Consumer Protection Act (Dodd-Frank Act), reduced total TARP purchase authority from $700 billion to a total of $475 billion.[3] TARP funds were meanly used in the bank Capital Purchase Program ($250 billion), but also for loans and direct equity investments to select car industry participants ($82 billion), to backstop credit markets ($27 billion), to provide a lifeline to the American International Group ($70 billion), and continuous support for government housing initiatives ($46 billion).[4]

TARP is considered to be one of the federal government's first reactions to the financial crisis. In 2008 and 2009, along with TARP, the US Treasury, the Federal Reserve, and the Federal Deposit Insurance Corporation (FDIC) established a broad set of emergency programs to stabilize the financial sector and the economy. Among these

[2] For details see: "The Emergency Economic Stabilization Act (EESA)" (October 3, 2008).
[3] For details see: "The Dodd-Frank Wall Street Reform and Consumer Protection Act" (July 21, 2010).
[4] Table A1 in the Appendix provides a financial summary for TARP programs during the period from October 3, 2008 up to September 30, 2017.

operations were: (i) purchases of mortgage-backed securities to avoid the rise of interest rates, (ii) guarantees of transaction accounts at banks and capital market funds, and (iii) liquidity facilities provided by the Federal Reserve. Furthermore, in 2009, the Congress adopted the American Recovery and Reinvestment Act (ARRA), aiming at creating and saving jobs, promoting economic activity and investing in long-term growth.[5]

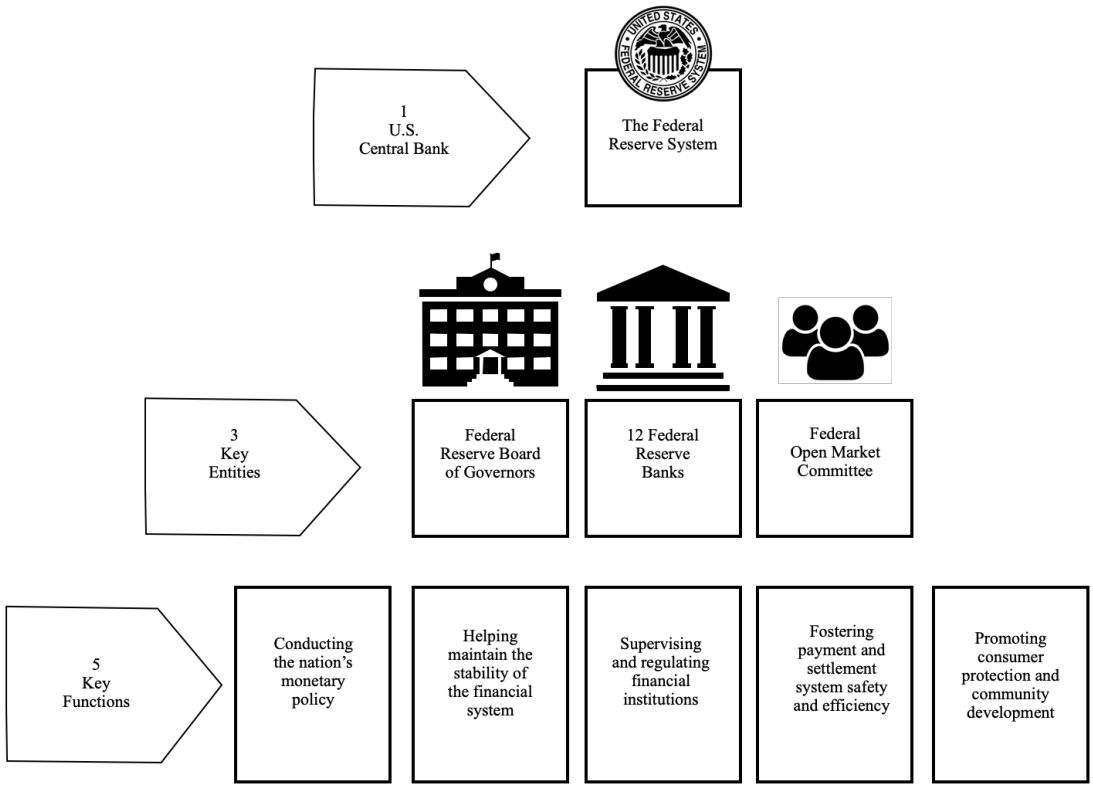
As a result of the government's coordinated reaction to the financial crisis, by the middle of 2009, the financial system was stabilized and the interest rates of loans were considerably lower, be it for businesses, private persons, or state and local governments. Companies issued equity and long term debt and could finance themselves in private markets.

2.2.2 The Federal Reserve System

In the United States the central bank is called The Federal Reserve System (see Figure 1). It was created in 1913, to enhance financial stability and prevent bank runs like those of the late 19th and early 20th centuries, which had brought deep economic recessions in the U.S.[6] The global financial crisis in 2007-2009 and the economic declines that followed unveiled weaknesses both in the architecture of the financial system and in its supervisory and regulatory framework. The Dodd-Frank Wall Street Reform and Consumer Protection Act of 2010 (Dodd-Frank Act) passed reforms that allocated the Federal Reserve new responsibilities aiming at boosting the stability of the financial system and keeping up with the fluctuation of the economy.

[5] For details see: "The American Recovery and Reinvestment Act (ARRA)" (February 19, 2009).
[6] For details see: "The Federal Reserve Act of 1913", as amended over the years, sets out the purposes, structure, and functions of the System as well as outlines aspects of its operations and accountability.

Figure 1. The Federal Reserve System



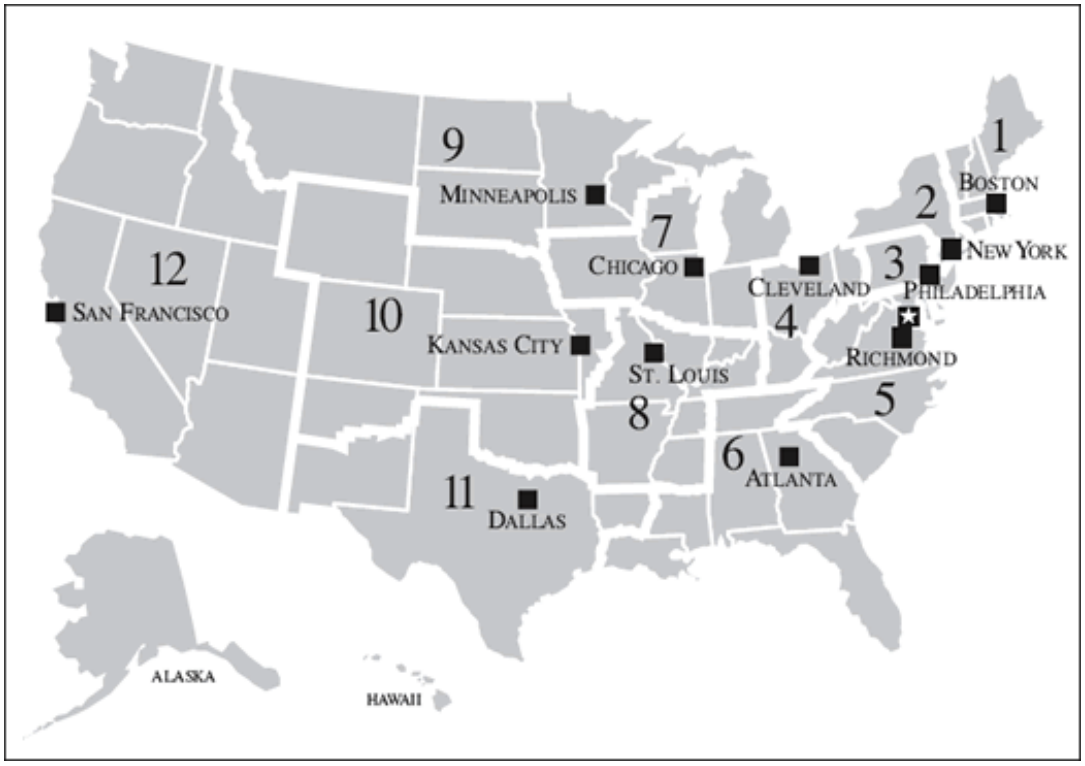
Source: Adopted from Feliz, R. A. (2021). "The Fed Explained: What the Central Bank Does," Reports and Studies 4860, Board of Governors of the Federal Reserve System (U.S.).

The Federal Reserve System has three key entities: the Federal Reserve Board of Governors (Board of Governors), the Federal Reserve Banks (Reserve Banks), and the Federal Open Market Committee (FOMC), which are described below.

The national component of the federal reserve system is managed by a seven-member Board of Governors, called the Federal Reserve Board. Its primary task is to guide monetary policy by coordinating with the FOMC and regional reserve banks. For this purpose, the board conducts a broad spectrum of research and analytical studies. Furthermore, the board must supervise the U.S. government's system of payments, as well as the financial services industry, including approve bank presidents, set capital requirements for the banks, and coordinate and oversee the actions of regional reserve banks.

The federal reserve banking system comprises 12 regional banks (see Figure 2), with 24 branches. These banks are regional sections of the U.S. central bank and function as mediators between local banks and the U.S. federal reserve banking system. The reserve banks perform federal reserve core functions by: (i) supervising and examining state banks, (ii) lending to depository institutions, (iii) providing key financial services, and (iv) enforcing the compliance of financial institutions with federal consumer protection and fair lending laws, while also promoting local community development.

Figure 2. Federal Reserve Banks



The Federal Open Market Committee is the body of the Federal Reserve System charged with the monetary policy. It comprises 12 members: the seven members of the Board of Governors of the Federal Reserve System, the president of the Federal Reserve Bank of New York, and four of the remaining 11 Reserve Bank presidents, serving one-

year terms in rotation. The FOMC evaluates the economic and financial environment and makes all decisions on the conduct of open market operations which affect the federal funds rate, the size and composition of the Federal Reserve's asset holdings, and communications with the public about the expected future course of monetary policy.

As the central bank of the U.S., the Federal Reserve System carries out five general missions. More specifically, it:

- ✓ carries out the monetary policy in order to promote full employment and price stability in the U.S. economy;
- ✓ promotes the stability of the financial system and aims at minimizing and containing systemic risks;
- ✓ promotes the safety and robustness of financial institutions;
- ✓ ensures the safety and efficiency of the payment and settlement system; and
- ✓ fosters the protection of consumers and the development of local communities.

2.2.3 Supervisory Capital Assessment Program

In 2009 the U.S. Federal Reserve carried out the Supervisory Capital Assessment Program (SCAP) to determine whether the largest bank holding companies (BHCs) had enough capital to absorb severe economic and financial shocks.[7] The results were made public, in order to assist recover market confidence (Petrella and Resti, 2013).

[7] For description and results of the SCAP exercise see Board of Governors of the Federal Reserve System: (i) "The Supervisory Capital Assessment Program: Design and Implementation" (April 24, 2009), and (ii) "The Supervisory Capital Assessment Program: Overview of Results" (May 7, 2009).

Domestic BHCs with assets over $100 billion as of December 31, 2008 participated in the SCAP. The SCAP results indicated that 19 BHCs would face almost $600 billion of losses under the adverse scenario, offset by $360 billion in net revenue less additional reserve needs. This led to an additional capital buffer of $185 billion across these BHCs, with 10 of the 19 institutions requiring additional capital. Ultimately, the capital buffer was reduced to $75 billion, after capital actions were taken and considering the performance of the BHCs in first quarter of 2009 (Hirtle et al., 2009).

2.2.4 Comprehensive Capital Analysis and Review

The Comprehensive Capital Analysis and Review (CCAR) is carried out every year, since 2011, by the Federal Reserve to assess whether BHCs and intermediate holding companies (IHCs) of foreign banking organizations, have enough capital for their operation under conditions of economic and financial stress and that they follow proper processes to manage their risks.

CCAR includes the supervisory and internal stress tests conducted as a part of the Board's Dodd-Frank Act stress tests, which is based on an analysis of the capital buffer needs of each firm, and an assessment of firms' capital plans.[8]

[8] For description and results of the 2011-2020 CCAR exercises see: "Comprehensive Capital Analysis and Reviews," Board of Governors of the Federal Reserve System.

2.2.5 Dodd-Frank Act Stress Tests

After the financial crisis, the Congress passed the Dodd-Frank Wall Street Reform and Consumer Protection Act (Dodd-Frank Act). This act requires the Federal Reserve to carry out an annual stress test of large, complex BHCs and all nonbank financial companies designated by the Financial Stability Oversight Council (FSOC). The Dodd-Frank Act additionally imposes a requirement to all BHCs and financial companies supervised by the Federal Reserve, to conduct their own stress tests. These requirement were adopted by the Federal Reserve in October 2012.

The Federal Reserve expects big BHCs to have enough capital in order to be able to continue lending and to support the real economic activity, even under conditions of economic stress. DFAST is a forward-looking tool that supports bank supervisors in assessing the capital adequacy of BHCs. Stress tests in the U.S. use a top-down approach that evaluates the effect that macroeconomic shocks have on the financial soundness of banks (Kapinos and Mitnik 2016).[9]

The Federal Reserve believes that the publication of stress test results improves transparency, and encourages market discipline. The projections offer a unique perspective on the soundness of the capital situation of these firms because they include comprehensive view on the risk profile and operations of each BHC. Furthermore, a uniform approach is used across all the BHCs for the estimation of the projections, producing comparable results across institutions.

[9] For details see: Federal Reserve / Supervision & Regulation / Stress Tests and Capital Planning / Dodd-Frank Act Stress Tests.

2.3 European Union

2.3.1 EU response to the crisis

In 2008-2009, during the global financial and economic crisis, the structural deficiencies of the EU, as well as the level of the interdependence between the Member States' economies, in particular between the eurozone countries, came to light. In 2010, after the crisis, and in replacement to the Lisbon Strategy, the European Commission launched the Europe 2020 Strategy to promote smart, sustainable, and inclusive growth across EU member states (European Commission, 2010).

The crisis of 2008-2009 was the most severe financial and economic crisis the EU had to face since its creation. It caused several challenges to the European banking architecture and its regulatory bodies. The European Commission played a crucial role in supporting Member States to respond in a coordinated and effective manner. The state aid legislation was adapted to concentrate on financial stability as an overall objective. At the same time, attention was paid to aid and distortions of competition between banks and across Member States, so that they were kept to the minimum. Taxpayers were protected by private loss sharing requirements.

The 2018 Scoreboard presents state aid to financial institutions during the period 2008-2017, by aid instrument (see Table A2 in the Appendix). The data include both the amounts of aid that the European Commission authorized, based on notifications by Member States and the amounts of aid actually disbursed by Member States. The recapitalizations reached €855 billion during 2008-2017, and apart from that, another €604 billion were approved for impaired assets measures, giving a total state aid approved amount of €1,459 billion to the financial sector in the form of capital or

capital-like instruments. Moreover, guarantees of €3,416 billion and other liquidity measures of €243 billion, were approved by the European Commission, representing a total of €3,659 billion liquidity aid instruments.[10]

Generally, the amount of approved state aid to the financial sector in the form of capital or capital-like instruments, has significantly decreased since the years of the financial crisis (2009-2010), as has the amount of the respective state aid used.[11]

2.3.2 European regulatory and financial supervision framework

The main institutions of the European Union (EU) are: the European Parliament, the European Council, and the European Commission. The Commission puts forward legislative proposals for adoption by the Council and the Parliament, which then goes through the legislative procedure following the "Lamfalussy approach", which involves four institutional levels:

- Level 1: the European Parliament and Council adopt the basic legislation proposed by the Commission.
- Level 2: the Commission can adopt, adapt, and update measures based on advice from specialist committees – EU countries representatives.
- Level 3: national supervising committees advise the Commission in the adoption of level 1 and 2 acts, and for issuing implementation guidelines.

[10] For details see: "The 2018 Scoreboard - Aid in the context of the financial and economic crisis," European Commission (January 24, 2019).
[11] Table A3 in the Appendix presents data for the approved and used state aid for the recapitalization of EU banks over the period 2008-2017.

- Level 4: the Lamfalussy report asks for a stronger role for the Commission on the enforcement of EU rules by national governments.

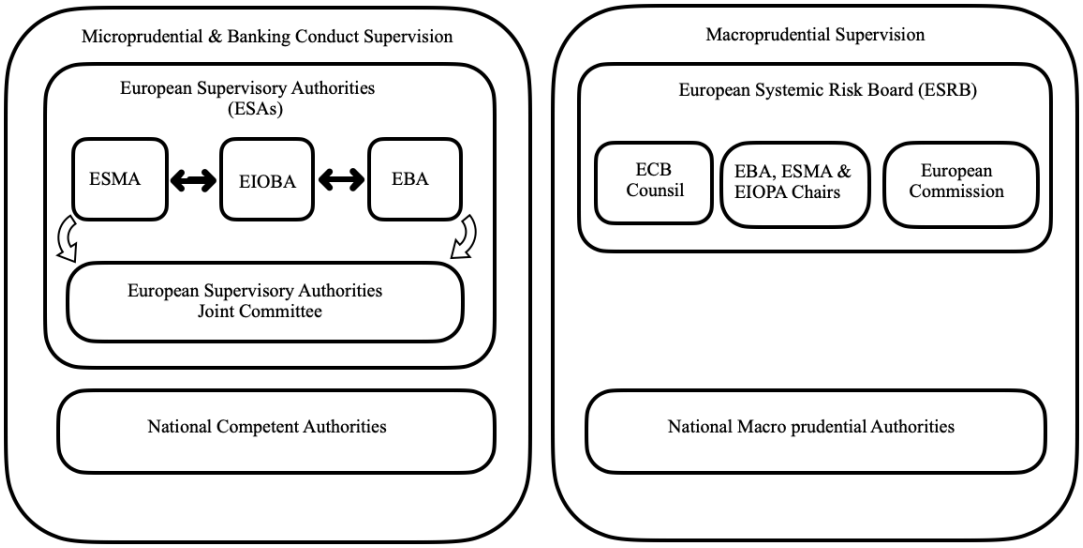
In reaction to the financial crisis the Commission tasked the de Larosière Group, to examine ways for enhancing financial supervision, protecting European citizens, and restoring trust in the financial system. The de Larosière Group stressed that supervisors should not only focus on individual banks, but also on the whole financial system. Following the 2009 de Larosière Report, the EU reformed its framework for financial supervision. Consequently, a new European Systemic Risk Board (ESRB) was established for monitoring macroprudential risks, while the level 3 Lamfalussy Committees were transformed into independent European Supervisory Authorities (ESAs), responsible for overseeing the European financial system and promoting the coordination of all Member States and national supervisors.

The European Banking Authority (EBA), the European Insurance and Occupational Pensions Authority (EIOPA), the European Securities and Markets Authority (ESMA), together with the Joint Committee of the ESAs (JC) and the European Systemic Risk Board (ESRB), form the European System of Financial Supervision (ESFS), whose purpose is to ensure the supervision of the EU financial system (see Figure 3).

The ESFS consists of two complementary pillars, namely macroprudential oversight and microprudential supervision. Macroprudential seeks to is to ensure the stability of the whole financial system as well as of individual financial institutions. As stated in the de Larosière Report "*macro-prudential supervision cannot be meaningful unless it can somehow impact on supervision at the micro-level; whilst micro-*

prudential supervision cannot effectively safeguard financial stability without adequately taking account of macro-level developments".[12]

Figure 3. European System of Financial Supervision



The above change in the regulatory framework of the EU occurred because of the general dismay among politicians and regulators concerning the failure of the previous EU regulatory system to cope with the 2007-2009 financial crisis. Targeted powers, including those allowing to overrule national regulators, were allocated to the new EU authorities. As regards macroprudential supervision, the changes primarily addressed a major gap of the previous system, namely the fact that national regulators were not tasked with the systemic supervision at an EU level.

In 2014, the Banking Union was established, bringing more major modifications to the supervisory architecture at the EU level. Its purpose was the creation of a framework that would enhance the stability of the eurozone. In this respect, the decision

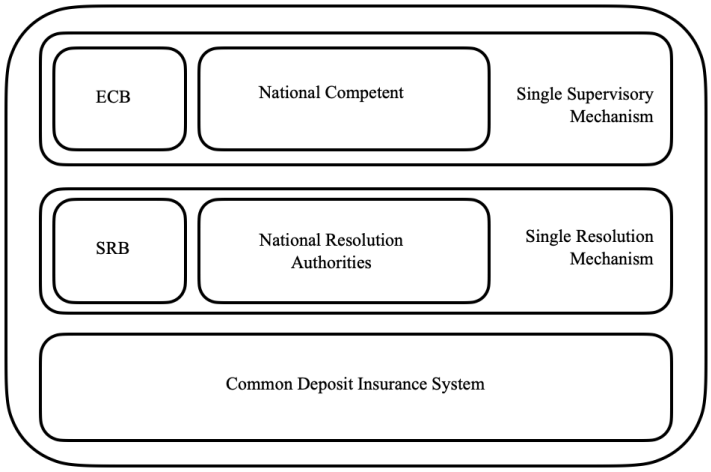
[12] For details see: "The High-level group on financial supervision in the EU Report," chaired by Jacques de Larosière, p. 38, paragraph 148 (February 25, 2009).

envisaged a three-pillar approach: a Single Supervisory Mechanism (SSM), a Single Resolution Mechanism (SRM) and a Common Deposit Guarantee Scheme, which has not entered into force yet.

SSM aims at ensuring the coherence in the prudential supervision of financial institutions, across all countries. The SSM comprises the European Central Bank (ECB) and the supervisors of the 19 Member States of the euro area. Within the SSM, the ECB bears the final responsibility for the direct supervision of significant credit institutions. The supervision of less significant credit institutions is a responsibility of national supervisors.

The SRM, sets up an integrated institutional system for the resolution of banks. This is based on a single resolution body, the Single Resolution Board (SRB), and a common mechanism that finances resolution measures, the Single Resolution Fund (SRF), which is financed by regular contributions from participating institutions (see Figure 4).

Figure 4. Banking Union



The ECB directly supervises the largest banks in the EU, in close cooperation with the national supervisors under the SSM. The main goals are: ensuring the safety and robustness of the European banking system, increasing financial integration and stability, and guaranteeing consistent and coherent supervision.

European Banking Supervision uses stress tests as a bank health check, to evaluate their ability to deal effectively with economic and financial shocks. The results of stress test help supervisors identify the weaknesses and vulnerabilities of financial institutions so that they can be addressed at an early stage through the supervisory dialogue with banks. The ECB carries out different sorts of stress tests: annual, thematic, stress tests as part of global assessments, and stress tests for macroprudential purposes. The most important of the above are discussed in the following sections.

2.3.3 EU Stress Tests

Since 2009-2010 the EU launched stress tests of big credit institutions, with the same goals as in the U.S. At first, those tests were conducted by the Committee of European Banking Supervisors (CEBS) and later by the European Banking Authority (EBA).[13] The EU stress tests consist of a bottom-up approach that assesses the impact of exogenous shocks on granular (intra-bank) variables, such as the credit risk of the loan portfolio. Each bank sends the test results to its respective National Supervisor for revision and consecutive submission to the EBA.

Annual stress tests consist of the "EU-wide stress tests" led by the EBA, plus the ECB's stress test under the Supervisory Review and Evaluation Process (SREP).

[13] For details see: European Banking Authority / Risk Analysis and Data / EU-wide stress testing.

Furthermore, the EBA conducts, every two years, “EU-wide stress tests” in cooperation with the ECB, the European Systemic Risk Board (ESRB) and the national supervisory authorities. The test sample covers the biggest important banks under direct supervision of the ECB. The exercise uses methodology and templates of the EBA, while the scenarios and key assumptions are developed jointly by the EBA, the ESRB, the ECB, and the European Commission. The EBA then publishes both individual and aggregate results.

In years when the EBA conducts its “EU-wide stress test”, the ECB runs its own stress test for those financial institutions under its direct supervision that are not participating at the EBA stress test. This test is part of the annual SREP procedure. It follows EBA methodology, adjusted to smaller institutions, according to their needs, so that they are treated proportionately. Once the test is completed, the ECB publishes the results.

In years without EU-wide EBA stress test, the ECB carries out tests assessing a particular type of shock for important banks it directly supervises. Those thematic tests are conducted jointly with national supervisors. The ECB then publishes the results on an aggregate basis. Example of such exercises are the 2017 Sensitivity Analysis of Interest Rate Risk in the Banking Book (IRRBB), the 2019 Sensitivity Analysis of Liquidity Risk, and the upcoming 2022 Climate Risk Stress Test (CST).

Furthermore, on top of the above-mentioned exercises, macroprudential goals can demand specific stress tests to be run by the ECB on individual financial institutions or groups of banks if need be (concentrating on financial stability and systemic impact rather than individual banks). These tests check the general impact on the system, rather

than the effects on individual banks. They are conducted top-down, without participation of the banks.

2.3.4 EU Comprehensive assessments

Since 2014, together with national supervising authorities, the ECB runs comprehensive financial checks for the banks under its direct supervision. These health checks contribute to guarantee that banks are sufficiently capitalized and can resist macroeconomic and financial shocks. This exercise generally consists of comprises two parts: (i) an asset quality review (AQR) to promote transparency about banks' exposures, including asset sufficiency, collateral valuations and related provisions, and (ii) a stress test, conducted in close cooperation with the European Banking Authority (EBA) to test the endurance of banks' balance sheets.

Comprehensive assessments are conducted: (i) when a bank is classified as significant and enters under direct supervision of the ECB, (ii) when an EU Member State outside the eurozone starts a close cooperation with the ECB, and (iii) on an ad hoc basis, when exceptional circumstances impose such an assessment. These tests follow the EBA methodology, but they can be modified if a bank's particular context so imposes.[14]

[14] For description and results of the 2014 – 2021 Comprehensive assessments see: "Supervisory practices / Tasks / Comprehensive assessments," European Central Bank.

2.3.5 EU Capital Exercises

In 2011/2012 the EBA carried out a capital exercise. This was not a regular stress test, but a one-off check conducted within a package of coordinated policy measures to regain confidence in the EU banking sector. In order to counter the situation in the capital markets and the worsening of the sovereign debt crisis in Europe, the EBA scrutinized the banks' actual capital positions and sovereign exposures and imposed to them capital requirements for extra buffers.[15]

[15] For description and results of the 2011 EU Capital exercise see: "EU Capital exercise final results," European Banking Authority.

3 The impact of the Greek financial crisis on banks

This chapter presents the impact of the Greek financial crisis on banks. The causes of the Greek financial crisis, factors that influenced the Greek banking sector, as well as the recapitalisation and restructuring of the Greek banking sector are presented.

3.1 The Greek financial crisis

In 2009, the Greek general government deficit reached a double-digit percentage of GDP (15.1%), due to poor revenue performance, increased general government expenditure, and the onset of a recession. At the same time, the public debt increased to 126.7% of GDP.[16] These negative developments triggered successive downgrading in Greece's credit ratings, and a large spread between the 10-year Greek and the German government bonds through mid-April of 2010, subsequently increasing borrowing and debt servicing costs for the Greek government as well as the country's recourse to a financial support mechanism.

The crisis that started in Greece had spillover effects to the eurozone as a whole. Moreover, apart from the Eurozone, the Greek crisis affected directly or indirectly other neighboring countries of Greece in Southeastern Europe (Bastian, 2011), while there was a potential risk even for the U.S. (Nelson et al., 2011). Countries with strong fundamentals returned to growth within a relatively short time period, while ones with macroeconomic imbalances and structural weaknesses experienced great problems. As of 2008, besides Greece, both euro area countries (Ireland, Portugal, Spain and Cyprus)

[16] In April 2010 the deficit had been estimated at 13.6% of GDP and the debt at 115.1% of GDP.

and non-euro area countries (Latvia, Hungary and Romania) requested international financial support.

Greece's real GDP growth rates over the 1996-2009 period were higher than other EU-15 countries by an average rate of 1.5%, especially during the years prior to the Athens 2004 Olympic Games.[17] The primary causes of the Greek crisis were macroeconomic imbalances (especially fiscal and current account ones), which were building up for years after the Euro adoption. The high Greek nominal growth had kept the dept to GDP ratio under control until 2009.

The Greek crisis, which lasted for eight years (2009-2017), had an unprecedented depth, economic and social impact, challenging the country's membership in the Eurozone, and sometimes even the Eurozone's cohesion (see Figure 5). As a result, the cost of the crisis was very high for the country due to several negative effects, like for example: (i) a cumulative decline of 26.3% in real GDP during 2008-2013, (ii) an increase in the unemployment rate from 7.6% in Q2-2008 to 27.7% in Q3-2013, (iii) a decline in the population (mainly due to migration abroad and low birth-rate), and an increase in poverty rates, (iv) a decrease in private investments from 18.2% of GDP in 2008, to 7.7% of GDP in 2015, and (v) a cumulative decline in housing prices by 42.4% between Q3-2008 to Q3-2017 (Karamouzis and Anastasatos, 2019).

[17] Over the period 2001-2004, the average GDP growth rate in Greece was 4.7% compared to 1.7% in EU-15.

Figure 5. The chronology of the Greek crisis

Source: Adopted from European Court of Auditors 2017, p.15.

1st programme (2010-2011): Greek Loan Facility (GLF), €52.9 bn in bilateral loans from euro area countries, and €20.1 bn from the IMF (2010-11), total amount of €73 bn disbursed

On May 2, 2010, the Eurogroup agreed to provide bilateral loans of €80 billion over the period May 2010 to June 2013. This amount was finally reduced by €2.7 billion, because Slovakia, Ireland, and Portugal did not participate in the programme. The financial assistance was part of a joint package, with the IMF committing an additional €30 billion.

2nd programme (2012-2015): European Financial Stability Facility (EFSF), €141.8 bn disbursed, and the IMF, €12 bn (2012-2015), total amount of €153.8 bn disbursed

On March 14, 2012, the euro area finance ministers approved financing of the 2nd economic adjustment programme for Greece. In more detail, the euro area countries and the IMF committed the unreleased amounts of the first programme together with an additional €130 billion for the period 2012-2014 (European Commission, 2012).

Unlike the 1st programme, which was based on bilateral loans, the euro area countries agreed that the 2nd programme would be financed by EFSF. The programme predicted total financial assistance of €164.5 billion until the end of 2014; however, this was later extended to June 30, 2015. The euro area contributed €144.7 billion, while the remaining €19.8 billion were provided by the IMF.

A private sector involvement (PSI) was also agreed. The high participation to Greece's debt exchange offer, in spring 2012, made an important contribution towards this goal.

3rd programme (2015-2018): European Stability Mechanism (ESM) €61.9 bn disbursed, IMF no financial participation

After the end of the 2nd programme on June 30, 2015, the Greek government requested to receive support from the ESM. The European Commission and the ECB responded positively to this request and provided an assessment of the sustainability of Greece's public debt and financing needs that was discussed by the Eurogroup and at the Euro summit on July 12 and July 13, 2015. After an agreement was reached, a bridge loan of €7.16 billion was extended under the European Financial Stability Mechanism (EFSM) to cover short-term financing needs. On August 19, 2015, Greece and the European Commission signed a memorandum of understanding to specify the terms of the loan (MoU, 2015). At the same time, the European Council approved the programme, thus mobilising funds up to €86 billion over the period 2015-2018. The funds were linked to the implementation progress of the agreed conditions.

On August 20, 2018, Greece concluded the ESM financial assistance programme, having gone through a range of reforms, like: (i) restoring fiscal sustainability (achieving a budget 0.8% surplus in 2017 from a 15.1% deficit in 2009), (ii) safeguarding financial stability, (iii) enhancing growth, competitiveness and investment, and (iv) implementing reforms on public administration and the judicial system (European Stability Mechanism, 2018).

Greece received a total funding of €288.7 billion from the three programmes, with the EFSF and ESM being the largest creditors with a combined €203.8 billion. The conditions focuses on three main goals, namely: (i) fiscal sustainability, (ii) financial stability, and (iii) restoration of growth. However, as we discuss in more detail below, these objectives were partially met (European Court of Auditors, 2017):

- *Fiscal sustainability:* even though fiscal consolidation was achieved in terms of structural balances, the debt to GDP ratio kept increasing due to negative macroeconomic developments and the burden from the existing debt.

- *Financial stability:* the programmes were not able to prevent the deterioration of the banks' balance sheets, which was cause by adverse macroeconomic developments and political turmoil.

- *Return to growth:* GDP decreased by more than 25%, and economic growth was not achieved by 2012, as planned.

3.2 Factors that influenced the Greek banking sector

During 2010-2012, the Greek banking sector was severely hit by three main factors: (i) the cut-off from international markets and deposit outflows, (ii) adverse economic conditions, which deteriorated asset quality, and (iii) the restructuring of the Greek sovereign debt through the PSI. These factors, which are analyzed below, put the liquidity and capital base of the Greek banks under pressure, threatening the stability and long-term sustainability of several banks and the sector as a whole (Bank of Greece, 2012).

(i) Cut-off from international markets and deposit outflows

Over the period of the Global Financial Crisis (GFC), the Greek banks were focused on traditional banking operations and the financing of the Greek economy, as well as on the expansion of their activities in the wider region of Southeastern Europe. The inflows of deposits that occurred immediately after the collapse of Lehman Brothers in September 2008, largely

reflect the confidence that depositors and investors had in the Greek banking system prior to the Greek public debt crisis.

The emergence of the liquidity crisis in the Greek banking sector started at the end of 2009 following the outburst of the Greek sovereign crisis. Greek banks' ratings were also deteriorated due to the wider economic environment of the country and the significant exposure of their portfolios to Greek government bonds, especially after the GFC. Despite that, due to lack of investment interest, Greek banks continued to absorb almost all Greek government bond issuances after 2010, effectively supporting the national economy in an extremely difficult period for the country.

Until 2009, Greek banks used different fund raising tools (i.e., interbank lending, securitization, deposits, covered bonds), securing the necessary financial resources to continue their activities. However, at the end of 2009 Greek banks lost easy access to the interbank market, as the Greek bonds which were used as collateral were no longer acceptable by foreign banks. This had also implications for the profitability of the banks because of the significant increase in borrowing costs.

October 2009 marked the beginning of an outflow of domestic deposits, which continued to increase until June 2012 (lag by €76.3 billion), putting the liquidity of several banks under pressure, and making the Eurosystem the main source of refinancing.

(ii) Adverse economic conditions and deteriorated asset quality

In 2005, the IMF conducted for the first time a stress test of Greek banks, as part of the Greek Financial System Stability Assessment. The results were satisfactory since, among other things, they showed that the Greek banking system was sufficiently capitalized to absorb potential

disruptions. In more detail, the stress tests found that the Greek banks' ability to withstand risks was good, with credit, equity, and interest rate risks having the largest impact on capital (IMF, 2006). Similar exercises, with similar results, due to bank's capital strengthening, were carried out in 2010 by the Committee of European Banking Supervisors, and in 2011 by the European Banking Authority (EBA) in cooperation with the Bank of Greece, the ECB, the European Commission, and the European Systemic Risk Board.

The Greek fiscal crisis and the unprecedented sovereign economic crisis that followed, resulted in a period of prolonged recession with many households and businesses becoming unable to repay their debts to the banks, subsequently leading to a significant increase of the non-performing loans (NPLs) rates despite the massive restructuring made in a large part of the relevant portfolios.[18] As it concerns the rates of arrears by the type of the counterparty, the highest rates were recorded in consumer loans, followed by business loans, and residential ones. In more detail, data from the Bank of Greece reveal that in 2012 the quality of the loan portfolios for all categories of loans deteriorated significantly, as the relative ratio of loans in arrears to total loans amounted to 31.3% compared to 21.5% in 2011, 14.1% in 2010, and 9.5% in 2009. As shown below, in Table 2, the largest increase was in the NPLs ratio of consumer loans (2012: 50.8% vs 2011: 38.1%), followed by business loans (2012: 29.3% vs 2011: 18.7%), and residential loans (2012: 27.6% vs 2011: 21.2%).

Furthermore, according to the 2012 report of the Bank of Greece on the Recapitalisation and Restructuring of the Greek Banking Sector, the estimated amount of Gross Credit Loss Projections (CLPs) for Greek, foreign, and state-related loan portfolios over the period June

[18] The macroeconomic environment (GDP, unemployment, interest rates) combined with the credit expansion that was widely followed by all banks in the years before the Greek financial crisis, are largely responsible for the increase in NPLs (Louzis et al., 2012).

2011 to December 2014 was € 46.8 billion (€ 36.8 billion, € 8.2 billion, and € 1.8 billion respectively).

Table 2. Evolution of Greek loans and non-performing loans

(€ billion)	2008	2009	2010	2011	2012	2013	2014	2015	2016	Mar 2016	2017	2018	2019	2020
Loans	255,699	271,167	272,405	242,771	217,474	230,003	224,763	221,594	215,985	218,996	200,116	180,180	168,707	157,319
Consumer	34,412	34,804	32,430	27,150	24,995	25,537	24,500	24,115	23,124	23,839	19,984	16,525	14,503	12,689
Residential	68,812	74,503	76,638	67,806	65,322	67,832	69,831	68,360	66,176	67,823	63,404	60,904	55,833	44,268
Business	152,475	161,860	163,336	147,814	127,157	136,634	130,433	129,118	126,685	127,334	116,727	102,752	98,371	100,362
NPLs	14,623	25,634	38,412	52,313	67,990	90,867	97,684	106,506	104,827	107,196	94,433	81,801	68,525	47,445
Consumer	2,979	5,430	8,648	10,357	12,708	14,248	14,172	15,195	14,432	15,203	11,558	8,756	7,053	5,857
Residential	3,743	6,762	10,914	14,369	17,997	23,350	24,851	28,033	27,481	28,487	27,576	27,116	23,684	13,705
Business	7,900	13,442	18,850	27,586	37,284	53,269	58,660	63,278	62,914	63,507	55,298	45,929	37,789	27,883
NPLs ratio	5.7	9.5	14.1	21.5	31.3	39.5	43.5	48.1	48.5	48.9	47.2	45.4	40.6	30.2
Consumer	8.7	15.6	26.7	38.1	50.8	55.8	57.8	63.0	62.4	63.8	57.8	53.0	48.6	46.2
Residential	5.4	9.1	14.2	21.2	27.6	34.4	35.6	41.0	41.5	42.0	43.5	44.5	42.4	31.0
Business	5.2	8.3	11.5	18.7	29.3	39.0	45.0	49.0	49.7	49.9	47.4	44.7	38.4	27.8

Source: Bank of Greece – Statistics time series.
Note: All items are on solo basis and refer to on-balance sheet gross loans and advances of Greek commercial and cooperative banks.

(iii) The restructuring of the Greek sovereign debt through the Private Sector Involvement (PSI)

The PSI process involved the exchange of Greek Government Bonds (GGBs) with new bonds at a significant discount. On February 24, 2012, after nine-months of discussions between the Greek Government, its creditors, and official sector lenders on the restructuring feasibility and scope, the Ministry of Finance announced the final debt exchange offer.

This offer permitted private sector holders to exchange selected GGBs and loans granted to companies in the wider public sector with new bonds, EFSF notes and detachable GDP linked securities.

The process was completed on April 25, 2012, having attracted high participation from creditors. About €197 billion bonds, of an eligible total of €205.6 billion, were exchanged for new bonds with longer maturities and lower coupon payments. According to Zettelmeyer et al. (2013), the PSI reduced the debt volume of Greece by €107 billion. A further reduction by €20 billion was achieved after the bond buy-back operation that the Greek government undertook near the end of 2012 (European Stability Mechanism, 2020).

On the other hand, the banks' loss from the debt exchange was estimated at €37.7 billion or approximately 78% of the bonds' face value (Bank of Greece, 2012).

3.3 Recapitalisation and restructuring of the Greek banking sector

During the first years of the Greek sovereign debt crisis, the capital base and the liquidity of the banking system came under strong pressure, affecting its ability to support the private sector during a particularly difficult period. Consequently, funding to enterprises and households was limited, as recorded in the relevant annual negative credit expansion rates as of September 2011

in the case of enterprises, and as of November 2010 in the case of households.[19] Thus, annual credit expansion to domestic private sector by domestic Monetary Financial Institutions (MFIs) volumes in 2012 amounted to -4.0% in total, compared to +15.9% in 2008 and +21.5% in 2007.[20] This lack of bank liquidity was a key mechanism of the transmission of the debt crisis to the real economy.[21]

Moreover, during the January-September 2012 period, the after-tax losses of the Athex-listed Greek commercial banks were €5.7 billion (compared to losses of €4.7 billion, in the January-September 2011 period), mainly due to higher provisioning for credit risk and the banks' participation in the PSI.[22] Liquidity constraints affecting the real economy and difficulties in accessing bank credit would have been far more severe should Greek banks had no access to the Eurosystem monetary policy operations (i.e., emergency liquidity assistance – ELA) and the support of the Bank of Greece.[23] By May 2012, Greek banks had raised €125 billion by the Eurosystem (compared to less than €10 billion in 2007), using government guarantees and banks' assets to cover their emergencies needs (Karavias et al., 2012). Bank pledges that had been used up to that time are estimated at €200 billion, while the total amount that banks had received through state aid equals €98 billion (Masourakis, 2013).

In the light of these conditions, the Bank of Greece and the Greek Government implemented a series of measures to safeguard financial stability and protect the interest of the

[19] Especially for smaller businesses since as known from the literature on the transmission of monetary policy effects through the "credit channel", credit contraction affects mainly smaller business due to their higher usually credit risk and limited access to alternative sources of financing. See: "Monetary Policy - Interim report 2012," Bank of Greece, p. 24-25 (November 2012).

[20] Source: "Bulletin of conjunctural indicators. No 144/May-Jun 2012," Bank of Greece (July 2012), and "Bulletin of conjunctional indicators. No 148/Jan-Feb 2013," Bank of Greece (March 2013).

[21] For a stylised representation of the transmission of the sovereign debt crisis to the real economy via bank funding markets and feedback loops see European Central Bank (2012).

[22] The corresponding figures in the case of the banking groups were €5.1 billion and €4.3 billion, respectively. Source: "Governor's 2012 Annual Report," Bank of Greece (February 2013).

[23] Source: "Monetary Policy - Interim report 2012," Bank of Greece (November 2012).

depositors. These are discussed in more detail below, while it should be noted that during this process, the European Commission, the ECB, and the IMF provided guidance and ensured consistency with the programme's objectives.

In 2012, the Bank of Greece in cooperation with BlackRock Solutions, started an assessment of the capital needs of the Greek banking sector. The capital needs were estimated in May 2012 at €40.5 billion (Bank of Greece, 2012). A significant part of this amount, namely €27.5 billion, corresponded to the four systemic banks (€9.8 billion for National Bank of Greece, €7.3 billion for Piraeus Bank, €5.8 billion for Eurobank and €4.6 billion for Alpha Bank).[24]

In December 2012, the Bank of Greece updated its estimates of the adequacy of the Financial Envelope over the 2012-2014 period to incorporate: (i) the net impact of completed bank resolutions and recapitalisations (€1.4 billion), (ii) the future restructuring costs over and above capital needs (€3.1 billion), and (iii) an appropriate capital buffer (€5.0 billion). The outcome of the Bank of Greece was that the €50 billion earmarked in the Economic Adjustment Programme were appropriate for covering the recapitalisation needs and the restructuring costs of the Greek banks.

In the second quarter of 2013, the four systemic banks (i.e., Alpha Bank, Eurobank, National Bank of Greece and Piraeus Bank) completed their recapitalisation on the basis of the 2012 capital needs assessment.

[24] The components of the €40.5 billion were: (i) starting point, reference CT1 in December 2011 of €22.1 billion, (ii) plus provisions for PSI of €5.8 billion, (iii) minus PSI loss of €37.7 billion, (iv) minus Credit Loss Projections of €46.8, net of loan loss reserves of €24.7 billion, as of December 2011, (v) plus banks' internal capital generation of €11.4 billion, and (vi) minus target CT1 capital level at December 2014 of €20.1 billion.

2013 Stress test of the Greek banking sector - Second recapitalisation

In 2013, the Bank of Greece conducted a follow-up stress test to re-estimate the banks' capital needs, as envisaged in the May 2013 Memorandum of Economic and Financial Policies. Therefore, BlackRock Solutions was commissioned to carry out a second evaluation of the loan portfolios of Greek banks over the period June 2013 – December 2016, while an advisory body with representatives from the Bank of Greece, the EBA, the European Commission, the ECB and the IMF provided guidance.[25] The assessment concluded that the Greek commercial banks would require €6.4 billion to be adequately capitalised,[26] out of which €5.8 billion corresponded to the four systemic banks (i.e., €2.9 billion for Eurobank, €2.2 billion for National Bank of Greece, €0.4 billion for Piraeus Bank, and €0.3 billion for Alpha Bank).[27]

The second recapitalisation of Greek banks took place in April 2014, being funded entirely by private investors who acquired a 27% equity stake in Greek banks in return for an injection of €8.3 billion (i.e., €2.8 billion at Eurobank, €2.5 billion at National Bank of Greece, €1.8 billion at Piraeus Bank, and €1.2 billion at Alpha Bank).

2015 Greek systemic banks comprehensive assessment – Third recapitalisation

In the fall of 2015, ECB conducted an evaluation of the capital needs of the systemic banks in Greece (Alpha Bank, Eurobank, National Bank of Greece, Piraeus Bank).

[25] For a detailed description of the methodology see: "Project Aura. Asset Quality Review and Credit Loss Projection methodology," BlackRock Solutions (March 2014).
[26] The components of the €6.4 billion were: (i) starting point, reference CT1 in June 2019 of €23.0 billion, (ii) minus Credit Loss Projections of €60.2, net of loan loss reserves of €38.4 billion, as of June 2013, (v) plus banks' internal capital generation of €10.3 billion, (vi) minus target CT1 capital level at December 2016 of €17.9 billion.
[27] For more details see: "2013 Stress test of the Greek banking sector," Bank of Greece (March 6, 2014).

The comprehensive assessment comprised an asset quality review (AQR) and a stress test (European Central Bank, 2015), aiming at assessing the capital needs of the banks under the 3rd economic adjustment program for Greece. The test showed a capital shortfall of €4.4 billion under the baseline scenario, and €14.4 billion under the adverse scenario, across the four participating banks (i.e., €4.9 billion for Piraeus Bank, €4.6 billion for National Bank of Greece, €2.8 billion for Alpha Bank and €2.1 billion for Eurobank).[28]

The recapitalisation process had to be finalised by the end of 2015, and eventually €9.1 billion were raised, including €3.4 billion by bondholders, something that minimized the participation of the Hellenic Financial Stability Fund.

[28] For details see: "Aggregate Report on the Greek Comprehensive Assessment 2015," European Central Bank (October 31, 2015).

4 Literature review

This chapter delves into the literature concerning banks' capital needs. It starts by examining studies in regulatory exercises as stress tests and capital exercises, then it looks into studies predicting bank's failure or distress.

4.1 Studies in regulatory stress tests and capital exercises

The 2018 Basel Committee on Banking Supervision "Stress Testing Principles" reflects that today stress testing are a major part of banking risk management and an essential tool for regulatory authorities. The principles focus on the core elements of stress testing frameworks (i.e., objectives, governance, policies, processes, methodology, resources, and documentation), providing considerations for banks and relevant financial authorities (Basel Committee on Banking Supervision, 2018b).

Moreover, according to the "Supervisory and bank stress testing: range of practices" report (Basel Committee on Banking Supervision, 2017), in recent years both banks and supervisory authorities have made significant steps in stress testing methodologies and infrastructure. The report describes and compares supervisory and bank stress testing practices across 24 countries, based on the results of two surveys which were made in 2016 with the participation of 31 distinct authorities and 54 banks accordingly.

A comparative analysis on the system-wide stress tests for banks in the euro area, Japan, Switzerland, and the U.S. has been made by Baudino et al. (2018). The analysis notes three main issues in setting up a stress test – governance, implementation, and outcomes – and relates

them to microprudential and macroprudential policy objectives. It is argued that stress tests are most effective when their design is fully aligned with the policy objectives.

Borio et al. (2012) reviewed the state of the art in macro stress testing, and analyzed the strengths and weaknesses of existing approaches. The authors argue that stress tests can be useful tools for managing the impacts of financial/economic crises on banks, but they are not suitable as early warning systems.

Philippon et al. (2017) provide an evaluation of the quality of banking stress tests in the European Union and found that stress tests are informative and unbiased on average, while Ravitz (2015) compares the requirements of stress tests by the Dodd-Frank Act with those of the Basel III regulation. Additionally, he dissects various supervisory guidance's and explores synergies between various stress testing regulations.

Glasserman and Tangirala (2016) noticed that the rankings according to the projected losses in 2013 and 2014 U.S. stress tests were highly correlated. They discuss the potential implications of these patterns for the development of improved stress tests, arguing that regulators should consider more diverse scenarios, so that higher losses are not always projected for the same banks.

In a stress testing context, Montesi and Papiro (2018) propose a stochastic model, which is based on simulation analysis, which allows the consideration of multiple macroeconomic impacts and scenarios.

Kolari et al. (2019) examine whether the results of stress tests are mainly driven by financial condition and operating environment of individual banks, rather than the scenarios imposed by regulators. They develop an early warning system based on ensemble methods to predict whether European banks pass stress tests in 2010, 2011 and 2014. Based on their results,

the likelihood that a bank will pass the stress tests, mainly depends on the risk characteristics of the bank.

Finally, there are studies on stress testing exercises outcomes communication. For example, Goldstein and Sapra (2013) discuss the optimal level of stress test results disclosure as well as the associated cost-benefit analysis, while European Central Bank (2010) and Bernanke (2013) argue that disclosure can make stress tests a useful tool to respond to a crisis when complemented with other measures (i.e., follow-up actions for banks that performed poorly in a stress test).

4.2. Studies in predicting bank failure or distress

4.2.1 Assessing the soundness of individual banks

Three extensive literature review papers present a wide range of methods and the empirical results concerning banks failure prediction, providing important insights for future research. Demyanyk and Hasan (2009), provide a review of studies that attempt to explain, predict or suggest remedies for financial crises and bank defaults. In the same direction, Bellovary et al. (2007) presented a historical review on general bankruptcy studies including bank failure since 1930, while Zopounidis and Doumpos (2002) provide a literature review on multicriteria decision aid to sorting problems, where a set of alternative actions is classified into several predefined classes.

Some studies provide an assessment for the overall financial strength of banks based either on pairwise comparisons along various criteria (Doumpos and Zopounidis, 2010) or the aggregation of the criteria into a single score through the use of an additive value function (Doumpos et al., 2017).

Other studies have proposed the development of early warning systems to predict bank failures (Kosmidou and Zopounidis, 2008; Manthoulis et al., 2020) or to replicate the assessment of bank creditworthiness issued by rating agencies (Pasiouras et al., 2007; Ioannidis et al., 2010; Bellotti et al., 2011).

Männasoo and Mayes (2009) focus on Eastern European banks during the nineteen-transition period and shows that macroeconomic, structural and bank-specific factors interact in their impact and have a rich dynamic profile which underlines the highly volatile cycles challenging the stability of banks in this region.

Thus, most of these studies: (i) rely on financial ratios of banks, while ignoring systemic risk, market conditions and other bank-specific non-financial attributes, (ii) they model rare events (i.e., failures) or they are based on the assessments of credit agencies that have attracted a lot of criticism, and (iii) they do not offer insights to policy makers for the potential capital needs of banking institutions.

4.2.2 Early-warning systems for the prediction of banking crises at the country-level

Since the 2007-2008 global financial crisis the literature on early warning systems has increased. Several researchers have developed such tools in order to support policy makers in the design of actions to prevent economic and financial crises. For a historical review of a number of bank monitoring systems in various G10 countries used or under development by bank supervisors till 2000 see Sahajwala and Van den Bergh (2000), while Jagtiani et al. (2003) provide a comparison between simple and more sophisticated early warning systems. More recent, Alessi et al. (2015) compare various models for predicting banking crises. Models' relative usefulness is evaluated by a comparison of false alarms and missed crises ratios, and

their results indicates that multivariate models have great potential added value over simple signaling models.

Several studies refer to early-warning systems for the prediction of system-wide banking crises at the country-level (Davis and Karim, 2008; Gutiérrez et al., 2010). However, Bell and Pain (2000) conclude that such models *"are subject to some significant weaknesses and limitations, especially as potential tools for policymakers"* (p. 113). For example, despite the renewed interest in recent years, most of these studies use data from the 1980s and the 1990s when we experienced the bulk of banking crises in emerging markets.

Also, there exist some studies that consider systemic banking crises that occurred in European countries and use more recent data, e.g. Holopainen and Sarlin (2017), and Beutel et al. (2019). However, these studies are not free of all the drawbacks that we discuss in the text; more importantly, they do not provide any information about the capitalization needs of individual banks.

Additionally, Bell and Pain (2000) and Davis and Karim (2008) refer to problems with the definition and dating of the banking crises, the way in which they capture the notion of contagion, and the existence of successions of crises episodes. Further to these shortcomings, these studies do not provide any insights about the weaknesses and capitalization needs of individual banks.

Betz et al. (2014) present an early-warning model for bank distress prediction in Europe. The proposed model combines bank-level and country-level risk indicators, which leads to improved results.

In the same direction, Lang et al. (2018) propose a framework for developing early-warning models with strong forecasting properties. The models were applied to distress prediction in European banks.

Finally, Aldasoro et al. (2018) assess the performance of household and international debt as potential early warning indicators for banking crises. These variables are found to provide valuable information about the risk and stability of a banking system.

4.2.3 Systemic risk of banking institutions

Another stream in the literature has adopted a systemic risk modeling perspective for the analysis of bank failures (Demirgüç-Kunt and Detragiache, 2005; Giesecke and Kim, 2011). Such studies typically use market data, financial models, and network methodologies (Calabrese et al., 2017; Fouque and Ichiba, 2013; Krause and Giansante, 2012; Rogers and Veraart, 2013). This kind of studies adopts a macroprudential approach, relevant to the supervisory and regulatory authorities framework for assessing systemic risks and designing policy measures to safeguard financial stability.

Steffen (2011), Acharya and Steffen (2014), and Acharya et al. (2013) consider the use of public data for developing stress test models for systemic risk analysis in a macroprudential context. Instead of using bank data, these models use historical data about systemic crises, such as capital shortfalls during stress periods as well as historical data about the distribution of specific risk factors.

As discussed in Benoit et al. (2017), four examples of models that estimate the systemic risk of banking institutions are the marginal expected shortfall (MES) and the systemic expected

shortfall (SES) of Acharya et al. (2010), the SRISK of Acharya et al. (2012), and Brownlees and Engle (2017), and the ΔCoVaR of Adrian and Brunnermeier (2014).

Following the popularity of these models, several variations have been proposed. Nonetheless, no matter which approach is being used, these studies tend to focus on the sensitivity of bank's stock returns to extreme shocks and the joint distribution of banks' stock extreme losses or returns. Hence, they are stock market-driven metrics that may ignore other important aspects.

The present study provide an overall decision support framework that takes into account an array of bank and market-specific attributes, including systemic risk and bank fundamentals, hence covering elements of all the three groups of studies discussed above.

5 Empirical setting

This chapter discusses the construction of the dataset, the evaluation criteria, and the modeling specifications. It is divided into different sections where first the data collection and the assumptions made during the construction are presented. Second, the evaluation criteria and their sources are discussed. Finally, it discusses the sampling method used for models construction, and the descriptive statistical analysis of the dataset.

5.1 Data collection

We construct a novel data set that consists of the U.S. and European financial institutions that: (i) participated in one of the regulatory exercises that we discuss in more detail below or (ii) received a capital injection during the period under review (2005Q4 – 2016Q4).

First, we consider banks that participated in the 2009 Supervisory Capital Assessment Program that was conducted by the U.S. federal banking supervisors to assess potential losses and capital shortfalls of the 19 largest U.S. Bank Holding Companies (BHCs). Additionally, we consider BHCs, that were included in subsequent annual *"Comprehensive Capital Analysis and Reviews"* conducted by the Fed over the period 2012-2017.

Second, we consider similar regulatory exercises that were conducted in Europe by the EBA (2012 EU Capital exercise) and the ECB (2014, 2015, and 2016 Comprehensive assessments).[29] Moreover, we consider the independent Asset Quality Reviews (AQRs) that

[29] EBA's Capital exercise was a one-off exercise performed in the context of a series of coordinated policy measures to restore confidence in the EU banking sector. Banks' actual capital positions and sovereign exposures were reviewed for the identification of potential capital buffers needs. ECB's Comprehensive assessments aim to ensure that the supervised by the ECB European banks are adequately capitalized and can withstand possible financial shocks. The assessment usually comprises an AQR (to enhance the transparency of bank exposures), and a stress test (to test the resilience of banks' balance sheets) performed in cooperation with the EBA.

were conducted during 2011-2013 in EU distressed countries under or near financial assistance (Cyprus[30], Greece[31], Ireland[32], Portugal[33], and Spain[34]). Details for the nature and the results of those exercises are presented in Table A4 in the Appendix. Finally, we consider different types of capital injections that took place in Europe from 2008 till 2013 (i.e., capital increase, ordinary and preference shares, recapitalization, hybrid securities, participation certificates, hybrid instrument, contingent capital, CoCo bonds, convertible notes), and in the U.S. during 2008-2009 (i.e., TARP Capital Purchase Program & Targeted Investment Program).

To be included in the final sample, banks must have information for the criteria discussed in subsection 5.2. The final sample comprises 76 large financial institutions (24 from the U.S. and 52 from Europe) operating in 20 countries. The collected data are on a quarterly basis, thus leading to a total of 1,843 bank-quarter observations spanning the period 2005Q4 – 2016Q4. The banks in the sample were classified as banks with capital needs or without capital needs according to the information contained in the above-mentioned regulatory exercises/capital injections. Table A5 in the Appendix provides details about the 76 financial institutions, including the date of the capital shortfall/surplus identification, the amount in local currency, and a short description of the observed event.

Overall, the sample includes 285 events (i.e., 111 for banks with capital needs and 174 for banks without capital needs). As it is common in the literature of early warning systems, we assume that the event occurs in time (i.e., *t*), and we use lagged data up to 12 quarters before

[30] A "Special Assessment of the Effectiveness of Customer Due Diligence Measures in the Banking Sector in Cyprus" has been conducted by Moneyval and Deloitte (April 24, 2013).
[31] For details see: (i) Bank of Greece "Report on the recapitalisation and restructuring of the Greek Banking Sector" (Dec, 2012), and (ii) BlackRock Solutions "Diagnostic Assessment of the Greek Banks" (December 2012).
[32] For details see: Central Bank of Ireland "The Financial Measures Programme Report" (March 2013).
[33] For details see: Ministry of Finance of Portugal, "Ministry of Finance Announcement on the Recapitalisation of the Banking System" (June 4, 2012).
[34] For details see: Ministry of Economy and Competitiveness & Bank of Spain, "Results of the Independent Evaluation of the Spanish Banking Sector" (September 28, 2012).

(i.e., $t - 12q$). The status of the banks was matched with their financial data prior to each event.[35] Thus, a bank with capital shortfall/surplus in year t appears with capital shortfall/surplus in the data set for up to twelve times (depending on the origination of observed events) in quarters $t - 1q$ to $t - 12q$.[36]

Table 3 summarizes the composition of the final sample by the banks' status for each year (2005-2016), as well as the number of banks with or without capital needs by year (from 2008 up to 2016). There appear to be two points in time with increased capital needs. The first was in 2008, shortly after the beginning of the financial crisis. The second, started in 2011 due to the sovereign debt crisis of several Eurozone member states (Cyprus, Greece, Ireland, Portugal, and Spain) and the assistance that they received from other Eurozone countries, the ECB, and/or the IMF.

Figures 6 and 7 present the distribution of the data and the capital needs rate (CNR) across the main U.S. and European geographical regions. In the U.S., most observations involve banks from the northeast region, whereas the southwest represents the smallest part of the sample. In Europe, most observations involve banks from western countries, whereas the eastern countries represent the smallest part of the sample. It is also worth noting that capital needs rates vary considerably across the regions with the northeast having the highest capital needs rate and the west the lowest one in the U.S., while in Europe the highest rates are recorded in the southwest region and the lowest ones in eastern countries.

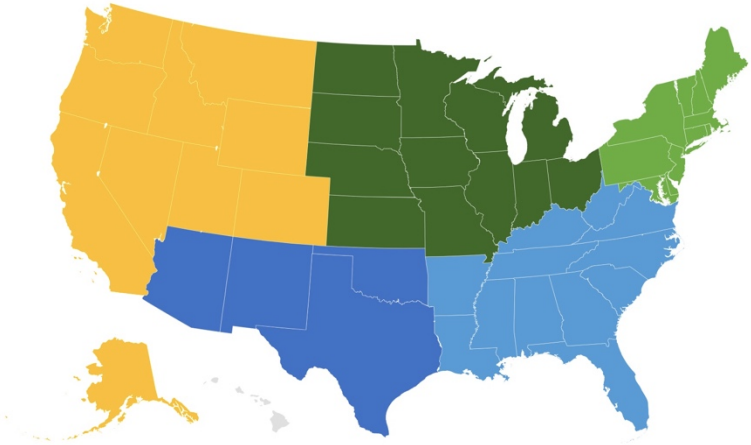
[35] For failure prediction purposes a lag of one-year is usually used (i.e., the data of year $t - 1$ are employed to predict failure in year t). However, a one-year lag may not be enough to derive early warning signals for banks capital shortfall/surplus. Thus, the data used in this study is based on an extended time window that spans a period of up to 12 quarters (i.e., three years) prior to the observation point.

[36] Banks from the U.S. have a two-year window, while those from European counties a three-year one due to the different projection horizons of the mentioned/used regulatory capital exercises.

Table 3. Sample breakdown by banks status, data year and number of banks with/without capital needs by the year of capital needs events

		2005 Q4	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Total
U.S.	bank-quarter observations without capital needs			32	32	30	60	69	82	86	92	92	96	671
	bank-quarter observations with capital needs			36	54	6	8	9	8	6				127
	number of banks events without capital needs				*8*			*15*	*16*	*20*	*23*	*23*	*24*	*129*
	number of banks events with capital needs				*27*	*2*		*2*	*1*	*2*				*34*
EUROPE	bank-quarter observations without capital needs				2	93	100	102	67	72				436
	bank-quarter observations with capital needs	3	54	64	72	109	104	105	52	30	16			609
	number of banks events without capital needs							*27*		*18*				*45*
	number of banks events with capital needs				*9*	*13*	*2*	*25*	*15*	*9*	*4*			*77*
Full sample	bank-quarter observations without capital needs			32	34	123	160	171	149	158	92	92	96	1,107
	bank-quarter observations with capital needs	3	54	100	126	115	112	114	60	36	16			736
	number of banks events without capital needs				*8*			*42*	*16*	*38*	*23*	*23*	*24*	*174*
	number of banks events with capital needs				*36*	*15*	*2*	*27*	*16*	*11*	*4*			*111*

Figure 6. Geographical distributions of U.S. data



Region	Obs	CNR
Northeast	357	5.26%
Southeast	197	3.86%
Midwest	161	1.75%
West	61	1.05%
Southwest	22	–

Figure 7. Geographical distribution of European data

Region	Obs	CNR
Western	312	6.32%
Southeast	282	8.42%
Northern	229	3.51%
Southwest	198	8.77%
Eastern	24	–

5.2 Evaluation criteria

As discussed earlier, to develop a comprehensive decision support system for the identification of banks' capital shortfall/surplus we rely on a wide range of criteria, falling in three general categories: (i) bank-level risk exposure criteria, (ii) other bank-level microeconomic criteria, and (iii) banking and financial market country-level aggregate criteria. We discuss these criteria in more detail below, while Table 4 presents a summary list with the corresponding sources of information.

5.2.1 Bank risk factors

We use three bank-specific risk factors/criteria. The first is taken from the Volatility Laboratory of the New York University Stern School of Business (V–Lab) and measures the capital shortfall of a financial firm in the case of a crisis, defined as a 40% semiannual decline of the world stock market (SRISK). It is based on publicly available information but is conceptually similar to the stress tests conducted by U.S. and European regulators (Acharya et al, 2012).[37]

The second criterion is the forward-looking one-year probability of default (PD) of each bank as estimated by the Credit Research Initiative (CRI) – Risk Management Institute of the National University of Singapore (Duan et al., 2012). This PD estimation is the outcome of a forward intensity model, that is governed by two independent doubly stochastic Poisson processes, operating on forward time instead of spot time, enabling the model to produce

[37] Details about SRISK and other risk measures for major global financial firms may be found at: NYU Stern Volatility Lab / Systemic Risk Analysis.

forward looking PDs of firms based on firm-specific attributes and macro-financial factors (e.g., stock index returns, short-term risk-free rates, etc.).[38]

Finally, the third criterion is another estimation by the CRI, namely the forward-looking one-year actuarial spread (AS) of each bank (Duan, 2014). This PD-based component of credit default swaps (CDS), is the premium rate that reflects the actuarial value of default protection.[39]

5.2.2 Other bank-level data

These data refer to bank-specific attributes, which involve corporate governance and financial data collected from Bloomberg and the banks' annual reports. To account for corporate governance we use the percentage of independent directors. Reports by policy makers and academic studies suggest that banks may benefit from maintaining highly independent boards (Basel Committee on Banking Supervision, 2015; Pathan, 2009; Wang and Hsu, 2013; Akbar et al., 2017). The financial performance criteria are based on the Capital, Asset quality, Management, Earnings, and Liquidity (CAMEL) framework, which is commonly used for the assessment of banks' soundness (Sahajwala and Van den Bergh, 2000). In particular, the following ratios are used in the analysis:

(i) Tier 1 capital ratio (TIER1), for capital adequacy;

(ii) non-performing loans / total loans (NPL), for asset quality;

(iii) efficiency ratio (EFF), for management efficiency;

[38] For details see: The Credit Research Initiative (CRI) – National University of Singapore. "Probability of Default", White Paper (January 8, 2019).
[39] For details see: The Credit Research Initiative (CRI) – National University of Singapore. "Actuarial Spread", White Paper (May 7, 2018).

(iv) return on assets (ROA), for earnings power; and

(v) Cash & Cash Equivalents + Interbanking Assets / Total Deposits + ST Borrowings & Repos (LIQ), for liquidity.

Table 4. Data – Early warning systems criteria & specifications

Specifications			Abbreviation	Criterion	Source	Unit
S1	S2	S4	SRISK	SRISK Capital needs	V–Lab	$ (ml)
			NUS_PD	CRI Probability of Default (1-year)	NUS	Percentage
			NUS_AS	CRI Actuarial Spread (1-year)	NUS	Percentage
	Banking and financial market aggregate conditions		FSI_TIER1	Capital adequacy, Regulatory Tier 1 Capital to Risk-Weighted Assets	IMF	Percentage
			FSI_NPL	Asset quality, Non-performing Loans to Total Gross Loans	IMF	Percentage
			FSI_ROA	Earnings & profitability, Return on Assets	IMF	Percentage
			FSI_LIQ	Liquidity, Liquid Assets to Short Term Liabilities	IMF	Percentage
			FSI_SENS	Sensitivity to market risk, Net Open Position in Foreign Exchange to Capital	IMF	Percentage
			GFDD_FI/DEP	Private credit by deposit money banks to GDP	World Bank	Percentage
			GFDD_FI/ACC	Access, Bank branches per 100k adults	World Bank	Number
			GFDD_FI/EFF	Efficiency, Bank net interest margin	World Bank	Percentage
			GFDD_FI/STAB	Stability, Bank Z-score	World Bank	Percentage
			GFDD_FM/DEP	Stock market capitalization and Outstanding domestic private debt securities to GDP	World Bank	Percentage
			GFDD_FM/ACC	Access, Market capitalization excluding top 10 companies to total market capitalization	World Bank	Percentage
			GFDD_FM/EFF	Efficiency, Stock market turnover ratio	World Bank	Percentage
			GFDD_FM/STAB	Stability, Stock price volatility	World Bank	Number
	S3	S4	GOV_BoD/ID	Governance, Board Independence, Independent Directors	Bloomberg	Percentage
			TIER1	Capital Adequacy, Tier 1 Capital Ratio	Bloomberg	Percentage
			NPL	Asset Quality, NPLs/Total Loans	Bloomberg	Percentage
			EFF	Management Efficiency, Efficiency Ratio	Bloomberg	Percentage
			ROA	Earning Power, Return on Assets	Bloomberg	Percentage
			LIQ	Liquidity, (Cash&Cash Equivalents + Interbanking Assets) / (Total Deposits + ST Borrowings&Repos)	Bloomberg	Percentage

Note: FSI stand for IMF Country Level Core FSIs-Deposit Takers, GFDD FI/ GFDD FM stand for WB Global Financial Development Database, Financial Institutions/ Financial Market.

5.2.3 Banking and financial market aggregate conditions

To account for country-wide conditions in the banking and financial markets, we also consider data from the IMF. In more detail, we use the following five indicators/criteria from the IMF's Country Level Core FSIs – Deposit Takers (International Monetary Fund, 2019):

(i) Regulatory Tier 1 capital to risk-weighted assets (for capital adequacy);

(ii) Nonperforming loans to total gross loans (for asset quality);

(iii) Return on assets (for earnings & profitability);

(iv) Liquid assets to short-term liabilities (for liquidity); and

(v) Net open position in foreign exchange to capital (for sensitivity to market risk).

Moreover, we use eight criteria from the World Bank Global Financial Development Database (WB GFDD), see Čihák et al. (2012). The first four refer to financial institutions:

(i) Private sector credit to GDP (for depth of banking services);

(ii) Commercial banks branches per 100,000 adults (for access to banking services);

(iii) banks' net interest margin (for efficiency of banking institutions); and

(iv) banks' Z-score (for stability of banking institutions).

The other four, describe the conditions in the financial markets:

(i) Stock market capitalization plus outstanding domestic private debt securities to GDP (for depth of the stock market);

(ii) Percent of market capitalization outside of top 10 largest Companies (for access);

(iii) Turnover ratio for stock market (for efficiency of the stock market); and

(iv) Volatility of stock price (for stability of the stock market).

5.3 Modeling specifications

To examine the added value of using different types of information for the prediction of banks' capital needs, we estimate a total of four specifications. On the one hand, a model with a large number of criteria may perform better due to the inclusion of more information into the model. On the other hand, there can also be trade-offs in terms of complexity and time for data collection when using a large set of variables. Hence, the most comprehensive specification S1 may provide the best results, assuming that the information pieces provided by the selected indicators do not cancel out due to the added complexity (i.e., overlaps). The other three specifications explore the information value of risk factors and microeconomic data of the banks, independently or as a whole. In more detail, the four specifications are as follows:

- S1: is the most comprehensive specification, where all the bank-specific criteria are used in the analysis (risk factors, other microeconomic data) together with the country-level data;
- S2: The second specification includes only the external risk assessments for each bank, as estimated by the V–Lab and the CRI;
- S3: This setting considers the CAMEL financial ratios and the board of directors' independence for each bank; and
- S4: The fourth specification combines the external risk assessments (S2) and the other microeconomic data (S3), without considering the country-level indicators.

Table 5 presents the means of all indicators for the two groups of banks (with or without capital needs). In addition the *p*-values according to Mann-Whitney *U* test are presented for the univariate power of the indicators in discriminating between the two classes of banks (those with capital needs versus bank without capital needs).

Table 5. Criterion ratios (means & p-values)

	Global			U.S.			EUROPE		
Abbreviation	capital needs: No	capital needs: Yes	p-value	Capital needs: No	capital needs: Yes	p-value	Capital needs: No	Capital needs: Yes	p-value
SRISK	2.837	3.319	0.059	2.201	2.762	0.000	3.815	3.436	0.000
NUS_PD	0.005	0.014	0.000	0.004	0.018	0.000	0.007	0.013	0.000
NUS_AS	21.110	72.102	0.000	14.439	113.976	0.000	31.377	63.370	0.000
FSI/TIER1	12.214	10.159	0.000	12.563	11.158	0.000	11.676	9.951	0.000
FSI/NPL	4.153	6.688	0.000	2.852	3.579	0.000	6.155	7.336	0.005
FSI/ROA	0.369	0.005	0.000	0.348	0.406	0.000	0.401	-0.079	0.000
FSI/LIQ	72.344	62.671	0.000	74.183	43.874	0.000	69.514	66.592	0.361
FSI/SENs	1.816	7.647	0.000	2.969	9.594	0.000	0.041	7.241	0.000
GFDD/FI_DEP	158.155	135.509	0.000	180.573	189.448	0.000	123.655	124.260	0.058
GFDD/FI_ACC	35.620	44.389	0.000	33.943	34.908	0.000	38.201	46.366	0.000
GFDD/FI_EFF	2.664	1.913	0.000	3.451	3.256	0.000	1.454	1.633	0.000
GFDD/FI_STAB	22.384	12.967	0.000	28.926	26.142	0.000	12.316	10.219	0.000
GFDD/FM_DEP	177.900	116.163	0.000	220.985	230.995	0.000	111.591	92.216	0.000
GFDD/FM_ACC	61.234	44.673	0.000	73.886	73.333	0.000	41.761	38.696	0.000
GFDD/FM_EFF	149.896	103.535	0.000	191.526	236.585	0.000	85.828	75.790	0.000
GFDD/FM_STAB	21.776	26.564	0.000	18.022	18.192	0.651	27.554	28.310	0.363
GOV/BoD_ID	77.238	58.063	0.000	87.486	85.602	0.000	61.467	52.320	0.000
TIER1	12.246	9.540	0.000	12.475	10.319	0.000	11.894	9.378	0.000
NPL	3.440	6.869	0.000	1.069	1.434	0.002	7.089	8.003	0.329
EFF	62.140	111.301	0.524	66.211	73.628	0.761	55.874	119.157	0.000
ROA	0.651	-0.343	0.000	0.944	0.546	0.000	0.201	-0.529	0.000
LI	20.494	14.834	0.000	20.810	16.213	0.109	20.007	14.546	0.000

Our empirical analysis is based on a reverse exercise conceptually similar to a reverse stress testing, based on publicly available information for the construction of a model to estimate potential capital needs of financial institutions with the use of a multi-criteria approach (details are presented in the following chapters, 6 and 7). The dependent variable is based on the results of the aforementioned regulatory exercises and the actual banks' capital injections. Hence, we model whether the banks need capital injections or no.

6 Methodology

This chapter discusses the methodological framework used in the analysis. The first part of the chapter provides a comprehensive description of the multicriteria value-function model used for the classification of the banks. In the second part, the metrics used to assess the classification performance of the model are presented, along with empirical setting used in the analysis.

6.1 Classification method

6.1.1 Multicriteria value–function model

The problem considered in this study falls within the classification (or sorting) problematic. To construct the model for the identification of the weak banks with capital needs we consider a multicriteria technique that relies on an additive value function, which is widely used for credit risk assessment and evaluation purposes of financial institutions (Gaganis et al., 2006; Kosmidou and Zopounidis, 2008; Doumpos et al., 2017):

$$V(\mathbf{x}_i) = \sum_{j=1}^{n} w_j v_j(x_{ij}) \quad (1)$$

where:

- $\mathbf{x}_i = (x_{i1}, x_{i2}, \dots, x_{in})$ is the data vector for bank *i* over *n* attributes (the above described criteria),
- w_j is the trade-off constant (weight) of attribute *j*, and
- $v_j(x_{ij})$ is the marginal value of bank *i* on attribute *j*.

In the additive model (1), the global value $V(\mathbf{x}_i)$ represents an overall performance for each bank-quarter observation *i*, measured on a scale from 0 to 1, with lower values indicating higher likelihood of capital needs.

The marginal value functions $v_j(\cdot), j = 1, \ldots, n$, provide a decomposition of the overall assessment into partial evaluations for each individual criterion. These partial assessments are defined on a 0 to 1 scale, with lower values representing higher likelihood of capital needs according to the corresponding attributes. The marginal value functions are monotone with respect to the attributes (i.e., non-decreasing/non-increasing for attributes that are negatively/ positively associated with the likelihood of a bank facing a capital shortfall). Moreover, the attributes' weights are defined to be non-negative and normalized such that they sum up to 1.

The parameters of model (1) can be estimated using a sample of banks classified into risk classes, based on non-parametric regression-like techniques. In the two-class setting of this study (banks that are likely to face capital shortfalls versus well-capitalized banks), the decision model can be constructed through the solution of the following optimization problem:

$$
\begin{aligned}
\min \quad & \frac{1}{m_1}\sum_{i=1}^{m_1} e_i + \frac{1}{m_2}\sum_{i=1}^{m_2} s_i \\
\text{s.t.} \quad & \sum_{j=1}^{n} w_j v_j(x_{ij}) + s_i \geq b + \delta \quad \text{Well-capitalized banks} \\
& \sum_{j=1}^{n} w_j v_j(x_{ij}) - e_i \leq b - \delta \quad \text{Banks with capital shortfall} \\
& w_1 + w_2 + \cdots + w_n = 1 \\
& w_j, b, e_i,\ s_i, v_j(x_{ij}) \geq 0
\end{aligned}
\tag{2}
$$

where:

- m_1 and m_2 denote, respectively, the number of well-capitalized banks and banks with capital shortfall;
- s_i is the error for the well-capitalized banks;

- e_i is the error for problematic banks;
- δ is a small user-defined constant; and
- $0 \leq b \leq 1$ is the threshold that distinguishes the two groups of banks (i.e., a bank i is considered to be well-capitalized if $V(\mathbf{x}_i) \geq b$).

The objective of the above optimization problem is to develop the additive value model so that the average error for the two classes of banks is minimized. The errors are weighted by the number of observations in each class, in order to mitigate the effect of the class imbalance problem that arises when there are significant differences in the number of observations from the two classes (e.g., the well-capitalized banks are much more than the ones with capital shortfall).

The above optimization problem can be expressed into linear programming form (Doumpos and Zopounidis, 2004). To this end, the marginal value functions in (1) are transformed as $u_j(x_j) = w_j v(x_j)$ for all criteria $j = 1, \ldots, n$, such $u_j(x_j)$ ranges between 0 and w_j. With this transformation the additive function (1) is expressed in the following equivalent form:

$$V(\mathbf{x}_i) = \sum_{j=1}^{n} u_j(x_{ij}) \tag{3}$$

Instead, of prespecifying the form of the marginal value functions, their estimation is based solely on the available data in a training (reference) set, with the only assumption being that they are non-decreasing piece-wise linear.[40] More specifically, denoting by $x_j^{\min}$ and $x_j^{\max}$ the minimum (worst) and maximum (best) levels of criterion j according to a given training set, the range of each criterion j is split into a subintervals $[x_j^0, x_j^1]$, $[x_j^1, x_j^2]$, …, $[x_j^{a-1}, x_j^a]$, where

[40] Without loss of generality, we assume that all evaluation criteria are expressed in maximization form.

$x_j^0 = x_j^{\min}$ and $x_j^a = x_j^{\max}$.[41] Denoting by $p_j^1, p_j^2, \ldots, p_j^a$ the value differences between successive breakpoints of criterion j, i.e., $p_j^k = u_j(x_j^k) - u_j(x_j^{k-1}) \geq 0$ (for $k = 1, \ldots, a$), the marginal value function for any bank i whose performance x_{ij} of criterion j belongs in a subinterval $\left[x_j^{k_j-1}, x_j^{k_j}\right]$ $(1 \leq k_j \leq a)$ is:

$$u_j(x_{ij}) = \sum_{\ell=1}^{k_j-1} p_j^\ell + \frac{x_{ij} - x_j^{k_j-1}}{x_j^{k_j} - x_j^{k_j-1}} p_j^{k_j} \tag{4}$$

With this specification, the weight of criterion j is $w_j = p_j^1 + p_j^2 + \cdots + p_j^a$, whereas the global value (performance score) of bank i according to the additive model (3) is written as:

$$V(\mathbf{x}_i) = \sum_{j=1}^{n} \left(\sum_{\ell=1}^{k_j-1} p_j^\ell + \frac{x_{ij} - x_j^{k_j-1}}{x_j^{k_j} - x_j^{k_j-1}} p_j^{k_j} \right) \tag{5}$$

This additive expression of the additive model (3) is fully defined by the variables $p_j^1, \ldots, p_j^a$ $(j = 1, \ldots, n)$, which can estimated through the solution of the following linear programming formulation of problem (2):

$$\begin{aligned}
\min \quad & \frac{1}{m_1} \sum\nolimits_{i=1}^{m_1} e_i + \frac{1}{m_2} \sum\nolimits_{i=1}^{m_2} s_i \\
\text{s.t.} \quad & V(\mathbf{x}_i) = \sum_{k=1}^{n} \left(\sum_{\ell=1}^{k_j-1} p_j^\ell + \frac{x_j^* - x_j^{k_j-1}}{x_j^{k_j} - x_j^{k_j-1}} p_j^{k_j} \right) \\
& V(\mathbf{x_i}) + s_i \geq b + \delta && \text{Well-capitalized banks} \\
& V(\mathbf{x_i}) - e_i \leq b - \delta && \text{Banks with capital shortfall} \\
& \sum_{j=1}^{n} \sum_{\ell=1}^{a} p_j^\ell = 1 \\
& p_{j\ell}, e_i, s_i, b \geq 0 && \forall\, j, i, \ell
\end{aligned} \tag{6}$$

[41] While the number of subintervals can vary across the criteria, we consider a simpler scheme using a constant set of subintervals. In the present analysis, we used three subintervals of equal width for all criteria.

6.2 Performance metrics

6.2.1 Contingency table and implications

Based on the comparison of the global value $V(\mathbf{x}_i)$ with the threshold b discussed in section 6.1, each bank is classified by the model as a bank with capital needs or a bank with no capital needs. Then, we compare the forecast of the model and the actual outcome. There are four possible outcomes:

(i) correct classification of banks with capital needs when they actually need capital injections;

(ii) correct classification of banks without capital needs when indeed they do not need capital injections;

(iii) wrong classification of a bank that needs capital injections as a bank that does not have capital needs (Type I error); and

(iv) wrong classification of banks as being in need of capital when they actually do not need capital injections (Type II error).

Taking into account, these outcomes and the banks in the two groups as well as the sample as a whole, the discriminatory and predictive power of rating systems is usually assessed based on various statistical metrics (Basel Committee on Banking Supervision, 2005). In the present study we rely on the following ones:

- Sensitivity (SENS), which represents the accuracy rate for banks without capital needs:

$$SENS = \frac{\text{Number of correctly classified banks without capital needs}}{\text{Total number of banks without capital needs}}$$

- Specificity (SPEC), which represents the accuracy rate for the banks with capital needs:

$$SPEC = \frac{\text{Number of correctly classified banks with capital needs}}{\text{Total number of banks with capital needs}}$$

- Average classification accuracy (ACA):

$$ACA = \frac{\text{Sensitivity (SENS)} + \text{Specificity (SPEC)}}{2}$$

- Overall classification accuracy (OCA):

$$OCA = \frac{\text{Number of correctly classified banks}}{\text{Total number of banks}}$$

It should be noted here that the presentation of these mentioned in a classification table may not consider the preferences of the policy makers on the different type of errors. As discussed earlier, the model might identify banks without capital needs as being in need of capital. In this case, the regulator will need to initiate an in-depth review of the bank's fundamentals and business model. While this may not have implications for the credibility of the policy makers, it will result in the waste of scarce resources in terms of personnel time. On the other hand, the model might identify banks with capital needs as not being in need of capital injection. Should the problems accelerate rapidly, the bank could fail, without giving the regulators the opportunity to intervene.

Therefore, one may argue that a policy maker has to be substantially more concerned of missing banks with need of capital injections than issuing false alarms. However, this might not always be the case. As discussed in Sobehart et al. (2000), among others, different decision makers have different cost and payoff structures, and it is therefore difficult to present a single cost function that is appropriate for everyone. Additionally, the case of banks with capital needs

can be seen as a rare event when considering the total bank population. This has implications for the calculation of the total expected costs (EC) of the decision making which is given as $EC = \pi_F E_I C_I + \pi_{NF} E_{II} C_{II}$, with π_F being the prior probability of banks with capital needs, π_{NF}being the prior probability of banks without capital needs, E_I being the type I error, E_{II} being the type II error, and $C_{I(II)}$ the costs for the two types of error. While C_I can possibly be higher than C_{II}, at the same time π_{NF} is much higher than π_F. Therefore, the issue of different costs and its impact on EC, is counterbalanced to some extent. Moreover, as discussed in Theodossiou (1991), in the absence of a specific weighting, the choice of equal weights appears to be a reasonable choice, which justifies the use of ACA as a relevant performance measure in this context. Following many studies in bankruptcy prediction, for the purposes of the present exercise we made no assumptions as for the cost of the two different types of errors. Nonetheless, such regulatory preferences could be taken into account in our framework should a specific regulator has given preferences.

6.2.2 Area Under Receiver Operating Characteristic curve

One way to overcome the above mentioned issue by generalizing the classification tables, is to use the receiver operating characteristic (ROC) curve that assesses the classification performance of a model across all possible cut-off points (Stein, 2002). Every cut-off point on the ROC gives a measure of Type I and Type II errors (Fawcett, 2006). As discussed in Stein (2002), an interesting way to summarize and interpret the graph of the ROC is the area under the curve (AUROC). This is calculated as follows:

$$\text{AUROC} = \int_0^1 F_F(V)\ f_{NF}(V)\, dV$$

where V is the global value score derived from the additive model (1), $F_F(V)$ is the cumulative distribution function of the performance scores (V) for banks with capital needs, and $f_{NF}(V)$ is the probability density function of the performance scores for banks without capital needs (Hand and Till, 2001).

6.2.3 Kolmogorov Smirnov distance

Apart from the above-mentioned measures we also consider the independent samples Kolmogorov-Smirnov distance (KS), which indicates the distance between the cumulative distribution functions of the global values of the banks in the two classes:

$$\text{KS} = \max_{0 \le V \le 1} |F_F(V) - F_{NF}(V)|$$

In other worlds, the Kolmogorov-Smirnov metric shows the maximum difference between the probability that a bank has not capital needs and is rejected, and the probability that a bank has capital needs and is rejected (Crook et al., 2007).

All the measures range between 0 and 1, with higher values indicating models with higher discriminating power.

6.3 Experimental design

The predictive power of the models, in forecasting the capital needs of the banks, is tested on a 70% training – 30% testing partitioning of the sample, as well as through bootstrap resampling. The latter is applied in two different ways. First, 1000 standard bootstrap tests are performed, by resampling with replacement from the full data set. However, in this setting, the panel

structure of the data set is not taken into consideration as the bootstrap samples are constructed by sampling with replacement from the full data set. This leads to out-of-the bootstrap samples that do not truly correspond to out-of-sample results. Due to the panel structure of the data, it is likely that an out-of-bootstrap sample will include an observation corresponding to a bank i for period t, while the corresponding bootstrap (i.e., training) sample will include an observation for the same bank in a different period $t' \neq t$. Therefore, there can be some overlap, leading to upward biased results.

To overcome this limitation, we additionally construct bootstrap samples by sampling with replacement from the set of unique banks in the full data set, rather than the individual bank-quarter observations. This leads to bootstrap samples that include all observations from banks selected with replacement, whereas the out-of-the-bootstrap samples include observations from banks not in the bootstrap sample. This procedure guarantees that the out-of-bootstrap samples will not have any overlap with the bootstrap samples, because the data set is split into non-overlapping partitions. The consideration of these different sampling schemes enables us to examine the robustness of the results over various ways of fitting and testing the models.

7 Empirical results

This chapter presents the results of the analysis. The first part of the chapter presents the results achieved by testing procedures, across specifications, performance metrics, and prediction horizon. The second part provides a comparison of the obtained results with the ones of others widely known and used measures.

7.1 Results by testing procedures

This section presents the results obtained through the three testing procedures described in the previous subsection (70% training – 30% testing sample segmentation, 1000 bootstrap tests, and 1000 out-of-sample bootstrap tests), the different specifications outlined in section 5.3 (specifications S1, S2, S3, and S4), and across the various geographical areas of our sample (full sample, U.S., and Europe).

Tables 6, 7 and 8 present the results of the analysis regarding the importance of the criteria that have been used for the identification of banks with a capital shortfall.

Table 6. Importance of criteria in the prediction models (sample partitioning: 70% training – 30% testing)

	Global				U.S.				EUROPE			
Criterion/ Model	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
SRISK	1.22	0.75	-	0.32	0.98	0.47	-	2.67	0.74	0.39	-	0.24
NUS_PD	5.83	7.41	-	8.67	2.03	4.50	-	2.46	1.34	9.53	-	4.96
NUS_AS	0.72	**91.84**	-	7.08	0.22	**95.03**	-	**43.25**	2.88	**90.08**	-	**30.55**
FSI/TIER1	2.76	-	-	-	2.56	-	-	-	4.11	-	-	-
FSI/NPL	0.49	-	-	-	7.74	-	-	-	0.17	-	-	-
FSI/ROA	9.08	-	-	-	1.61	-	-	-	6.00	-	-	-
FSI/LIQ	1.23	-	-	-	1.40	-	-	-	0.16	-	-	-
FSI/SENs	10.00	-	-	-	5.18	-	-	-	18.51	-	-	-
GFDD/FI_DEP	1.60	-	-	-	1.68	-	-	-	0.54	-	-	-
GFDD/FI_ACC	0.10	-	-	-	11.73	-	-	-	0.87	-	-	-
GFDD/FI_EFF	0.09	-	-	-	9.00	-	-	-	1.89	-	-	-
GFDD/FI_STAB	0.16	-	-	-	7.34	-	-	-	0.57	-	-	-
GFDD/FM_DEP	3.83	-	-	-	0.43	-	-	-	2.39	-	-	-
GFDD/FM_ACC	0.12	-	-	-	1.95	-	-	-	3.95	-	-	-
GFDD/FM_EFF	7.75	-	-	-	9.83	-	-	-	3.29	-	-	-
GFDD/FM_STAB	0.52	-	-	-	0.14	-	-	-	9.67	-	-	-
GOV/BoD_ID	2.31	-	10.99	9.67	3.25	-	6.53	5.35	5.57	-	5.93	4.71
TIER1	**43.60**	-	**66.65**	**56.47**	3.99	-	23.07	18.74	**19.25**	-	**46.55**	28.57
NPL	0.54	-	8.36	8.25	**21.81**	-	16.04	15.20	0.22	-	4.40	6.00
EFF	0.32	-	2.17	1.33	0.19	-	**43.33**	6.63	0.35	-	13.30	2.49
ROA	4.96	-	10.73	6.86	6.79	-	8.66	2.19	11.68	-	21.24	12.72
LI	2.76	-	1.10	1.35	0.16	-	2.36	3.51	5.87	-	8.56	9.76

Note: The most important criteria are marked in bold.

Table 7. Importance of criteria in the prediction models (standard bootstrap average weights and standard deviations)

	Global				U.S.				EUROPE			
Criterion/ Model	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
SRISK	0.68	0.56	-	0.33	1.17	0.40	-	1.78	0.49	0.33	-	0.19
	(0.02)	(0.01)		(0.01)	(0.04)	(0.01)		(0.05)	(0.02)	(0.00)		(0.00)
NUS_PD	7.25	10.30	-	8.41	0.94	5.69	-	4.40	3.94	14.62	-	10.13
	(0.11)	(0.20)		(0.12)	(0.03)	(0.12)		(0.13)	(0.11)	(0.27)		(0.19)
NUS_AS	5.36	**89.14**	-	15.81	0.82	**93.91**	-	**37.58**	2.29	**85.04**	-	20.32
	(0.12)	(0.20)		(0.17)	(0.04)	(0.12)		(0.27)	(0.05)	(0.27)		(0.28)
FSI/TIER1	4.97	-	-	-	3.15	-	-	-	5.77	-	-	-
	(0.05)				(0.09)				(0.05)			
FSI/NPL	1.95	-	-	-	6.82	-	-	-	0.35	-	-	-
	(0.05)				(0.12)				(0.01)			
FSI/ROA	8.87	-	-	-	0.36	-	-	-	11.55	-	-	-
	(0.14)				(0.02)				(0.18)			
FSI/LIQ	0.92	-	-	-	3.17	-	-	-	0.20	-	-	-
	(0.02)				(0.11)				(0.01)			
FSI/SENs	11.09	-	-	-	4.27	-	-	-	**17.15**	-	-	-
	(0.07)				(0.11)				(0.07)			
GFDD/FI_DEP	1.09	-	-	-	2.97	-	-	-	0.59	-	-	-
	(0.03)				(0.07)				(0.02)			
GFDD/FI_ACC	0.31	-	-	-	6.09	-	-	-	1.47	-	-	-
	(0.01)				(0.12)				(0.03)			
GFDD/FI_EFF	0.14	-	-	-	11.58	-	-	-	1.17	-	-	-
	(0.00)				(0.16)				(0.04)			
GFDD/FI_STAB	0.66	-	-	-	2.93	-	-	-	1.88	-	-	-
	(0.02)				(0.10)				(0.04)			
GFDD/FM_DEP	2.50	-	-	-	0.80	-	-	-	2.02	-	-	-
	(0.03)				(0.03)				(0.02)			
GFDD/FM_ACC	0.14	-	-	-	3.35	-	-	-	3.17	-	-	-
	(0.00)				(0.07)				(0.03)			
GFDD/FM_EFF	7.44	-	-	-	11.15	-	-	-	3.95	-	-	-
	(0.04)				(0.08)				(0.02)			
GFDD/FM_STAB	0.44	-	-	-	0.74	-	-	-	7.33	-	-	-
	(0.02)				(0.03)				(0.06)			
GOV/BoD_ID	3.34	-	10.53	9.07	3.49	-	8.35	4.72	5.38	-	6.17	5.15
	(0.04)		(0.06)	(0.06)	(0.06)		(0.09)	(0.08)	(0.03)		(0.04)	(0.04)
TIER1	**31.87**	-	**60.68**	**45.37**	6.93	-	**34.72**	24.26	15.45	-	**42.87**	**31.29**
	(0.14)		(0.21)	(0.19)	(0.09)		(0.21)	(0.11)	(0.15)		(0.30)	(0.21)
NPL	1.14	-	9.27	9.00	**20.74**	-	15.35	13.05	0.27	-	6.01	6.32
	(0.04)		(0.08)	(0.08)	(0.10)		(0.10)	(0.09)	(0.01)		(0.09)	(0.07)
EFF	0.30	-	3.77	1.68	0.83	-	25.34	6.04	0.31	-	13.36	4.14
	(0.00)		(0.09)	(0.03)	(0.05)		(0.31)	(0.14)	(0.00)		(0.25)	(0.11)
ROA	5.97	-	14.21	8.58	7.41	-	14.97	5.00	8.82	-	21.59	12.47
	(0.09)		(0.15)	(0.09)	(0.05)		(0.19)	(0.06)	(0.09)		(0.23)	(0.11)
LIQ	3.58	-	1.53	1.73	0.26	-	1.28	3.17	6.47	-	9.99	9.99
	(0.03)		(0.03)	(0.03)	(0.02)		(0.04)	(0.07)	(0.06)		(0.10)	(0.10)

Note: The most important criteria are marked in bold.
Note: Parentheses indicate standard deviations.

Table 8. Importance of criteria in the prediction models (out-of-sample bootstrap average weights and standard deviations)

	Global				U.S.				EUROPE			
Criterion/ Model	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
SRISK	0.83	0.72	-	0.64	3.63	1.04	-	4.25	0.65	0.43	-	0.38
	(0.03)	(0.03)		(0.02)	(0.14)	(0.05)		(0.14)	(0.03)	(0.02)		(0.02)
NUS_PD	4.61	12.83	-	7.95	1.01	7.34	-	6.57	2.36	16.54	-	8.84
	(0.13)	(0.39)		(0.19)	(0.05)	(0.35)		(0.24)	(0.09)	(0.38)		(0.26)
NUS_AS	5.60	**86.45**	-	15.99	1.24	**91.63**	-	**31.19**	1.41	**83.03**	-	17.08
	(0.16)	(0.39)		(0.31)	(0.08)	(0.35)		(0.54)	(0.05)	(0.38)		(0.36)
FSI/TIER1	7.13	-	-	-	3.79	-	-	-	7.76	-	-	-
	(0.13)				(0.11)				(0.11)			
FSI/NPL	2.06	-	-	-	5.51	-	-	-	0.99	-	-	-
	(0.07)				(0.12)				(0.04)			
FSI/ROA	6.49	-	-	-	0.13	-	-	-	9.12	-	-	-
	(0.19)				(0.01)				(0.24)			
FSI/LIQ	2.37	-	-	-	4.21	-	-	-	0.75	-	-	-
	(0.07)				(0.14)				(0.04)			
FSI/SENs	10.54	-	-	-	3.34	-	-	-	12.41	-	-	-
	(0.17)				(0.10)				(0.21)			
GFDD/FI_DEP	2.56	-	-	-	2.40	-	-	-	3.58	-	-	-
	(0.11)				(0.06)				(0.14)			
GFDD/FI_ACC	1.46	-	-	-	5.50	-	-	-	2.69	-	-	-
	(0.06)				(0.15)				(0.09)			
GFDD/FI_EFF	0.42	-	-	-	10.64	-	-	-	2.20	-	-	-
	(0.03)				(0.15)				(0.09)			
GFDD/FI_STAB	1.34	-	-	-	2.88	-	-	-	2.36	-	-	-
	(0.05)				(0.12)				(0.07)			
GFDD/FM_DEP	2.10	-	-	-	1.05	-	-	-	1.90	-	-	-
	(0.08)				(0.06)				(0.08)			
GFDD/FM_ACC	1.13	-	-	-	4.55	-	-	-	3.13	-	-	-
	(0.07)				(0.10)				(0.08)			
GFDD/FM_EFF	5.74	-	-	-	10.30	-	-	-	5.32	-	-	-
	(0.11)				(0.10)				(0.09)			
GFDD/FM_STAB	1.13	-	-	-	0.86	-	-	-	5.38	-	-	-
	(0.05)				(0.04)				(0.13)			
GOV/BoD_ID	3.95	-	10.82	9.29	5.26	-	10.07	7.11	5.92	-	8.79	7.58
	(0.10)		(0.16)	(0.15)	(0.17)		(0.22)	(0.20)	(0.09)		(0.16)	(0.14)
TIER1	**27.88**	-	**53.45**	**42.05**	8.10	-	**35.55**	25.95	**13.80**	-	**41.02**	**31.20**
	(0.25)		(0.36)	(0.30)	(0.16)		(0.30)	(0.22)	(0.18)		(0.41)	(0.29)
NPL	1.72	-	8.98	8.65	**16.49**	-	11.55	9.08	0.99	-	7.23	6.86
	(0.07)		(0.17)	(0.15)	(0.23)		(0.22)	(0.19)	(0.05)		(0.16)	(0.15)
EFF	0.27	-	5.44	1.88	0.81	-	21.15	4.82	0.35	-	10.32	4.14
	(0.00)		(0.18)	(0.05)	(0.04)		(0.43)	(0.21)	(0.02)		(0.32)	(0.16)
ROA	6.53	-	17.28	9.34	6.50	-	19.80	6.73	9.63	-	21.57	13.20
	(0.15)		(0.24)	(0.15)	(0.14)		(0.35)	(0.18)	(0.20)		(0.30)	(0.22)
LIQ	4.13	-	4.02	4.21	1.81	-	1.88	4.30	7.30	-	11.08	10.73
	(0.08)		(0.13)	(0.13)	(0.09)		(0.10)	(0.12)	(0.12)		(0.19)	(0.18)

Note: The most important criteria are marked in bold.
Note: Parentheses indicate standard deviations.

7.1.1 Results across specifications

The results show that when we focus on specification S1 that includes all the variables, the Tier 1 capital ratio (TIER1) and country-level sensitivity to market risk (FSI/SENs) are the most important criteria in the case of the full sample (Global). This holds regardless of whether we focus on the 30/70 sampling (Table 4), the standard bootstrap (Table 5) or the out-of-sample bootstrap (Table 6) with the two aforementioned criteria accounting together from 38.42% to 53.60% of the importance of all the criteria.

However, when we split the sample into the U.S. and the European countries there appear to be important differences between the two. This reflects possible differences between U.S. and European regulators concerning the criteria that drive the decision as for whether a bank needs capital or not. More detailed, in the case of the U.S., asset quality (NPL) as well as GFDD financial institutions and financial markets efficiency (GFDD/FI_EFF, GFDD/FM_EFF) are the most important criteria. In contrast, in the case of the corresponding specification for the European S1 model, the most important criteria are the Tier 1 capital ratio (TIER1) and the country-level FSI sensitivity to market risk (FSI_SENS), followed by return on assets (ROA). Such differences in our findings could possibly be explained by differences in the stress tests / capital exercises, the supervision and regulatory approaches, and the operating environment in the two regions. For example, the regulatory capital threshold used to calculate capital shortfalls in the V–Lab's SRISK indicator is set to 8% for banks in Africa, Asia and Americas and 5.5% for banks in Europe due to differences in accounting standards (Engle & Zazzara, 2017).

Furthermore, Pugliese (2016) highlights that the EU and U.S. apply differently the standards of the Basel Committee and they have different systems of financial supervision. She also argues that the EU establishes norms that lower the banking risk exposure without

excessively braking their activity, while the U.S. does not allow those operations that could expose banking institutions to higher risks.

Besides, there can be differences in the regulatory exercises across various dimensions between the two regions. For example, Ahnert et al. (2020) compare the stress-tests in the two regions, and highlight that the US CCAR evaluates banks based on a quantitative as well as a qualitative dimension, whereas the EBA only assesses the quantitative information.

Also, the Federal Reserve Bank in the US uses its own models to estimate profit and loss implications of the stress test, whereas the EBA approach relies on bank internal models. Consequently, the European stress tests are being regarded as less homogenous than the US ones. Along the same lines, Steffen (2014) reveals various differences between the 2014 US Comprehensive Capital Analysis and Review and the EBA comprehensive assessment for the same year, like for example that the regulatory thresholds for the capital ratios vary, there is an evolving (CCAR) vs static balance sheet assumption (EBA), etc.

Turning to specification S2 that includes the three market-driven risk criteria, the CRI actuarial spread (NUS_AS), is by far, the most important one regardless of the geographical orientation of the model.

Similarly, we observe that in the case of specification S3 that includes the financial and corporate governance data, there appears to be a great extent of consistency across the sampling approaches and geographical regions, with the Tier 1 capital ratio being the most important attribute (TIER1). The only exception is the U.S. data set in the case of the 30/70 partitioning where the importance of the efficiency ratio (43.33%) exceeds that of the Tier 1 capital ratio (23.07%).

Finally, in the case of specification S4 that includes all the bank-specific attributes (financial market driven risk, and governance), there appear to be two criteria that account together for around 50% to 60% in most estimations, namely the Tier 1 capital ratio and the CRI actuarial spread (NUS_AS). As before, we observe some differences between the U.S. and the European countries. While in most cases the Tier 1 capital ratio is the most important among the two criteria in the European countries, this is reversed in the case of the U.S.

Further to the above, it is also of interest to have a more general view for the importance of the criteria by category (i.e., market risk, market conditions, financial attributes) rather than on an individual basis. Naturally, in this occasion, we turn the spotlight on specifications S1 and S4. Starting with S4, we observe that, in general, the financial attributes play collectively a more important role than the market-driven indicators. However, the contribution of the two categories is more balanced in the case of U.S. data set compared to the one for Europe. In this latter case, the financial data appear to be more important (as a whole) than the market-driven risk indicators. Nonetheless, the importance of the market-driven risk metrics diminishes considerably when we account for market conditions in specification S1. Collectively, the importance of the market conditions range from 37.73% (Global sample, 30/70 sample split) to 60.59% (U.S. sample, 30/70 sample split), while the market driven risk indicators weight from something between 2.93% (U.S. sample, standard bootstrap) to 13.29% (Global sample, standard bootstrap).

7.1.2 Results across the performance metrics

Table 9 presents the obtained classification results across the performance metrics described earlier. In each case. Since the results in the training sample are upwards biased, we focus on the classification accuracies in the testing sample. In all cases, the highest average and overall

classification accuracy (ACA and OCA) are achieved by specification S1, regardless of whether we consider the global sample or the two regional samples. As expected, the most optimistic results are the ones obtained by the 70/30 partitioning and the less pessimistic are the ones obtained by the out-of-sample bootstrap approach. To be more precise, taking the S1 and the Global sample as an example, the OCA in the case of the testing data set equals 87.52% (70%/30%), 85.64% (standard bootstrap), and 79.48% (out-of-sample bootstrap). The results for ACA are very comparable. At the same time, the model achieves very balanced classification accuracies between the two groups – hence the rates of the two types of error are approximately the same. In the case of the global sample and the 70%-30% data set partitioning, the accuracy rate for banks without capital needs (SENS) in the testing sample is 86.17%, while the accuracy rate for banks with capital needs (SPEC) is 89.26%. The corresponding results for the standard bootstrap are 84.73% and 87.01%, and the ones for the out-of-sample bootstrap are 78.90% and 80.21%, respectively.

We now turn our attention to AUROC, which as discussed earlier, provide an overall assessment across all the cut-off points. Similarly to the classification metrics discussed above, the accuracy of the model differs, to some extent, across the alternative sample partitioning approaches. Consistent with previously described classification metrics, the simplest approach (70/30 sample partitioning) provides the most optimistic AUROC results for specification S1, i.e., 93.70% for global, 95.79% for U.S., and 92.32% for Europe. However, given that this approach is more naïve, one may easily argue in favor of the resampling testing procedures, despite the fact that they provide less optimistic AUROC estimates, ranging between 90.32% and 92.63% for specification S1 under the standard bootstrap, and 80.61 – 86.99% under the out-of-sample bootstrap. We also observe that in all cases, the predictions for banks with capital needs are better for U.S. institutions rather than the European ones. While in some cases the difference is small (e.g., 1.49% in the case of the out-of-sample bootstrap for specification S3),

there are also cases with notable differences. Especially, in the case of specification S2, the differences range approximately between 16 – 21%, possibly reflecting differences in the importance assigned to the market driven risk metrics across the two continents.

Table 9. Capital needs prediction models classification results

		Global				U.S.				EUROPE			
Sample partition:		S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
70% training - 30% testing													
training	SENS	**86.93**	45.85	84.30	84.55	**84.39**	69.82	79.47	80.90	**87.06**	69.26	80.26	81.55
	SPEC	**85.43**	95.14	82.19	83.20	**93.10**	75.86	81.61	82.76	**87.71**	50.12	76.17	76.90
	ACA	**86.18**	70.50	83.24	83.87	**88.75**	72.84	80.54	81.83	**87.39**	59.69	78.21	79.23
	OCA	**86.36**	64.73	83.49	84.03	**85.71**	70.73	79.79	81.18	**87.43**	58.38	77.93	78.91
testing	SENS	**86.17**	37.94	83.60	83.92	**82.61**	61.96	83.15	81.52	**84.25**	68.50	81.10	79.53
	SPEC	**89.26**	96.69	85.95	87.19	**97.50**	82.50	82.50	92.50	**88.12**	49.01	80.20	81.68
	ACA	**87.71**	67.32	84.78	85.56	**90.05**	72.23	82.83	87.01	**86.19**	58.76	80.65	80.61
	OCA	**87.52**	63.65	84.63	85.35	**85.27**	65.63	83.04	83.48	**86.63**	56.53	80.55	80.85
	AUROC	**93.70**	75.15	90.27	91.39	**95.79**	81.33	91.97	93.78	**92.32**	60.17	86.71	86.17
Standard bootstrap													
training	SENS	**86.02**	51.23	84.16	83.98	**84.35**	74.99	79.15	81.40	**87.25**	72.90	81.33	81.76
	SPEC	**88.33**	88.71	83.06	84.20	**94.90**	70.08	85.10	85.95	**88.24**	47.02	77.45	78.79
	ACA	**87.17**	69.97	83.61	84.09	**89.63**	72.53	82.12	83.68	**87.75**	59.96	79.39	80.28
	OCA	**86.94**	66.20	83.72	84.07	**86.03**	74.20	80.09	82.13	**87.83**	57.82	79.07	80.03
	AUROC	**92.58**	76.29	89.25	90.15	**94.79**	78.80	88.65	91.26	**91.55**	62.52	85.85	86.46
testing	SENS	**84.73**	50.82	83.69	83.19	**83.23**	74.87	78.45	80.57	**86.12**	72.77	79.65	80.60
	SPEC	**87.01**	88.06	82.42	83.20	**90.15**	68.73	81.01	81.38	**86.76**	46.78	75.96	77.46
	ACA	**85.87**	69.44	83.06	83.24	**86.69**	71.80	79.73	80.97	**86.44**	59.77	77.81	79.03
	OCA	**85.64**	65.70	83.18	83.24	**84.32**	73.89	78.86	80.70	**86.49**	57.62	77.50	78.77
	AUROC	**91.72**	76.23	88.83	89.63	**92.63**	78.62	86.71	89.09	**90.32**	62.47	84.35	85.12
Out-of-sample bootstrap													
training	SENS	**87.99**	55.34	85.75	85.45	**87.21**	76.14	80.92	84.09	**87.92**	74.00	82.39	82.82
	SPEC	**88.76**	84.36	83.41	84.52	**95.32**	69.88	86.04	87.97	**90.81**	46.45	80.65	81.46
	ACA	**88.37**	69.85	84.58	84.98	**91.27**	73.01	83.48	86.03	**89.36**	60.22	81.52	82.14
	OCA	**88.32**	67.39	84.84	85.09	**88.51**	75.22	81.78	84.72	**89.59**	57.93	81.34	82.00
	AUROC	**93.38**	76.46	90.00	90.87	**95.88**	79.31	89.97	92.72	**93.39**	62.76	87.35	87.89
testing	SENS	**78.90**	55.12	81.75	81.06	**83.03**	75.11	78.57	79.83	**73.14**	71.67	72.61	73.26
	SPEC	**80.21**	82.45	78.12	78.89	**73.79**	65.01	65.76	65.70	**77.92**	45.87	72.58	73.94
	ACA	**79.55**	68.79	79.93	79.97	**78.41**	70.06	72.17	72.76	**75.53**	58.77	72.60	73.60
	OCA	**79.48**	65.79	80.43	80.28	**81.21**	73.29	76.42	77.48	**75.75**	56.68	72.51	73.63
	AUROC	**86.99**	76.32	86.19	87.05	**86.73**	78.00	80.36	81.31	**80.61**	61.97	78.87	79.73

Note: The highest classification accuracy are marked in bold.

7.1.3 Results by prediction horizon

Table 10 presents additional results using data from different time periods (quarters) prior to the observed re-capitalization event (i.e., different lags). Aggregating the quarterly results to present them on a yearly basis, shows that the global S1 model (i.e., full sample, all variables) achieves strong AUROC results, of 90.48% at the 1-year horizon (i.e., first 4 quarters), and 78,88% at the 2-year horizon. However, this deterioration in performance is to be expected as we move further away from the observed event, and hence the attributes of the banks and the countries may not be so distinct.

Examining the results over the different geographical areas, some discrepancies are observed, with the U.S. S1 model achieving an AUROC of 86.51% at the 1-year horizon (i.e., aggregate over the first four quarters) and 72.42% at 2-year, respectively. As far as the European S1 model is concerned, the AUROC varies from 85.01% at the 1-year horizon, 78.62% at the 2-year period, and 67.38% at the 3-year horizon.

Table 10. Data on Financial institution capital shortfall/surplus – S1 specifications models (out-of-sample bootstrap)

	Global					U.S.					EUROPE				
Quarters before capital shortfall/ surplus	OCA (%)		AUROC (%)		KS (%)	OCA (%)		AUROC (%)		KS (%)	OCA (%)		AUROC (%)		KS (%)
t – 1q	85.91		91.79		75.67	86.73		87.40		74.18	80.74		87.10		70.14
t – 2q	86.16	*t – 1y*	91.05	*t – 1y*	74.68	*t – 1y*	*t – 1y*	86.34	*t – 1y*	73.34	*t – 1y*	*t – 1y*	85.58	*t – 1y*	68.88	*t – 1y*
t – 3q	84.73	84.67	89.97	90.48	72.83	71.76	84.61	85.04	86.51	71.40	69.74	79.08	83.68	85.01	64.24	65.15
t – 4q	80.09		86.93		69.45	76.54		86.60		71.82	79.81		83.02		68.12	
t – 5q	73.07		80.51		59.09	63.38		73.64		57.23	76.55		80.48		62.59	
t – 6q	70.29	*t – 2y*	76.61	*t – 2y*	54.77	*t – 2y*	*t – 2y*	71.70	*t – 2y*	55.42	*t – 2y*	*t – 2y*	77.16	*t – 2y*	59.24	*t – 2y*
t – 7q	71.36	71.50	79.19	78.88	56.62	54.21	62.68	73.47	74.42	58.18	51.66	74.93	81.37	78.62	62.62	56.80
t – 8q	71.10		79.31		58.94	60.53		61.52		72.96	70.95		74.07		53.86	
t – 9q	-		-		-	-		-		-	67.57		70.16		48.81	
t – 10q	-	*t – 3y*	-	*t – 3y*	-	*t – 3y*	*t – 3y*	-	*t – 3y*	-	*t – 3y*	*t – 3y*	67.77	*t – 3y*	45.30	*t – 3y*
t – 11q	-	-	-	-	-	-	-	-	-	-	-	67.31	64.23	67.38	40.54	39.88
t – 12q	-		-		-	-		-		-	86.64		-		-	

Note: Results are based on Test Sample.

7.2 Comparison with other measures

In order to further assess the predictive power of our UTADIS-based models, we compare the results with a model developed with logistic regression (LR) as well as with two widely used measures: (i) the SRISK, discussed earlier in section 5.2.1, and (ii) the Texas Ratio of RBC Capital Markets.

The Texas Ratio was developed by RBC Capital Markets during the early 1980s while analyzing the recession of the banking industry in Texas. It is the ratio of a bank's non-performing assets to the sum of its tangible capital and loan loss reserves. If the ratio is ≥100%, the bank is at severe risk of failure since it might not have enough capital to cover its losses (Jesswein, 2009; Siems, 2012).

We focus on the results obtained with the use of the most comprehensive specification S1 and the out-of-sample bootstrap approach in the case of UTADIS and LR. As show in Table 11, the predictive power of the UTADIS-based models is superior to either the LR-based one or the one of the SRISK and the Texas Ratio. In more detail, LR achieves overall classification accuracies equal to 66.04% (Europe), 77.47% (Global), and 80.87% (U.S.), while the corresponding AUROC figures are 69.13 (Europe), 81.94 (Global) and 86.24 (U.S.).[42] The overall classification accuracies of the SRISK and Texas Ratio (TR) are in general lower, for example being 52.85% (SRISK) and 68.99% (TR) in the case of the Global sample, 46.12% and 84.42% in the case of the U.S. sample, and 57.99% and 52.20% in the case of Europe.

However, both SRISK and TR appear to be successful in identifying banks from one of the two groups only. In more detailed, SRISK classifies correctly only 29.99% of the banks

[42] For illustrative purposes and to be more informative, Table A6 in the Appendix provides a bank-by-bank comparison between our decision support system / Capital Needs Prediction Model & Logistic Regression model (Global S1 specification, 1000 out-of-sample bootstrap sample segmentation), SRISK, Texas Ratio, and the actual results as of December 2011.

without capital needs (SENS) in the Global sample, and TR classifies correctly only 19.53% of the banks with capital needs (SPEC). As a result both show a relatively poor performance in terms of the average classification accuracy (ACA) and AUROC. Nonetheless, it should be noted that our UTADIS and LR models contain several criteria, including SRISK, a bank-specific NPL ratio, and a market-wide NPL ratio, whereas the SRISK and the Texas Ratio have been developed for specific, possibly more narrow, purposes. For example, the Texas Ratio focuses solely on the overall credit quality of the bank's loan portfolio. Even within this context though, its value may be questioned as it assesses the state of the loan portfolio as a total and it does not examine the composition of the loan portfolio and differences across different types of loans.

Finally, it ignores share price information which can be observed in real time and relies only on financial data information that is reported with a lag. In contrast, SRISK considers share price information but ignores valuable information that can be obtained from the financial statements. At the same time, preliminary evidence in the literature suggests that market-based signals became less informative at the depth of the recent financial crisis (Friend and Levonian, 2013). Therefore, a model like the one that we propose in the present study that combines information from various sources into a single metric and is customized for analyzing and predicting the outcomes of stress tests and capital exercises can be more valuable from the perspective of a decision support system.

Table 11. Comparison of Capital Needs Prediction Model classification results with Logistic Regression model, SRISK & Texas Ratio

		Global						U.S.						EUROPE					
	S1 specification (22 criteria)	70% train 30% test	standard bootstrap	out-of-sample bootstrap	LR out-of-sample bootstrap	SRISK	Texas Ratio	70% train 30% test	standard bootstrap	out-of-sample bootstrap	LR out-of-sample bootstrap	SRISK	Texas Ratio	70% train 30% test	standard bootstrap	out-of-sample bootstrap	LR out-of-sample bootstrap	SRISK	Texas Ratio
Training	SENS	86.93	86.02	87.99	87.30	-	-	84.39	84.35	87.21	86.48	-	-	87.06	87.25	87.92	86.81	-	-
	SPEC	85.43	88.33	88.76	87.31	-	-	93.10	94.90	95.32	94.65	-	-	87.71	88.24	90.81	85.80	-	-
	ACA	86.18	87.17	88.37	87.30	-	-	88.75	89.63	91.27	90.57	-	-	87.39	87.75	89.36	86.31	-	-
	OCA	86.36	86.94	88.32	87.29	-	-	85.71	86.03	88.51	87.75	-	-	87.43	87.83	89.59	86.21	-	-
	AUROC	**-**	**92.58**	**93.38**	**92.92**	**-**	**-**	**-**	**94.79**	**95.88**	**95.30**	**-**	**-**	**-**	**91.55**	**93.39**	**92.77**	**-**	**-**
Testing	SENS	86.17	84.73	78.90	79.57	29.99	95.51	82.61	83.23	83.03	82.39	42.32	100.00	84.25	86.12	73.14	63.79	11.01	86.15
	SPEC	89.26	87.01	80.21	74.26	87.23	19.53	97.50	90.15	73.79	75.20	66.14	0.00	88.12	86.76	77.92	68.25	91.63	25.45
	ACA	87.71	85.87	79.55	76.91	58.61	57.52	90.05	86.69	78.41	78.80	54.23	50.00	86.19	86.44	75.53	66.02	51.32	55.80
	OCA	87.52	85.64	79.48	77.47	52.85	68.99	85.27	84.32	81.21	80.87	46.12	84.42	86.63	86.49	75.75	66.04	57.99	52.20
	AUROC	**93.70**	**91.72**	**86.99**	**81.94**	**58.60**	**57.50**	**95.79**	**92.63**	**86.73**	**86.24**	**54.20**	**50.00**	**92.32**	**90.32**	**80.61**	**69.13**	**51.30**	**55.80**

8 Conclusions and future research

The 2007-2008 global financial crisis highlighted the importance of early warning models to assess the stability of the banking sector. The identification of week or distress banks is a complicated issue which remains of great interest for different stakeholders (i.e., supervisors, bank managers, and risk analysts). This research examines this issue from many different perspectives and methods, in order to provide a comprehensive approach in developing an early-warning system for the continuous, automated, and timely identification of weak banks in need of capitalization.

This thesis follows an innovative approach: it combines the above elements in one research study, using unique, extensive data, that lead to robust results. This study can be a valuable tool for researchers, bank regulatory or supervisory authorities, and financial institutions worldwide, developing or working on early-warning systems to predict banks' capital needs. Moreover, it can be a very useful tool for financial institutions themselves as a tool for capital management and strategic planning.

Although recently there have been similar studies, the analysis presented in this research has four main contributions.

First, different sets of factors/criteria and their combination as inputs were examined for constructing various multi-attribute models to distinguish between banks with capital needs and well-capitalized ones. The first set of factors/criteria consisted of bank-level risk exposure criteria. The second one contained additional information related to other bank-level microeconomic data, involving corporate governance and financial performance criteria. Finally, in order to account for country-wide conditions in the banking and financial markets, the third set contained several banking and financial market country-level aggregate criteria.

The second contribution of this research is the comprehensive comparison of three testing procedures (70% training – 30% testing sample segmentation, 1000 bootstrap tests, and 1000 out-of-sample bootstrap tests), the different modeling specifications outlined earlier in Section 5.3 (specifications S1, S2, S3, and S4), and across the various geographical areas of the sample (full sample, U.S., and Europe). The performance of popular and widely-used measures such as logistic regression, SRISK and Texas Ratio were compared.

Third, the analysis is based on a comprehensive dataset consisting of 76 large U.S. and European financial institutions operating in 20 countries (24 from the U.S. and 52 from Europe), with 1843 bank-quarter observations, during the period 2005Q4 – 2016Q4, as a result of the analysis of the 285 events (i.e., 111 for banks with capital needs and 174 for banks without capital needs) of the overall sample. Moreover, different prediction horizons were examined, up to three years prior to the bank capitalization event, in order to investigate the robustness of the results over different prediction periods.

Finally, for the evaluation of the discriminatory and predictive power of the models, different statistical metrics have been considered including Sensitivity (i.e., accuracy rate for banks without capital needs), Specificity (i.e., accuracy rate for banks with capital needs), Average classification accuracy, and Overall classification accuracy. In addition, the well-known AUROC, and the Kolmogorov-Smirnov metric were used.

The above setup makes this research unique, as it effectively and diversely approaches the problem of banks' capital needs assessment. The models developed in the present study could be used primarily by supervisors, but also by banks managers, as a decision support tool, for the identification of banks with potential capital shortfalls.

The results and findings suggest that the most comprehensive models (i.e., specification S1) achieved good classification results under various comprehensive tests and for up to three

years prior to the bank capitalization event. On the other hand, models used for benchmarking purposes performed worse.

These empirical results could be extended towards various directions. Among others, these include: (i) the extension of the data coverage to include further geographical areas, apart from the U.S. and Europe, (ii) the introduction of additional predictor attributes, such as market-based variables, and (iii) the development of models to predict the bank capital needs in absolute monetary terms (i.e., USD, euros, etc.).

Additionally, regulators like the Bank of England, EBA, and the ECB have announced their intention to take environmental, social and governance factors into account in the future. For example, the European Banking Authority (2020) published a discussion paper for the incorporation of ESG risks into the governance, risk management and supervision of credit institutions. Also, the European Central Bank (2020) announced that Eurozone banks will be stress-tested on their ability to withstand climate change risks in 2022, and the results will be likely taken into account into prudential capital requirements.

Furthermore, a recent report by Fitch Ratings (2020) also points out that French and UK banks will run exploratory 30-year climate-change scenarios set out by the Banque de France and the Bank of England in 2021 and 2022. While these two exercises will not formally test banks' capital adequacy nor be used to set capital requirements, Fitch Ratings (2020) asserts that it is likely that the outcomes will influence how much capital banks need to set aside for Pillar 2 risks. Should the necessary data and the outcomes of these exercises become available, the model presented in the present study could be calibrated to incorporate these factors.

Finally, the DSS model proposed in the present thesis could form the basis for the development of an interface or software that will automatically collect bank and market data and provide the regulators and bank managers with updated outcomes.

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APPENDIX

Table A1. TARP summary – From TARP inception through September 30, 2017 (U.S. dollars in millions)

	Purchase Price or Guarantee Amounts	Total Dollars Disbursed	Investment Repayments	Write-offs and Losses	Outstanding Balance	Received from Investments
Bank Support Programs						
Capital Purchase Program	204,895	204,895	-199,663	-5,184	48	27,090
Targeted Investment Program	40,000	40,000	-40,000	N/A	N/A	4,432
Asset Guarantee Program	5,000	N/A	N/A	N/A	N/A	4,126
Community Development Capital Initiative	570	570	-468	-27	75	64
Credit Market Programs						
Public Private Investment Program	18,625	18,625	-18,625	N/A	N/A	3,852
Term Asset-Backed Securities Loan Facility	100	100	-100	N/A	N/A	685
SBA 7(a) Securities Purchase Program	367	367	-363	-4	N/A	13
Other Programs						
Automotive Industry Financing Program	79,692	79,692	-63,037	-16,656	N/A	7,500
American International Group Investment Program	67,835	67,835	-54,350	-13,485	N/A	959
Subtotal for Investment Programs	417,085	412,085	-376,606	-35,356	123	48,719
Treasury Housing Programs under TARP	37,425	26,410	N/A	N/A	N/A	N/A
Total for TARP Program	454,510	438,494	-376,606	-35,356	123	48,719

Source: U.S. Department of the Treasury, “Citizens' Report on TARP Fiscal Year 2017”.

Table A2. Total amount of State aid to banks approved (used) in the EU over the period 2008-2017 (in billion EUR)

Aid instrument	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2008-2017
Recapitalization	269.9	110.0	184.0	37.5	150.8	29.6	20.3	18.8	8.5	25.7	855.1
	(115.2)	(90.7)	(93.5)	(35.0)	(90.8)	(20.5)	(7.6)	(11.3)	(0.0)	(11.3)	(475.9)
Impaired asset measures	4.8	338.5	78.0	6.3	157.5	14.7	3.5	1.0	0.0	0.0	604.3
	(9.8)	(79.5)	(54.0)	(0.0)	(35.4)	(9.5)	(0.3)	(0.3)	(0.5)	(0.0)	(189.2)
Total of capital-like aid instruments	274.7	448.5	262.0	43.8	308.3	44.3	23.9	19.8	8.5	25.7	1,459.4
	(125.0)	(170.2)	(147.4)	(35.0)	(126.3)	(30.0)	(7.9)	(11.6)	(0.5)	(11.3)	(665.1)
Guarantees	3,097.3	87.6	54.8	179.7	275.8	76.0	38.7	165.4	310.7	328.5	3,415.7
	(400.4)	(835.8)	(799.8)	(589.0)	(492.1)	(352.3)	(204.5)	(170.6)	(126.1)	(110.8)	(1,188.1)
Other liquidity measures	85.5	5.5	66.8	50.2	37.5	9.7	1.7	0.0	0.0	14.2	243.0
	(22.2)	(70.1)	(62.6)	(60.6)	(44.3)	(34.6)	(31.6)	(21.8)	(12.4)	(10.9)	(108.4)
Total of liquidity aid instruments	3,182.8	93.1	121.6	229.9	313.2	85.7	40.4	165.4	310.7	342.7	3,658.6
	(422.6)	(906.0)	(862.5)	(649.5)	(536.4)	(386.9)	(236.2)	(192.4)	(138.5)	(121.7)	(1,296.5)

Source: European Commission, 2019. “The 2018 Scoreboard - Aid in the context of the financial and economic crisis”.

Table A3. State aid for the recapitalization of banks approved (used) in the EU over the period 2008-2017 (in billion EUR)

Member State	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Total, 2008-2017
Belgium	12.9 (14.4)	5.0 (3.5)	2.5	-	2.9 (2.9)	-	-	-	-	-	23.3 (20.8)
Bulgaria	-	-	-	-	-	-	-	-	-	-	-
Czech Republic	-	-	-	-	-	-	-	-	-	-	-
Denmark	0.5 (0.5)	13.5 (8.0)	(1.9)	(0.3)	0.5	-	-	-	-	0.1	14.6 (10.8)
Germany	99.3 (20.0)	11.0 (32.9)	0.7 (6.7)	2.7 (3.6)	0.9 (0.9)	-	-	-	-	-	114.6 (64.2)
Estonia	-	-	-	-	-	-	-	-	-	-	-
Ireland	-	12.5 (11.0)	52.1 (35.3)	26.1 (16.5)	-	-	0.3	0.8	0.8	0.8	93.2 (62.8)
Greece	5.0	(3.8)	10.0	0.5 (2.6)	20.3 (30.9)	0.9 (3.5)	12.4	10.6 (5.8)	-	-	59.6 (46.7)
Spain	-	(1.3)	101.1 (9.5)	(8.5)	72.6 (40.4)	0.6 (2.1)	0.1	-	-	-	174.3 (61.9)
France	23.5 (13.2)	0.5 (9.3)	2.7	-	2.6 (2.6)	-	-	-	-	-	29.2 (25.0)
Croatia	-	-	-	-	-	-	-	-	-	-	-
Italy	20.0	(4.1)	-	-	2.0 (2.0)	(1.9)	-	3.8 (3.6)	-	11.3 (11.3)	37.1 (22.8)
Cyprus	-	-	-	-	1.8 (1.8)	-	1.5 (1.5)	0.2 (0.2)	-	-	3.5 (3.5)
Latvia	0.3	0.1 (0.4)	0.5 (0.1)	-	-	-	-	-	-	-	0.8 (0.5)
Lithuania	-	-	0.6	-	-	0.2 (0.2)	-	-	-	0.1	0.9 (0.3)
Luxembourg	2.4 (2.5)	0.1 (0.1)	-	-	-	-	-	-	-	-	2.5 (2.6)
Hungary	-	1.1 (0.2)	-	-	-	-	-	-	-	-	1.1 (0.2)
Malta	-	-	-	-	-	-	-	-	-	-	-
Netherlands	26.6 (14.0)	-	11.1 (4.8)	-	-	2.2 (4.2)	-	-	-	-	39.8 (23.0)
Austria	15.0 (0.9)	0.7 (5.9)	(0.6)	-	3.2 (2.0)	21.3 (1.8)	(0.8)	-	-	-	40.1 (11.8)
Poland	-	4.6	-	-	29.3	-	0.8	0.8	7.7	7.6	50.8
Portugal	-	4.0	-	8.0	14.3 (6.8)	1.1 (1.1)	4.9 (4.9)	2.6 (1.8)	-	5.9	40.7 (14.5)
Romania	-	-	-	-	-	-	-	-	-	-	-
Slovenia	-	-	-	0.3 (0.3)	0.5 (0.5)	3.3 (2.4)	0.4 (0.4)	-	-	-	4.5 (3.6)
Slovakia	-	0.7	-	-	-	-	-	-	-	-	0.7
Finland	-	4.0	-	-	-	-	-	-	-	-	4.0
Sweden	0.3 (0.3)	4.7 (0.5)	-	-	-	-	-	-	-	-	5.0 (0.8)
United Kingdom	64.1 (49.4)	47.6 (9.7)	2.9 (34.6)	(3.2)	-	(3.3)	-	-	-	-	114.6 (100.1)
Total	269.9 (115.2)	110.0 (90.7)	184.0 (93.5)	37.5 (35.0)	150.8 (90.8)	29.6 (20.5)	20.3 (7.6)	18.8 (11.3)	8.5 (0.0)	25.7 (11.3)	855.1 (475.9)

Source: European Commission, 2019. “The 2018 Scoreboard - Aid in the context of the financial and economic crisis”.

Table A4. Asset quality reviews conducted in European countries

Ireland Jan-Mar 2011	Greece Aug-Dec 2011	Portugal Jul-Nov 2011	Cyprus Sept-Dec 2012	Spain May-Jun 2012
In December 2010, as part of the EU/IMF program, BlackRock Solutions was engaged to perform a loan diagnosis of over €275 billion across the five largest Irish banks. The diagnosis had five building blocks: ▪ an asset quality review to assess the quality of aggregate and individual loan portfolios and the monitoring processes employed; ▪ a distressed credit operation review to assess the operational capability and effectiveness of distressed loan portfolio management in the banks including arrears management and workout practices in curing NPLs and reducing loan losses; ▪ a data integrity validation exercise to assess the reliability of banks' data; ▪ a loan loss forecast (LLF) under base and stress scenarios; and ▪ a public communication. Under the Loan Loss Forecast, Blackrock estimated future losses with forecasted financial statements through end-2013 (three- year horizon) as well as baseline losses.	As part of the 2nd Memorandum of Economic and Financial Policies, BlackRock was engaged to perform a loan diagnosis over all Greek banks. Individual results were communicated to banks disclosure has been made to the public in December 2012.	Under the EU/IMF program, the supervisor led detailed asset quality reviews of the eight largest national banking groups' loan portfolios and regulatory capital (RWA) calculations. Those eight largest banking groups account for more than 80 percent of the banking system's total assets. This "Special Inspection Program" (SIP) was carried out with support from external parties, Ernst & Young, PWC and Oliver Wyman. The SIP had three different work streams (WS): ▪ the valuation of the credit portfolio, ▪ a credit risk capital requirements calculation, and ▪ a stress test conducted (by Olivier and Wyman). The results of the W1 and W2 were made public in December 2011. The results of the W3 were not disclosed.	An asset quality review of the Cypriot banks has been conducted, including a stress test exercise. The Central Bank of Cyprus appointed the investment companies Pimco and Deloitte to conduct the asset quality review of 22 institutions, which is a mix of EU subsidiaries, co- operative credit institutions, and domestic banks. The participating banks account for 73 percent of the Cyprus banking system. The stress test had a three- year horizon from mid-2012 to mid-2015.	Olivier and Wyman and Roland Berger were assigned to assess the resilience of the main Spanish banking groups (14 which hold 88 percent of the market asset share). Cumulative credit losses for the top-down stress test with a three- year horizon are €250-270 billion in the adverse scenario and €170-190 billion in the base scenario. The estimated capital needs range from €51-62 billion and €16-25 billion in the adverse and base scenario, respectively, and the capital buffer requirement of €37 billion for a core Tier 1 threshold of 7 percent. The second part of the assessment with four domestic auditors was completed at the end of September.

Source: IMF, 2013. "European Union: Publication of Financial Sector Assessment Program Documentation-Technical Note on Progress with Bank Restructuring and Resolution in Europe", IMF Country Report No 13/67.

Table A5. Data on Financial Institutions capital shortfall/surplus

Country	Period	Financial institutions	Capital needs	Description
Austria	Mar-09	Erste Group Bank AG	€1.00 bn	€1bn capital injection in the form of participation certificates (Source: Finance Ministry of Austria; Erste Group Annual Report 2009)
Austria	May-09	Erste Group Bank AG	€0.22 bn	€224m capital injection in the form of participation certificates (Source: Finance Ministry of Austria; Erste Group Annual Report 2009)
Austria	Dec-11	Erste Group Bank AG	€0.17 bn	€165m capital shortfall (Source: EBA 2011 EU Capital exercise)
Austria	Dec-13	Erste Group Bank AG	€ 0.00	€0.00 Capital shortfall/surplus (Source: ECB 2014 Comprehensive assessment)
Austria	Apr-09	Raiffeisen Bank International	€1.75 bn	€1.75bn capital injection (Source: Finance Ministry of Austria; RZB Group Annual Report 2009)
Austria	Dec-11	Raiffeisen Bank International	€1.23 bn	Group: €1.23bn capital shortfall (Source: EBA 2011 EU Capital exercise)
Belgium	Oct-08	Dexia S.A.	€6.37 bn	Capital injection of €3bn by Belgian state and regions. Dexia also received €3bn of capital injections from France, and Dexia's Luxembourg subsidiary €376m from Luxemburg in the form of convertible bonds (Source: State aid C 9/2009 - ex NN 49/2008)
Belgium	Dec-12	Dexia S.A.	€5.50 bn	Capital injection by Belgium €2.9bn and France €2.6bn (Source: IMF Country Report No 13/124; Dexia Annual Report 2012)
Belgium	Dec-13	Dexia S.A.	€0.34 bn	€339 m capital shortfall (Source: ECB 2014 Comprehensive assessment)
Belgium	Dec-08	KBC Group NV	€3.50 bn	Capital injection of €3.5bn by Belgian state (Source: State aid C 18/2009 - ex N 360/2009)
Belgium	Sep-09	KBC Group NV	€3.50 bn	Capital injection of €3.5bn by Flemish government (Source: State aid C 18/2009 - ex N 360/2009)
Belgium	Dec-11	KBC Group NV	€-1.05 bn	€1,052m Capital surplus (Source: EBA 2011 EU Capital exercise)
Belgium	Dec-13	KBC Group NV	€ 0.00	€0.00 Capital shortfall/surplus (Source: ECB 2014 Comprehensive assessment)
Cyprus	Dec-11	Bank of Cyprus PCL	€0.69 bn	€691m Capital shortfall (Source: EBA 2011 EU Capital exercise)
Cyprus	Jun-12	Bank of Cyprus PCL	€3.96 bn	€3.96 Capital shortfall (Source: PIMCO 2013 Independent Due Diligence of the Banking System of Cyprus)
Cyprus	Dec-13	Bank of Cyprus PCL	€0.92 bn	€919m Capital shortfall (Source: ECB 2014 Comprehensive assessment)
Cyprus	Dec-11	Cyprus Popular Bank PCL	€2.66 bn	€2,663m Capital shortfall (Source: EBA 2011 EU Capital exercise)
Cyprus	Jun-12	Cyprus Popular Bank PCL	€3.84 bn	€3,835m Capital shortfall (Source: PIMCO 2013 Independent Due Diligence of the Banking System of Cyprus)
Cyprus	Jun-12	Hellenic Bank PCL	€0.33 bn	€333m Capital shortfall (Source: PIMCO 2013 Independent Due Diligence of the Banking System of Cyprus)
Cyprus	Dec-13	Hellenic Bank PCL	€0.28 bn	€277m Capital shortfall (Source: ECB 2014 Comprehensive assessment)
Denmark	Dec-11	Danske Bank A/S	€-6.37 bn	€6,369m Capital surplus (Source: EBA 2011 EU Capital exercise)
Denmark	Dec-11	Jyske Bank A/S	€-0.45 bn	€448m Capital surplus (Source: EBA 2011 EU Capital exercise)
Denmark	Dec-11	Sydbank A/S	€-0.40 bn	€399m Capital surplus (Source: EBA 2011 EU Capital exercise)

Table A5. *(continued)*

Country	Period	Financial institutions	Capital needs	Description
France	Dec-08	BNP Paribas SA	€2.55 bn	Injection of €2,550m in hybrid instrument (TSS), qualifying as Tier 1 capital by SPPE (Source: State aid N 613/2008)
France	Dec-11	BNP Paribas SA	€-1.20 bn	€1.203mn Capital surplus (Source: EBA 2011 EU Capital exercise)
France	Dec-13	BNP Paribas SA	€ 0.00	€0.00 Capital shortfall/surplus (Source: ECB 2014 Comprehensive assessment)
France	Dec-08	Credit Agricole SA	€3.00 bn	Injection of €3bn in hybrid instrument (TSS), qualifying as Tier 1 capital by SPPE (Source: State aid N 613/2008)
France	Dec-11	Credit Agricole SA	€-3.16 bn	€3,163m Capital surplus (Source: EBA 2011 EU Capital exercise
France	Dec-13	Credit Agricole SA	€ 0.00	€0.00 Capital shortfall/surplus (Source: ECB 2014 Comprehensive assessment)
France	Dec-08	Societe Generale SA	€1.70 bn	Injection of €1.7bn in hybrid instrument (TSS), qualifying as Tier 1 capital by SPPE (Source: State aid N 613/2008)
France	Dec-11	Societe Generale SA	€-0,11 bn	€113m Capital surplus (Source: EBA 2011 EU Capital exercise)
France	Dec-13	Societe Generale SA	€ 0.00	€0.00 Capital shortfall/surplus (Source: ECB 2014 Comprehensive assessment)
Germany	Nov-08	Commerzbank AG	€8.20 bn	Capital injection of €8.2bn by SoFFin in the form of silent participation (Source: State aid S.A. 34539 - 2012/N)
Germany	Jan-09	Commerzbank AG	€10.00 bn	Additional capital injection of €8.2bn in in the form of silent participation and €1.8bn in ordinary shares (Source: State aid S.A. 34539 - 2012/N)
Germany	Dec-11	Commerzbank AG	€1.82 bn	€1,819m Capital shortfall (Source: EBA 2011 EU Capital exercise)
Germany	Dec-13	Commerzbank AG	€ 0.00	€0.00 Capital shortfall/surplus (Source: ECB 2014 Comprehensive assessment)
Germany	Dec-11	Deutsche Bank AG	€-1.90 bn	€1,903m Capital surplus (Source: EBA 2011 EU Capital exercise)
Germany	Dec-13	Deutsche Bank AG	€ 0.00	€0.00 Capital shortfall/surplus (Source: ECB 2014 Comprehensive assessment)
Greece	Jun-11	Agricultural Bank of Greece SA	€0.58 bn	Capital increase €584.5m approved by the EC in May 2011, implemented till end of June 2011. Gross capital injection by the state €1,144.5m of which €675m used to repurchase shares from May 2009 recapitalization (Source: State aid N 429/2010)
Greece	Nov-11	Agricultural Bank of Greece SA	€0.29 bn	Capital injection of €290m in the form of capital rights in November 2011 (Source: State aid S.A. 35460, 2013/NN)
Greece	May-12	Agricultural Bank of Greece SA	€4.92 bn	€4.92bn Capital shortfall (Source: BoG 2012 Report on the Recapitalization and Restructuring of the Greek Banking Sector)
Greece	May-12	Alpha Bank AE	€4.57 bn	€4,571m Capital shortfall (Source: BoG 2012 Report on the Recapitalization and Restructuring of the Greek Banking Sector)
Greece	Dec-13	Alpha Bank AE	€ 0.00	€0.00 Capital shortfall/surplus (Source: ECB 2014 Comprehensive assessment)

Table A5. *(continued)*

Country	Period	Financial institutions	Capital needs	Description
Greece	Dec-14	Alpha Bank AE	€2.74 bn	€2,743m Capital shortfall (Source: ECB 2015 Comprehensive assessment)
Greece	May-12	Attica Bank SA	€0.40 bn	€396m Capital shortfall (Source: BoG 2012 Report on the Recapitalization and Restructuring of the Greek Banking Sector)
Greece	May-12	EFG Eurobank Ergasias SA	€5.84 bn	€5,839m Capital shortfall (Source: BoG 2012 Report on the Recapitalization and Restructuring of the Greek Banking Sector)
Greece	Dec-13	EFG Eurobank Ergasias SA	€0.02 bn	€17.6m Capital shortfall (Source: ECB 2014 Comprehensive assessment)
Greece	Dec-14	EFG Eurobank Ergasias SA	€2.12 bn	€2,122m Capital shortfall (Source: ECB 2015 Comprehensive assessment)
Greece	Dec-11	National Bank of Greece SA	€1.00 bn	Capital injection of €1bn approved by the EC on 22 December 2011 (Source: State aid S.A. 34824 (2012/C - ex 2012/NN)
Greece	May-12	National Bank of Greece SA	€9.76 bn	€9,756m Capital shortfall (Source: BoG 2012 Report on the Recapitalization and Restructuring of the Greek Banking Sector)
Greece	Dec-13	National Bank of Greece SA	€ 0.00	Capital shortfall/surplus (Source: ECB 2014 Comprehensive assessment)
Greece	Dec-14	National Bank of Greece SA	€4.60 bn	€4,602m Capital shortfall (Source: ECB 2015 Comprehensive assessment)
Greece	Dec-11	Piraeus Bank SA	€0.38 bn	Capital injection of €380m approved by the EC on December 2011 (Source: State aid S.A. 34122 - 2011/N)
Greece	May-12	Piraeus Bank SA	€7.34 bn	€7,335m Capital shortfall (Source: BoG 2012 Report on the Recapitalization and Restructuring of the Greek Banking Sector)
Greece	Dec-13	Piraeus Bank SA	€ 0.00	Capital shortfall/surplus (Source: ECB 2014 Comprehensive assessment)
Greece	Dec-14	Piraeus Bank SA	€4.93 bn	€4,933m Capital shortfall (Source: ECB 2015 Comprehensive assessment)
Greece	Dec-11	TT Hellenic Postbank SA	€0.68 bn	In December 2011 T Bank was put into liquidation. €2.16bn of its liabilities and €1.483bn of assets were transferred to TT. TT was compensated for the funding gap of €677m (Source: State aid S.A. 31155, 2013/C, 2013/NN - ex 2010/N)
Greece	May-12	TT Hellenic Postbank SA	€3.74 bn	€3,737m Capital shortfall (Source: BoG 2012 Report on the Recapitalization and Restructuring of the Greek Banking Sector)
Greece	Jan-13	TT Hellenic Postbank SA	€0.50 bn	Capital injection of €500m into bridge bank NEW TT (Source: State aid S.A. 31155, 2013/C, 2013/NN - ex 2010/N)
Hungary	Dec-11	OTP Bank Plc	€-0.64 bn	€641m Capital surplus (Source: EBA 2011 EU Capital exercise)
Ireland	May-09	Allied Irish Bank Plc	€3.50 bn	Capital injection of €3.5bn approved by EC on 12 May 2009 (Source: State aid S.A. 33296 - 2011/N)
Ireland	Dec-10	Allied Irish Bank Plc	€12.60 bn	€12,604m Capital shortfall (Source: Central Bank of Ireland 2011 The Financial Measures Programme Report)

Table A5. *(continued)*

Country	Period	Financial institutions	Capital needs	Description
Ireland	Jul-11	Allied Irish Bank Plc	€14.80 bn	Merger of Allied Irish Bank and EBS: €14.8bn recapitalization provided to facilitate the merger (€5bn by National Pensions Reserve Fund Commission, €6.5bn by Ministry of Finance, €1.6bn contingent capital, €1.7bn from liability management exercises) in July 2011 (Source: State aid S.A. 33296 - 2011/N)
Ireland	Dec-11	Allied Irish Bank Plc	€-6.76 bn	€6,757m Capital surplus – Source: EBA 2011 EU Capital exercise
Ireland	Dec-13	Allied Irish Bank Plc	€ 0.00	€0.00 Capital shortfall/surplus (Source: ECB 2014 Comprehensive assessment)
Ireland	Mar-09	Bank of Ireland	€3.50 bn	€3.5bn injection of preferred stock in March 2009, €1.67bn was converted into common stock in June (Source: State aid S.A. 33216 - 2011/N); State aid S.A. 33443 - 2011/N)
Ireland	Dec-10	Bank of Ireland	€10.12 bn	€10,119m Capital shortfall (Source: Central Bank of Ireland 2011 The Financial Measures Programme Report)
Ireland	Jul-11	Bank of Ireland	€5.30 bn	€200m state participation; €1.9bn rights issue; €1bn injection of contingent capital in July 2011. Liability management exercises (conversion of liabilities into equity) contributed €2.3-2.5bn of capital (Source: State aid S.A. 33216 (2011/N); State aid S.A. 33443 - 2011/N)
Ireland	Dec-11	Bank of Ireland	€-3.47 bn	€3,473m Capital surplus (Source: EBA 2011 EU Capital exercise)
Italy	Dec-09	Banca Monte dei Paschi di Siena SpA	€1.90 bn	Capital injection of €1.9bn in the form of Tier 1 qualifying hybrid instruments in December 2009 (Source: State aid 425/2013)
Italy	Dec-11	Banca Monte dei Paschi di Siena SpA	€2.92 bn	€2,919m Capital shortfall (Source: EBA 2011 EU Capital exercise)
Italy	Jan-13	Banca Monte dei Paschi di Siena SpA	€2.00 bn	Capital injection of €3.9bn in the form of Tier 1 qualifying hybrid instruments. The recapitalization was approved by EC on 17 December 2012 and implemented in January. €1.9bn of the issue was used to replace the December 2009 recapitalization (Source: State aid S.A. 35137 - 2012/N)
Italy	Dec-13	Banca Monte dei Paschi di Siena SpA	€4.25 bn	€4,250m Capital shortfall (Source: ECB 2014 Comprehensive assessment)
Italy	Jul-09	Banca Popolare di Milano Scarl	€ 1.45 bn	Gruppo Banco Popolare: Capital injection of EUR 1.45 bn in the form of Tier 1 qualifying hybrid instruments in July 2009. Source: State aid N 425/2010
Italy	Dec-09	Banca Popolare di Milano Scarl	€0.50 bn	Capital injection of €500m in the form of Tier 1 qualifying hybrid instruments in December 2009 (Source: State aid N 425/2011)
Italy	Dec-11	Banca Popolare di Milano Scarl	€2.13 bn	€2,128m Capital shortfall (Source: EBA 2011 EU Capital exercise)
Italy	Dec-13	Banca Popolare di Milano Scarl	€0.68 bn	€684m Capital shortfall (Source: ECB 2014 Comprehensive assessment)

Table A5. *(continued)*

Country	Period	Financial institutions	Capital needs	Description
Italy	Dec-11	Intesa Sanpaolo SpA	€-1.08 bn	€1,077m Capital surplus (Source: EBA 2011 EU Capital exercise)
Italy	Dec-13	Intesa Sanpaolo SpA	€ 0.00	€0.00 Capital shortfall/surplus (Source: ECB 2014 Comprehensive assessment)
Italy	Dec-11	Unicredit SpA	€5.20 bn	€5,201m Capital shortfall (Source: EBA 2011 EU Capital exercise)
Italy	Dec-13	Unicredit SpA	€ 0.00	€0.00 Capital shortfall/surplus (Source: ECB 2014 Comprehensive assessment)
Italy	Dec-11	Unione di Banche Italiane SpA (UBI BANCA)	€1.27 bn	€1,271m Capital shortfall (Source: EBA 2011 EU Capital exercise)
Italy	Dec-13	Unione di Banche Italiane SpA (UBI BANCA)	€ 0.00	€0.00 Capital shortfall/surplus (Source: ECB 2014 Comprehensive assessment)
Malta	Dec-11	Bank of Valletta (BOV)	€-0.04 bn	€43m Capital surplus (Source: EBA 2011 EU Capital exercise)
Malta	Dec-13	Bank of Valletta (BOV)	€ 0.00	€0.00 Capital shortfall/surplus (Source: ECB 2014 Comprehensive assessment)
Netherlands	Nov-08	ING Groep NV	€10.00 bn	Capital injection of €10bn approved on 12 November 2008. On 26 January ING entered into an a swap agreement under which the Netherlands receive 80% of cash flow from ING's Alt-A RMS portfolio; in exchange ING receives cash flows from a synthetic government bond portfolio (Source: State aid C 10/2009 ex N 138/2009)
Netherlands	Dec-11	ING Groep NV	€-2.03 bn	€2,034m Capital surplus (Source: EBA 2011 EU Capital exercise)
Netherlands	Dec-13	ING Groep NV	€ 0.00	€0.00 Capital shortfall/surplus (Source: ECB 2014 Comprehensive assessment)
Norway	Dec-11	DnB NOR Bank ASA	€-0.45 bn	€452m Capital surplus (Source: EBA 2011 EU Capital exercise)
Poland	Dec-11	Powszechna Kasa Oszczędności Bank Polski SA	€-0.74 bn	€744m Capital surplus (Source: EBA 2011 EU Capital exercise)
Portugal	Jun-11	Banco BPI SA	Yes	The Economic Adjustment Programme for Portugal (30 May 2011) included efforts to safeguard the financial sector through market-based mechanisms supported by back-up facilities, up to €12.000m (Source: The Economic Adjustment for Portugal, Occasional Papers 79, June 2011, EC). Moreover, reinforcement of the eight largest national banking groups aggregate impairments was estimated as of 30 June 2011, under BdP Special on-site Inspection Programme (Source: Banco de Portugal Special Inspection Program Results, 16 December 2011).
Portugal	Dec-11	Banco BPI SA	€1.23 bn	€1,228m Capital shortfall (Source: EBA 2011 EU Capital exercise)
Portugal	Jun-12	Banco BPI SA	€1.50 bn	Capital injection of €1.5bn in the form of hybrid securities in June 2012 under the Portuguese recapitalization scheme (Source: EC Press Release. State aid: Commission finalizes discussions on restructuring plans for Portuguese banks CGD, Banco BPI, BCP, 24 July 2013)
Portugal	Dec-13	Banco BPI SA	€ 0.00	€0.00 Capital shortfall/surplus (Source: ECB 2014 Comprehensive assessment)

Table A5. *(continued)*

Country	Period	Financial institutions	Capital needs	Description
Portugal	Jun-11	Banco Comercial Portugues SA (BCP)	Yes	The Economic Adjustment Programme for Portugal (30 May 2011) included efforts to safeguard the financial sector through market-based mechanisms supported by back-up facilities, up to €12.000m (Source: The Economic Adjustment for Portugal, Occasional Papers 79, June 2011, EC). Moreover, reinforcement of the eight largest national banking groups aggregate impairments was estimated as of 30 June 2011, under BdP Special on-site Inspection Programme (Source: Banco de Portugal Special Inspection Program Results, 16 December 2011).
Portugal	Dec-11	Banco Comercial Portugues SA (BCP)	€1.23 bn	€1,226m Capital shortfall (Source: EBA 2011 EU Capital exercise)
Portugal	Jun-12	Banco Comercial Portugues SA (BCP)	€3.00 bn	Capital injection of €3bn in the form of hybrid securities in June 2012 under the Portuguese recapitalization scheme (Source: EC Press Release. State aid: Commission finalizes discussions on restructuring plans for Portuguese banks CGD, Banco BPI, BCP, 24 July 2013)
Portugal	Dec-13	Banco Comercial Portugues SA (BCP)	€1.14 bn	€1,137m Capital shortfall (Source: ECB 2014 Comprehensive assessment)
Portugal	Jun-11	Banco Espirito Santo SA (BES)	€ 0.00	The Economic Adjustment Programme for Portugal (30 May 2011) included efforts to safeguard the financial sector through market-based mechanisms supported by back-up facilities, up to €12.000m (Source: The Economic Adjustment for Portugal, Occasional Papers 79, June 2011, EC). Moreover, reinforcement of the eight largest national banking groups aggregate impairments was estimated as of 30 June 2011, under BdP Special on-site Inspection Programme (Source: Banco de Portugal Special Inspection Program Results, 16 December 2011). Banco Espírito Santo S.A. informs on the conclusion of the Special Inspections Programme (Source: Banco Espírito Santo S.A. Press Release, 1 March 2012).
Portugal	Dec-11	Banco Espirito Santo SA (BES)	€0.37 bn	€371m Capital shortfall (Source: EBA 2011 EU Capital exercise)
Spain	Dec-11	Banco Bilbao Vizcaya Argentaria SA (BBVA)	€-11.18 bn	€11,183m Capital surplus (Source: Oliver Wyman 2012 Asset Quality Review and Bottom-Up Stress Test Exercise)
Spain	Dec-13	Banco Bilbao Vizcaya Argentaria SA (BBVA)	€ 0.00	€0.00 Capital shortfall/surplus (Source: ECB 2014 Comprehensive assessment)
Spain	Dec-11	Banco de Sabadell SA	€5.25 bn	€5,249m capital injection from the Deposit Guarantee Fund in December 2011 (Source: Fund for Orderly Bank Restructuring / slides from FROB webpage, 1 April 2013)

Table A5. *(continued)*

Country	Period	Financial institutions	Capital needs	Description
Spain	Dec-11	Banco de Valencia SA	€3.46 bn	€3,462m Capital shortfall (Source: Oliver Wyman 2012 Asset Quality Review and Bottom-Up Stress Test Exercise)
Spain	Jun-12	Banco de Valencia SA	€1.00 bn	Injection of €1bn of ordinary shares by FROB in June 2012 (Source: State aid S.A. 34053 - 2012/N)
Spain	Dec-12	Banco de Valencia SA	€4.50 bn	Injection of €4.5bn of CoCo bonds by FROB, approved by the EC and implemented in December 2012 (Source: State aid S.A. 34053 - 2012/N)
Spain	Dec-11	Banco Popular Espanol SA	€2.34 bn	€2,336m Capital shortfall (Source: Oliver Wyman 2012 Asset Quality Review and Bottom-Up Stress Test Exercise)
Spain	Dec-11	Banco Santander SA	€-25.30 bn	€25,297m Capital surplus (Source: Oliver Wyman 2012 Asset Quality Review and Bottom-Up Stress Test Exercise)
Spain	Dec-11	Bankinter SA	€2.15 bn	€2,152m Capital shortfall (Source: Oliver Wyman 2012 Asset Quality Review and Bottom-Up Stress Test Exercise)
Sweden	Dec-11	Nordea Bank AB (PUBL)	€-4.18 bn	€4,176m Capital surplus (Source: EBA 2011 EU Capital exercise)
Sweden	Dec-11	Skandinaviska Enskilda Banken AB	€-3.74 bn	€3,736m Capital surplus (Source: EBA 2011 EU Capital exercise)
Sweden	Dec-11	Svenska Handelsbanken AB (PUBL)	€-3.82 bn	€3,817m Capital surplus (Source: EBA 2011 EU Capital exercise)
Sweden	Dec-11	Swedbank AB (PUBL)	€-2.81 bn	€2,810m Capital surplus (Source: EBA 2011 EU Capital exercise)
Switzerland	Dec-08	UBS Group AG	€6.00 bn	Capital injection of SFR 6bn in the form of convertible notes (MCN) on 9 December 2008 (Source: IMF Country Report No 09/164; UBS Annual Report 2008)
United Kingdom	Dec-11	Barclays Plc	€-5.80 bn	€5,802m Capital surplus (Source: EBA 2011 EU Capital exercise)
United Kingdom	Dec-11	HSBC Holdings Plc	€-10.54 bn	€10,542m Capital surplus (Source: EBA 2011 EU Capital exercise)
United Kingdom	Jan-09	Lloyds Banking Group Plc	£17.00 bn	Capital injection of £13bn in ordinary shares and £4bn in preference shares, implemented on 20 January 2019 (Source: State aid No N 428/2009)
United Kingdom	Dec-11	Lloyds Banking Group Plc	€-7.41 bn	€7,406m Capital surplus (Source: EBA 2011 EU Capital exercise)
United Kingdom	Oct-08	Royal Bank of Scotland Group Plc	£20.00 bn	Capital injection of £15bn in ordinary and £5bn in preference shares in October 2018 (Source: State aid No N 422/2009)
United Kingdom	Jan-09	Royal Bank of Scotland Group Plc	Yes	On 19 January 2009, following the announcement of further losses by RBS (£24.1bn), the State made public its intention to convert its preference shares into ordinary shares (Source: RNS Number: 8387L, HM Treasury, 19 January 2009).
United Kingdom	Dec-09	Royal Bank of Scotland Group Plc	£25.50 bn	Capital injection of £25.5 bn in non-voting B shares, approved by the EC in December 2009 (Source: State aid No N 422/2009 and N 621/2009; RBS Annual Report 2009)

Table A5. *(continued)*

Country	Period	Financial institutions	Capital needs	Description
United Kingdom	Dec-11	Royal Bank of Scotland Group Plc	€-6.94 bn	€6,940m Capital surplus (Source: EBA 2011 EU Capital exercise)
United States	Dec-08	American Express Company	No Need	$0.00 Capital shortfall/surplus (Source: FED Supervisory Capital Assessment Program 2009)
United States	Jan-09	American Express Company	$3.39 bn	$3,389m funds received, as part of the TARP Capital Purchase Program, in the form of preferred stock through warrants, in 9 January 2009 (Source: U.S. Department of the Treasury "Troubled Assets Relief Program: Eighth Tranche Report to Congress", October 7, 2009)
United States	Sep-11	American Express Company	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2012)
United States	Sep-12	American Express Company	Fail	Fail regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2013)
United States	Sep-13	American Express Company	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2014)
United States	Sep-14	American Express Company	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2015)
United States	Dec-15	American Express Company	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2016)
United States	Dec-16	American Express Company	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2017)
United States	Oct-08	Bank of America Corporation	$15.00 bn	$15bn funds received, as part of the TARP Capital Purchase Program, in the form of preferred stock through warrants, in 28 October 2009 (Source: U.S. Department of the Treasury "Troubled Assets Relief Program: Eighth Tranche Report to Congress", October 7, 2009)
United States	Dec-08	Bank of America Corporation	$33.90 bn	$33.9bn Capital shortfall (Source: FED Supervisory Capital Assessment Program 2009)
United States	Jan-09	Bank of America Corporation	$30.00 bn	$10bn funds received, as part of the TARP Capital Purchase Program, in the form of preferred stock through warrants, in 9 January 2009. Additional $20bn funds received, as part of the TARP Targeted Investment Program, in the form of preferred stock through warrants, in 16 January 2009 (Source: U.S. Department of the Treasury "Troubled Assets Relief Program: Eighth Tranche Report to Congress", October 7, 2009)
United States	Sep-11	Bank of America Corporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2012)
United States	Sep-12	Bank of America Corporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2013)

Table A5. *(continued)*

Country	Period	Financial institutions	Capital needs	Description
United States	Sep-13	Bank of America Corporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2014)
United States	Sep-14	Bank of America Corporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2015)
United States	Dec-15	Bank of America Corporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2016)
United States	Dec-16	Bank of America Corporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2017)
United States	Oct-08	Bank of New York Mellon Corp/The	$3.00 bn	$3bn funds received, as part of the TARP Capital Purchase Program, in the form of preferred stock through warrants, in 28 October 2009 (Source: U.S. Department of the Treasury "Troubled Assets Relief Program: Eighth Tranche Report to Congress", October 7, 2009)
United States	Dec-08	Bank of New York Mellon Corp/The	No Need	$0.00 Capital shortfall/surplus (Source: FED Supervisory Capital Assessment Program 2009)
United States	Sep-11	Bank of New York Mellon Corp/The	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2012)
United States	Sep-12	Bank of New York Mellon Corp/The	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2013)
United States	Sep-13	Bank of New York Mellon Corp/The	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2014)
United States	Sep-14	Bank of New York Mellon Corp/The	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2015)
United States	Dec-15	Bank of New York Mellon Corp/The	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2016)
United States	Dec-16	Bank of New York Mellon Corp/The	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2017)
United States	Nov-08	BB&T Corporation	$3.13 bn	$3,134m funds received, as part of the TARP Capital Purchase Program, in the form of preferred stock through warrants, in 14 November 2008 (Source: U.S. Department of the Treasury "Troubled Assets Relief Program: Eighth Tranche Report to Congress", October 7, 2009)
United States	Dec-08	BB&T Corporation	No Need	$0.00 Capital shortfall/surplus (Source: FED Supervisory Capital Assessment Program 2009)

Table A5. *(continued)*

Country	Period	Financial institutions	Capital needs	Description
United States	Sep-11	BB&T Corporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2012)
United States	Sep-12	BB&T Corporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2013)
United States	Sep-13	BB&T Corporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2014)
United States	Sep-14	BB&T Corporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2015)
United States	Dec-15	BB&T Corporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2016)
United States	Dec-16	BB&T Corporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2017)
United States	Nov-08	Capital One Financial Corporation	$3.56 bn	$3,555m funds received, as part of the TARP Capital Purchase Program, in the form of preferred stock through warrants, in 14 November 2008 (Source: U.S. Department of the Treasury "Troubled Assets Relief Program: Eighth Tranche Report to Congress", October 7, 2009)
United States	Dec-08	Capital One Financial Corporation	No Need	$0.00 Capital shortfall/surplus (Source: FED Supervisory Capital Assessment Program 2009)
United States	Sep-11	Capital One Financial Corporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2012)
United States	Sep-12	Capital One Financial Corporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2013)
United States	Sep-13	Capital One Financial Corporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2014)
United States	Sep-14	Capital One Financial Corporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2015)
United States	Dec-15	Capital One Financial Corporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2016)
United States	Dec-16	Capital One Financial Corporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2017)
United States	Dec-16	CIT Group Inc	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2017)

Table A5. *(continued)*

Country	Period	Financial institutions	Capital needs	Description
United States	Oct-08	Citigroup, Inc.	$25.00 bn	$25bn funds received, as part of the TARP Capital Purchase Program, in the form of common stock, in 28 October 2008 (Source: U.S. Department of the Treasury "Troubled Assets Relief Program: Eighth Tranche Report to Congress", October 7, 2009)
United States	Dec-08	Citigroup, Inc.	$5.50 bn	$5.5bn Capital shortfall (Source: FED Supervisory Capital Assessment Program 2009)
United States	Dec-08	Citigroup, Inc.	$20.00 bn	$20bn funds received, as part of the TARP Targeted Investment Program, in the form of trust preferred securities, in 31 December 2008 (Source: U.S. Department of the Treasury "Troubled Assets Relief Program: Eighth Tranche Report to Congress", October 7, 2009)
United States	Sep-11	Citigroup, Inc.	Fail	Fail regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2012)
United States	Sep-12	Citigroup, Inc.	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2013)
United States	Sep-13	Citigroup, Inc.	Fail	Fail regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2014)
United States	Sep-14	Citigroup, Inc.	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2015)
United States	Dec-15	Citigroup, Inc.	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2016)
United States	Dec-16	Citigroup, Inc.	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2017)
United States	Sep-14	Citizens Financial Group, Inc.	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2015)
United States	Dec-15	Citizens Financial Group, Inc.	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2016)
United States	Dec-16	Citizens Financial Group, Inc.	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2017)
United States	Sep-13	Comerica Incorporated	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2014)
United States	Sep-14	Comerica Incorporated	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2015)
United States	Dec-15	Comerica Incorporated	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2016)

Table A5. *(continued)*

Country	Period	Financial institutions	Capital needs	Description
United States	Dec-16	Comerica Incorporated	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2017)
United States	Dec-08	Fifth Third Bancorp	$3.41 bn	$3,408m funds received, as part of the TARP Capital Purchase Program, in the form of preferred stock through warrants, in 31 December 2008 (Source: U.S. Department of the Treasury "Troubled Assets Relief Program: Eighth Tranche Report to Congress", October 7, 2009)
United States	Dec-08	Fifth Third Bancorp	$1.10 bn	$1.1bn Capital shortfall (Source: FED Supervisory Capital Assessment Program 2009)
United States	Sep-11	Fifth Third Bancorp	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2012)
United States	Sep-12	Fifth Third Bancorp	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2013)
United States	Sep-13	Fifth Third Bancorp	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2014)
United States	Sep-14	Fifth Third Bancorp	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2015)
United States	Dec-15	Fifth Third Bancorp	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2016)
United States	Dec-16	Fifth Third Bancorp	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2017)
United States	Oct-08	Goldman Sachs Group Inc/The	$10.00 bn	$10bn funds received, as part of the TARP Capital Purchase Program, in the form of preferred stock through warrants, in 28 October 2008 (Source: U.S. Department of the Treasury "Troubled Assets Relief Program: Eighth Tranche Report to Congress", October 7, 2009)
United States	Dec-08	Goldman Sachs Group Inc/The	No Need	$0.00 Capital shortfall/surplus (Source: FED Supervisory Capital Assessment Program 2009)
United States	Sep-11	Goldman Sachs Group Inc/The	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2012)
United States	Sep-12	Goldman Sachs Group Inc/The	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2013)
United States	Sep-13	Goldman Sachs Group Inc/The	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2014)
United States	Sep-14	Goldman Sachs Group Inc/The	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2015)

Table A5. *(continued)*

Country	Period	Financial institutions	Capital needs	Description
United States	Dec-15	Goldman Sachs Group Inc/The	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2016)
United States	Dec-16	Goldman Sachs Group Inc/The	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2017)
United States	Sep-13	Huntington Bancshares Incorporated	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2014)
United States	Sep-14	Huntington Bancshares Incorporated	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2015)
United States	Dec-15	Huntington Bancshares Incorporated	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2016)
United States	Dec-16	Huntington Bancshares Incorporated	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2017)
United States	Oct-08	JPMorgan Chase & Co.	$25.00 bn	$25bn funds received, as part of the TARP Capital Purchase Program, in the form of preferred stock through warrants, in 28 October 2008 (Source: U.S. Department of the Treasury "Troubled Assets Relief Program: Eighth Tranche Report to Congress", October 7, 2009)
United States	Dec-08	JPMorgan Chase & Co.	No Need	$0.00 Capital shortfall/surplus (Source: FED Supervisory Capital Assessment Program 2009)
United States	Sep-11	JPMorgan Chase & Co.	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2012)
United States	Sep-12	JPMorgan Chase & Co.	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2013)
United States	Sep-13	JPMorgan Chase & Co.	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2014)
United States	Sep-14	JPMorgan Chase & Co.	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2015)
United States	Dec-15	JPMorgan Chase & Co.	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2016)
United States	Dec-16	JPMorgan Chase & Co.	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2017)
United States	Nov-08	Keycorp	$2.50 bn	$2.5bn funds received, as part of the TARP Capital Purchase Program, in the form of preferred stock through warrants, in 14 November 2008 (Source: U.S. Department of the Treasury "Troubled Assets Relief Program: Eighth Tranche Report to Congress", October 7, 2009)

Table A5. *(continued)*

Country	Period	Financial institutions	Capital needs	Description
United States	Dec-08	Keycorp	$1.80 bn	$1.8bn Capital shortfall (Source: FED Supervisory Capital Assessment Program 2009)
United States	Sep-11	Keycorp	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2012)
United States	Sep-12	Keycorp	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2013)
United States	Sep-13	Keycorp	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2014)
United States	Sep-14	Keycorp	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2015)
United States	Dec-15	Keycorp	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2016)
United States	Dec-16	Keycorp	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2017)
United States	Sep-13	M&T Bank Corporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2014)
United States	Sep-14	M&T Bank Corporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2015)
United States	Dec-15	M&T Bank Corporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2016)
United States	Dec-16	M&T Bank Corporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2017)
United States	Oct-08	Morgan Stanley	$10.00 bn	$10bn funds received, as part of the TARP Capital Purchase Program, in the form of preferred stock through warrants, in 28 October 2008 (Source: U.S. Department of the Treasury "Troubled Assets Relief Program: Eighth Tranche Report to Congress", October 7, 2009)
United States	Dec-08	Morgan Stanley	$1.80 bn	$1.8bn Capital shortfall (Source: FED Supervisory Capital Assessment Program 2009)
United States	Sep-11	Morgan Stanley	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2012)
United States	Sep-12	Morgan Stanley	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2013)
United States	Sep-13	Morgan Stanley	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2014)

Table A5. *(continued)*

Country	Period	Financial institutions	Capital needs	Description
United States	Sep-14	Morgan Stanley	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2015)
United States	Dec-15	Morgan Stanley	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2016)
United States	Dec-16	Morgan Stanley	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2017)
United States	Sep-13	Northern Trust Corporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2014)
United States	Sep-14	Northern Trust Corporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2015)
United States	Dec-15	Northern Trust Corporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2016)
United States	Dec-16	Northern Trust Corporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2017)
United States	Dec-08	PNC Financial Services Group Inc/The	$7.58 bn	$7,579m funds received, as part of the TARP Capital Purchase Program, in the form of preferred stock through warrants, in 31 December 2008 (Source: U.S. Department of the Treasury "Troubled Assets Relief Program: Eighth Tranche Report to Congress", October 7, 2009)
United States	Dec-08	PNC Financial Services Group Inc/The	$0.60 bn	$0.6bn Capital shortfall (Source: FED Supervisory Capital Assessment Program 2009)
United States	Sep-11	PNC Financial Services Group Inc/The	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2012)
United States	Sep-12	PNC Financial Services Group Inc/The	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2013)
United States	Sep-13	PNC Financial Services Group Inc/The	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2014)
United States	Sep-14	PNC Financial Services Group Inc/The	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2015)
United States	Dec-15	PNC Financial Services Group Inc/The	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2016)
United States	Dec-16	PNC Financial Services Group Inc/The	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2017)

Table A5. *(continued)*

Country	Period	Financial institutions	Capital needs	Description
United States	Nov-08	Regions Financial Corporation	$3.50 bn	$3.5bn funds received, as part of the TARP Capital Purchase Program, in the form of preferred stock through warrants, in 14 November 2008 (Source: U.S. Department of the Treasury "Troubled Assets Relief Program: Eighth Tranche Report to Congress", October 7, 2009)
United States	Dec-08	Regions Financial Corporation	$2.50 bn	$2.5bn Capital shortfall (Source: FED Supervisory Capital Assessment Program 2009)
United States	Sep-11	Regions Financial Corporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2012)
United States	Sep-12	Regions Financial Corporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2013)
United States	Sep-13	Regions Financial Corporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2014)
United States	Sep-14	Regions Financial Corporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2015)
United States	Dec-15	Regions Financial Corporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2016)
United States	Dec-16	Regions Financial Corporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2017)
United States	Oct-08	State Street Corporation	$2.00 bn	$2bn funds received, as part of the TARP Capital Purchase Program, in the form of preferred stock through warrants, in 28 October 2008 (Source: U.S. Department of the Treasury "Troubled Assets Relief Program: Eighth Tranche Report to Congress", October 7, 2009)
United States	Dec-08	State Street Corporation	No Need	$0.00 Capital shortfall/surplus (Source: FED Supervisory Capital Assessment Program 2009)
United States	Sep-11	State Street Corporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2012)
United States	Sep-12	State Street Corporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2013)
United States	Sep-13	State Street Corporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2014)
United States	Sep-14	State Street Corporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2015)
United States	Dec-15	State Street Corporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2016)

Table A5. *(continued)*

Country	Period	Financial institutions	Capital needs	Description
United States	Dec-16	State Street Corporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2017)
United States	Nov-08	SunTrust Banks, Inc	$3.50 bn	$3.5bn funds received, as part of the TARP Capital Purchase Program, in the form of preferred stock through warrants, in 14 November 2008 (Source: U.S. Department of the Treasury "Troubled Assets Relief Program: Eighth Tranche Report to Congress", October 7, 2009)
United States	Dec-08	SunTrust Banks, Inc	$2.20 bn	$2.2bn Capital shortfall (Source: FED Supervisory Capital Assessment Program 2009)
United States	Dec-08	SunTrust Banks, Inc	$1.35 bn	$1.35bn funds received, as part of the TARP Capital Purchase Program, in the form of preferred stock through warrants, in 31 December 2008 (Source: U.S. Department of the Treasury "Troubled Assets Relief Program: Eighth Tranche Report to Congress", October 7, 2009)
United States	Sep-11	SunTrust Banks, Inc	Fail	Fail regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2012)
United States	Sep-12	SunTrust Banks, Inc	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2013)
United States	Sep-13	SunTrust Banks, Inc	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2014)
United States	Sep-14	SunTrust Banks, Inc	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2015)
United States	Dec-15	SunTrust Banks, Inc	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2016)
United States	Dec-16	SunTrust Banks, Inc	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2017)
United States	Nov-08	U.S. Bancorp	$6.60 bn	$6,599m funds received, as part of the TARP Capital Purchase Program, in the form of preferred stock through warrants, in 14 November 2008 (Source: U.S. Department of the Treasury "Troubled Assets Relief Program: Eighth Tranche Report to Congress", October 7, 2009)
United States	Dec-08	U.S. Bancorp	No Need	$0.00 Capital shortfall/surplus (Source: FED Supervisory Capital Assessment Program 2009)
United States	Sep-11	U.S. Bancorp	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2012)
United States	Sep-12	U.S. Bancorp	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2013)
United States	Sep-13	U.S. Bancorp	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2014)

Table A5. *(continued)*

Country	Period	Financial institutions	Capital needs	Description
United States	Sep-14	U.S. Bancorp	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2015)
United States	Dec-15	U.S. Bancorp	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2016)
United States	Dec-16	U.S. Bancorp	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2017)
United States	Oct-08	Wells Fargo & Company	$25.00 bn	$25bn funds received, as part of the TARP Capital Purchase Program, in the form of preferred stock through warrants, in 28 October 2008 (Source: U.S. Department of the Treasury "Troubled Assets Relief Program: Eighth Tranche Report to Congress", October 7, 2009)
United States	Dec-08	Wells Fargo & Company	$13.70 bn	$13.7bn Capital shortfall (Source: FED Supervisory Capital Assessment Program 2009)
United States	Sep-11	Wells Fargo & Company	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2012)
United States	Sep-12	Wells Fargo & Company	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2013)
United States	Sep-13	Wells Fargo & Company	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2014)
United States	Sep-14	Wells Fargo & Company	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2015)
United States	Dec-15	Wells Fargo & Company	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2016)
United States	Dec-16	Wells Fargo & Company	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2017)
United States	Sep-13	Zions Bancorporation	Fail	Fail regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2014)
United States	Sep-14	Zions Bancorporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2015)
United States	Dec-15	Zions Bancorporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2016)
United States	Dec-16	Zions Bancorporation	Pass	Pass regulatory minimum levels under the hypothetical stress scenario (Source: FED Comprehensive Capital Analysis and Review 2017)

Table A6. Banks ranking: Capital needs prediction model & Logistic Regression model (Global S1 specifications/ out-of-sample bootstrap), SRISK, and Texas ratio Vs Actual results as of Dec 2011

Rank	Institution	Country	CNPM	LR	SRISK	TR	Actual results
1	Piraeus Bank SA	Greece	Yes(23.17)	Yes (1.19)	Yes	Yes	Yes (€0,38 bn)
2	Agricultural Bank of Greece SA (ATEbank)	Greece	Yes (35.36)	Yes (1.86)	Yes	N/A	Yes (€4,92 bn)
3	Alpha Bank AE	Greece	Yes (43.07)	Yes (2.70)	Yes	No	Yes (€4,57 bn)
4	National Bank of Greece SA	Greece	Yes (45.12)	Yes (3.41)	Yes	Yes	Yes (€1,00 bn)
5	Attica Bank SA	Greece	Yes (45.89)	Yes (4.28)	Yes	Yes	Yes (€0,40 bn)
6	TT Hellenic Postbank SA	Greece	Yes (46.00)	Yes (4.94)	Yes	N/A	Yes (€0,68 bn)
7	Bank of Cyprus PCL	Cyprus	Yes (46.39)	Yes (5.94)	Yes	No	Yes (€0,69 bn)
8	EFG Eurobank Ergasias SA	Greece	Yes (48.99)	Yes (6.59)	Yes	Yes	Yes (€5,84 bn)
9	Cyprus Popular Bank Public Co LTD/ Laiki Bank Group	Cyprus	Yes (50.80)	Yes (9.87)	Yes	Yes	Yes (€2,66 bn)
10	Banco Espirito Santo SA	Portugal	Yes (51.38)	Yes (12.51)	Yes	No	Yes (€0,37 bn)
11	Banco de Valencia SA	Spain	Yes (52.57)	Yes (16.00)	Yes	No	Yes (€3,46 bn)
12	Banco BPI SA	Portugal	Yes (53.55)	Yes (18.41)	Yes	No	Yes (€1,23 bn)
13	Banco Comercial Portugues SA	Portugal	Yes (54.39)	Yes (25.56)	Yes	No	Yes (€1,23 bn)
14	OTP Bank Plc	Hungary	Yes (55.82)	Yes (27.62)	Yes	No	No (-€0,64 bn)
15	Dexia S.A.	Belgium	Yes (55.84)	Yes (29.85)	Yes	No	Yes (€5,50 bn)
16	Banca Popolare di Milano Scarl	Italy	Yes (56.81)	Yes (35.37)	Yes	No	Yes (€2,13 bn)
17	Hellenic Bank Pcl	Cyprus	Yes (56.84)	Yes (37.18)	Yes	N/A	Yes (€0,33 bn)
18	Bank of Valletta (BOV)	Malta	Yes (57.25)	Yes (40.58)	No	N/A	No (-€0,04 bn)
19	Unione di Banche Italiane SpA (UBI BANCA)	Italy	Yes (58.04)	Yes (42.05)	Yes	No	Yes (€1,27 bn)
20	Unicredit SpA	Italy	Yes (58.94)	Yes (44.23)	Yes	Yes	Yes (€5,20 bn)
21	Credit Agricole SA	France	Yes (60.06)	Yes (47.42)	Yes	N/A	No (-€3,16 bn)
22	Powszechna Kasa Oszczędności Bank Polski SA (PKO)	Poland	Yes (60.51)	No (50.51)	No	No	No (-€0,74 bn)
23	Bankinter SA	Spain	Yes (60.93)	No (56.53)	Yes	No	Yes (€2,15 bn)

Table A6. *(continued)*

Rank	Institution	Country	CNPM	LR	SRISK	TR	Actual results
24	Banca Monte dei Paschi di Siena SpA	Italy	Yes (61.10)	No (57.45)	Yes	N/A	Yes (€2,92 bn)
25	Societe Generale SA	France	Yes (61.37)	No (57.46)	Yes	No	No (-€0,11 bn)
26	Erste Group Bank AG	Austria	Yes (61.57)	No (58.63)	Yes	Yes	Yes (€0,17 bn)
27	Allied Irish Banks Plc	Ireland	Yes (62.02)	No (64.50)	No	N/A	No (-€6,76 bn)
28	KBC Group NV	Belgium	Yes (62.10)	No (64.93)	Yes	Yes	No (-€1,05 bn)
29	Intesa Sanpaolo SpA	Italy	Yes (62.53)	No (67.65)	Yes	No	No (-€1,08 bn)
30	Banco Bilbao Vizcaya Argentaria SA (BBVA)	Spain	No (63.15)	No (68.91)	Yes	No	No (-€11,18 bn)
31	BNP Paribas SA	France	No (63.71)	No (72.62)	Yes	No	No (-€1,20 bn)
32	Banco Santander SA	Spain	No (63.90)	No (73.03)	Yes	No	No (-€25,30 bn)
33	Nordea Bank AB (PUBL)	Sweden	No (63.97)	No (74.08)	Yes	No	No (-€4,18 bn)
34	Banco de Sabadell SA	Spain	No (64.05)	No (76.98)	Yes	No	Yes (€5,25 bn)
35	Bank of Ireland	Ireland	No (64.33)	No (77.63)	Yes	Yes	No (-€3,47 bn)
36	Deutsche Bank AG	Germany	No (65.22)	No (78.16)	Yes	No	No (-€1,90 bn)
37	Skandinaviska Enskilda Banken AB	Sweden	No (65.76)	No (80.84)	Yes	No	No (-€3,74 bn)
38	Raiffeisen Bank International	Austria	No (65.94)	No (81.75)	Yes	No	Yes (€1,23 bn)
39	Banco Popular Espanol SA	Spain	No (66.01)	No (81.97)	Yes	No	Yes (€2,34 bn)
40	ING Groep NV	Netherlands	No (66.04)	No (82.04)	Yes	N/A	No (-€2,03 bn)
41	M&T Bank Corporation	United States	No (66.29)	No (82.94)	No	No	No
42	Svenska Handelsbanken AB (PUBL)	Sweden	No (66.35)	No (83.44)	Yes	No	No (-€3,82 bn)
43	Commerzbank AG	Germany	No (66.71)	No (83.72)	Yes	No	Yes (€1,82 bn)
44	Swedbank AB (PUBL)	Sweden	No (67.26)	No (84.71)	Yes	No	No (-€2,81 bn)
45	Comerica Incorporated	United States	No (67.88)	No (86.13)	Yes	No	No
46	SunTrust Banks, Inc	United States	No (67.90)	No (86.31)	Yes	No	No
47	Royal Bank of Scotland Group Plc	United Kingdom	No (68.28)	No (86.62)	Yes	No	No (-€6,94 bn)

Table A6. *(continued)*

Rank	Institution	Country	CNPM	LR	SRISK	TR	Actual results
48	Regions Financial Corporation	United States	No (68.46)	No (87.85)	Yes	No	No
49	Lloyds Banking Group Plc	United Kingdom	No (68.60)	No (88.22)	Yes	Yes	No (-€7,41 bn)
50	BB&T Corporation	United States	No (69.23)	No (88.24)	Yes	No	No
51	HSBC Holdings Plc	United Kingdom	No (69.47)	No (88.79)	Yes	No	No (-€10,54 bn)
52	Barclays Plc	United Kingdom	No (69.58)	No (89.14)	Yes	No	No (-€5,80 bn)
53	Sydbank A/S	Denmark	No (69.66)	No (89.30)	Yes	No	No (-€0,40 bn)
54	Bank of America Corporation	United States	No (69.72)	No (89.58)	Yes	No	No
55	DnB NOR Bank ASA	Norway	No (70.03)	No (90.18)	Yes	N/A	No (-€0,45 bn)
56	Wells Fargo & Company	United States	No (70.04)	No (90.26)	Yes	No	No
57	Huntington Bancshares Incorporated	United States	No (70.16)	No (90.31)	Yes	No	No
58	US Bancorp	United States	No (70.28)	No (90.57)	No	No	No
59	Capital One Financial Corporation	United States	No (70.54)	No (93.81)	Yes	No	No
60	Morgan Stanley	United States	No (70.95)	No (96.02)	Yes	N/A	No
61	PNC Financial Services Group Inc/ The	United States	No (71.44)	No (96.16)	Yes	No	No
62	Fifth Third Bancorp	United States	No (71.52)	No (96.59)	Yes	No	No
63	Jyske Bank A/S	Denmark	No (71.52)	No (96.78)	Yes	No	No (-€0,45 bn)
64	Keycorp	United States	No (71.73)	No (97.75)	Yes	No	No
65	Goldman Sachs Group Inc/The	United States	No (72.04)	No (98.15)	Yes	N/A	No
66	Danske Bank A/S	Denmark	No (72.05)	Yes (0.00)	Yes	No	No (-€6,37 bn)
67	Citigroup, Inc.	United States	No (72.81)	Yes (0.00)	Yes	No	No
68	JPMorgan Chase & Co.	United States	No (73.12)	Yes (0.00)	Yes	No	No
69	Northern Trust Corporation	United States	No (73.38)	Yes (0.01)	Yes	No	No
70	Bank of New York Mellon Corp/ The	United States	No (73.55)	Yes (0.01)	Yes	N/A	No
71	Zions Bancorporation	United States	No (74.07)	Yes (0.01)	Yes	No	Yes

Table A6. *(continued)*

Rank	Institution	Country	CNPM	LR	SRISK	TR	Actual results
72	State Street Corporation	United States	No (74.26)	Yes (0.12)	Yes	No	No
73	American Express Company	United States	No (76.94)	Yes (0.41)	No	No	Yes

Note: Thresholds/ cut-offs for Capital needs prediction model and Logistic Regression model are 63.02 and 50.00 percent respectively. U.S. actual results do not include specific capital shortfall/ surplus amounts due to data source/ FED CCAR format (pass/ fail).