IMPROVING THE BANK'S BALANCE SHEET IN ANTICIPATION OF STRESS

A view on the interaction between the bank's solvency, liquidity and profitability under stress

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Improving the bank's balance sheet in anticipation of stress

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Abstract

A bank should safeguard shareholder's value, deposits and other funding in tranquil and tumultuous times, while the funding is used to provide credit to the real economy. Banks funnel the numerous short-term deposits to sizeable long-term loans. The provided credit yields interests to pay funders and to gain profits. Solvency risk and liquidity risk are inherent in this transformation process.

The solvency, liquidity and profitability profile of a bank are seen as the key performance indicators. The first two indicate the bank's resilience to shocks, the latter is closely monitored by shareholders, since it increases shareholders' value. In this thesis we call the three profiles together: 'the bank's Trias'. Since 2008 there is a big argument whether the financial crisis was a solvency or a liquidity crisis and the debate about the interaction between both sources of risk is intensified. Banks are ought to strengthen both positions by prudential supervision.

We examine the impact of a severe stress scenario on the bank's Trias. The scenario is derived from the 2014 EU-wide stress test. Our model is a stylized reflection of an average Dutch bank under this stress scenario. Our findings show the trade-offs within the bank's Trias and which changes are possible in the balance sheet structure to make the bank more robust for this scenario. We find that by changing a bank's solvency and liquidity position, the solvency position has a greater impact on the bank's profitability, while a liquidity shock could have an immediate disastrous effect on the bank's viability. The model optimizes the profitability position, while being subjected to Basel's solvency and liquidity restrictions. All Basel's solvency and liquidity restrictions are binding, which suggests that the four metrics are a complementary set of restrictions. The Markowitz restriction, a restriction on the asset portfolio variance is likewise redundant and satisfied by Basel regulation. This finding indicates that Basel's framework is effective and provides enough incentives for banks to structure solid balance sheets.

With this research we show how stress tests can generate valuable information for bank management and how the presented decision space within the bank's Trias can contribute to the debate of bank's safety versus economic cost.

Preface

The journey to my thesis, the final work for obtaining my master degree in Financial Engineering and Management, began in 2007. A memorable time, upon which I look back with great delight. Since my first class, a stunning and unforgettable repetition of all high-school mathematics, I took part in numerous enjoyable extracurricular activities. I have made many friends during my time at Euros, PIP Advice and Pythias. I will never forget the studytrip to Vietnam and Singapore, nor my Bachelor assignment on the island of Curacao with my friend Bart or being part of the organization committee of the think tank Create Tomorrow.

I always had curiosity about the financial world, but my interest in this complex system was rekindled by the unprecedented crisis of 2008. Therefore, I decided two years ago to participate in the master of Financial Engineering and Management and choose particularly this subject for my thesis. I would like to express my gratitude to my future colleagues of the FS Risk department of EY for granting me the opportunity to conduct this thesis within their department and their support. A special thanks to Dr. D. Fokkema of EY, and my supervisors Dr. B. Roorda and Dr. R. Joosten.

Last, but definitely not least, I want to thank Ellen, my family and friends for their support and welcome distractions.

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Chapter 1

Introduction

This chapter provides context to the thesis' subject, rationale for this research and structure to the thesis.

I wrote my thesis during a six-months internship at EY, formerly known as Ernst & Young. I am employed within the *Financial Services Risk* (FS Risk) department located in Amsterdam, the department is specialized in financial risks and compliance challenges. One of today's main challenge is the consult to banks in helping them executing the EU-wide stress test of 2014.

1.1 Background: the 2008 crisis

In the aftermath of the financial crisis one thing became clear, banks need to assess their vulnerabilities and reconsider their risk profiles. The turmoil, which ultimately led to the fall of Lehman Brothers in 2008, evidently demonstrated the fragility of the financial system.

Banks behave in a way to maximize economic value, while avoiding bankruptcy. A bank can default due to insolvency or illiquidity. The first case describes a state of having liabilities that exceed the value of the asset portfolio, it is the inability to meet long-term obligations. The latter scenario describes a state were the bank is unable to meet short-term obligations, but it may be that the bank is sufficiently capitalized.

The two sources of financial distress are fiercely debated, often treated separately in risk management, but are intertwined as the turmoil during the latest financial crisis revealed. Below, the crisis in a nutshell.

> The Federal Reserve Bank *of* New York (FED) gradually lowered the interest rates after the DOT-com bubble to fuel the economy. The monetary excesses amplified the housing boom and are regarded as the main cause of today's crisis.
>
> The historically low interest rates encouraged risk taking. Banks constructed, sold and traded ingeniously complex products, derivatives of residential mortgage loans. This was made possible due to the financial liberation in the Eighties. Banks increased their balance sheets, relied more on cheap short-term funding and increased their leverage. The economy was booming, but then the boom turned to bust.
>
> Property owners were deeply leveraged in an era of low interest rates, which ended suddenly. People defaulted on their loans with increasing frequency and house prices went down the hill. The property pledged as collateral fell below the value of the principal loan. Securities tied by the residential mortgages ignited a deep flow of security write-downs.
>
> Bank's asset portfolios incurred great losses. Interbank lending was considerably impaired, since banks were afraid to lend to counter-parties and sought for additional liquidity for their own needs. Confidence and trust among banks reached unprecedented levels. Assets once thought to be liquid, were impossible to liquidate without significant loss. Bailouts and economic stimulus programs were inevitable. The global economy experienced severe damage and partly due to bailout costs sovereign states needed bailout funds as well, which led to the sovereign debt crisis we experience today.

Liquidity problems in the wholesale market, a market which is generally sensitive to the bank's solvency position, seemed being the key consequence in the wake of the write-downs, killing many banks which were well capitalized under various capital requirements, but unable to meet short-term demands.

Contrarily, one could claim that during the supreme crisis the markets realized that banks were under-capitalized due to the lack of transparency of the risk exposures of various securities. The securities were in fact worth a lot less than initially thought. Possibly, this fragility was induced by banks themselves since *too big to fail* banks took more risks than socially optimal.

The distinction is important, but the true cause of the failure of the system is hard to unravel. The crisis emphasized that both solvency and liquidity profiles of banks are crucial in determining bank's resilience. Since stress can originates from one or a combination of both sources of risk.

The banking crisis had immense contagion effects, distrust and confidence hit rock bottom. Restoring confidence in the financial system is now a policy priority of supervisory authorities. The EU-wide comprehensive assessment conducted by the European Banking Authority (EBA) comprising a system-wide stress test, is a means to add credibility and reduce uncertainty in the European banking sector.

1.2 Research motivation

The previous section mentioned three important ingredients of this thesis: solvency, liquidity and profitability, in this thesis we call the three profiles together: 'the bank's Trias'. In recent decades solvency risk and liquidity risk got varied attention. The new Basel framework (Basel III) introduced liquidity metrics, while capital adequacy ratios exist since the first Basel framework. Both liquidity problems and solvency issues are regarded as causes of the failure of the banking system in 2008. In this thesis equal consideration is given to both sources of risk, together with the profitability component.

With the use of a severe stress scenario, we assess the interaction between the solvency, liquidity and profitability of a bank. During stress (as we have seen in the previous section), the dynamics within the bank's Trias tends to become clearly visible. In the wake of the crisis, stress testing is seen as a promising tool, used as a supplement to the static metrics of Basel III. The United States (US) already adopted two approaches to measure capital requirements (Wall, 2013). Basel III and stress testing methodologies. The latter to mitigate the deficiencies of the Basel III unconditional static capital requirements according to Wall (2013). The stress tests simulate how these ratio's evolve over time.

The Basel Committee on Banking Supervision (Basel Committee on Banking Supervision, 2013, p.1) argues that properly implemented stress tests are able to generate valuable information which cannot be generated from standardized metrics. Concerning the newly added Liquidity Coverage Ratio (LCR), the Basel Committee argues that the LCR should be viewed as a minimum requirement. "Banks are expected to conduct their own stress tests to assess the level of liquidity they should hold beyond this minimum" (Basel Committee on Banking Supervision, 2013, p.6).

Observation 1:
Stress tests are able to generate valuable information and can be used as supplement of the set of Basel III metrics to provides a more comprehensive picture of the risk exposure of a bank. With the use of stress tests a bank should assess whether the bank's Trias is sufficient to withstand severe stress.

We simulate the dynamics between the liquidity and solvency position of a bank, as the work-group argues: "liquidity and solvency risks are often interlinked but frequently treated separately in (supervisory) stress tests". Brunnermeier *et al.* (2009) argues that in order to strengthen resilience in the financial world, both risks should be closely monitored and contained within metrics which incorporate both sources of risk.

Observation 2:
The combination of solvency risk and liquidity risk in stress tests is often neglected. But referring the previous section, the combination was clearly visible during the crisis of 2008.

The thesis provides a model which measures the impact of a stress scenario and uses the outcome to restructure the balance sheet. The integration of stress test results into banks' business practices is desirable (Basel Committee on Banking Supervision, 2013, p.1). "Even the best designed, most robust stress test will have no impact if its results are not used to set risk limits and inform the bank's operations" (Basel Committee on Banking Supervision, 2013, page 2).

Observation 3:
Stress test outcomes need to be integrated in risk management.

If we add the three observations together we get a clear motivation for this research and research objective. With the use of a stress scenario, including both solvency and liquidity risk, we assess the dynamics within the bank's Trias. We provide a model which optimizes the profitability of a bank, under the same scenario, while considering multiple prudent solvency and liquidity profiles. A decision space is the result.

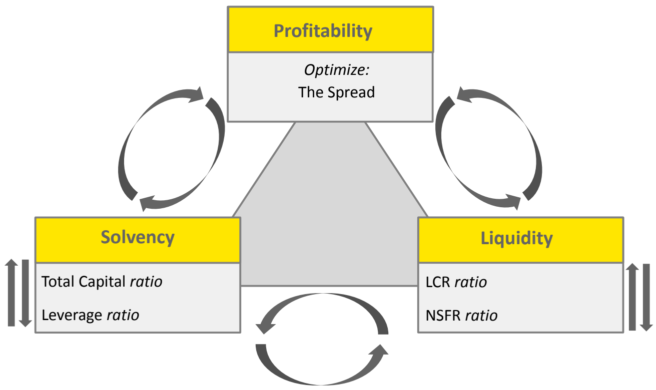


Figure 1.1: The Interaction within the bank's Trias

1.3 Research Objective

We assess the impact of a stress scenario on a stylized bank balance sheet considering the bank's Trias. The solvency and liquidity profiles are defined by Basel's capital and liquidity metrics. During stress we observe how these metrics evolve over time (observation 1). Funding and deposit withdrawals are assumed to be sensitive to the bank's solvency and liquidity position, since solvency and liquidity risk should be combined in stress test (observation 2). With this assumption, the balance sheet is not only vulnerable to asset impairments which effect the solvency position directly, but also for potential liquidity problems.

If the bank's Trias appears to be unable to withstand the stress, we assess which measures a bank should take in order to make the bank's Trias more resilient over the overall horizon of the stress (observation 3). Secondly, Basel's solvency and liquidity requirements are minimum requirements, by performing a sensitivity analysis by changing the solvency and liquidity position, we obtain a better understanding of the relation between the solvency, liquidity and profitability of a bank and the decision space a bank has considering the bank's Trias, see figure 1.1.

The thesis emphasizes the threefold perspective on the three performance indicators of banks: solvency, liquidity and profitability.

The research goal is: *Develop a model for enhancing bank's profitability, while maintaining a prudent solvency and liquidity profile under a severe, yet plausible, scenario.*

Given the research motivation and objective as presented above, this thesis aims to answer the following main research question:

'How could banks use stress test methods to improve the balance sheet in anticipation of a severe stress scenario, considering the solvency and liquidity position, while improving the bank's profitability?'

To answer this main research question, we specified five sub-questions, which on one hand divide the main question in manageable parts, and on the other hand gives structure to this thesis. Each of the upcoming chapters will focus on one of sub-questions.

Sub-questions:

1. (a) How do we measure solvency, liquidity and profitability?
   (b) What causes solvency and liquidity risk?
2. How are the solvency position, liquidity position and the bank's profitability related?
3. How could we stress a stylized balance sheet, considering both solvency and liquidity risk, while enhancing profitability?
4. How could the outcome of a stress test be used and integrated in the banks' risk management?

1.4 Outline

The subsequent chapters are arranged in the following order:

Chapter 2 describes comprehensively the context of the thesis, including the concepts of solvency(risk), liquidity(risk) and profitability. This chapter concludes with a debate about the presence of both types of risks in the subprime crisis. In Chapter 3, we review the principles of stress-testing and the interaction between solvency, liquidity and profitability. In Chapter 4 we explain the developed model for stressing and improving a stylized balance sheet. Chapter 5 provides and interprets the results, including multiple sensitivity analyses. The thesis concludes with Chapter 6, the conclusions and recommendations.

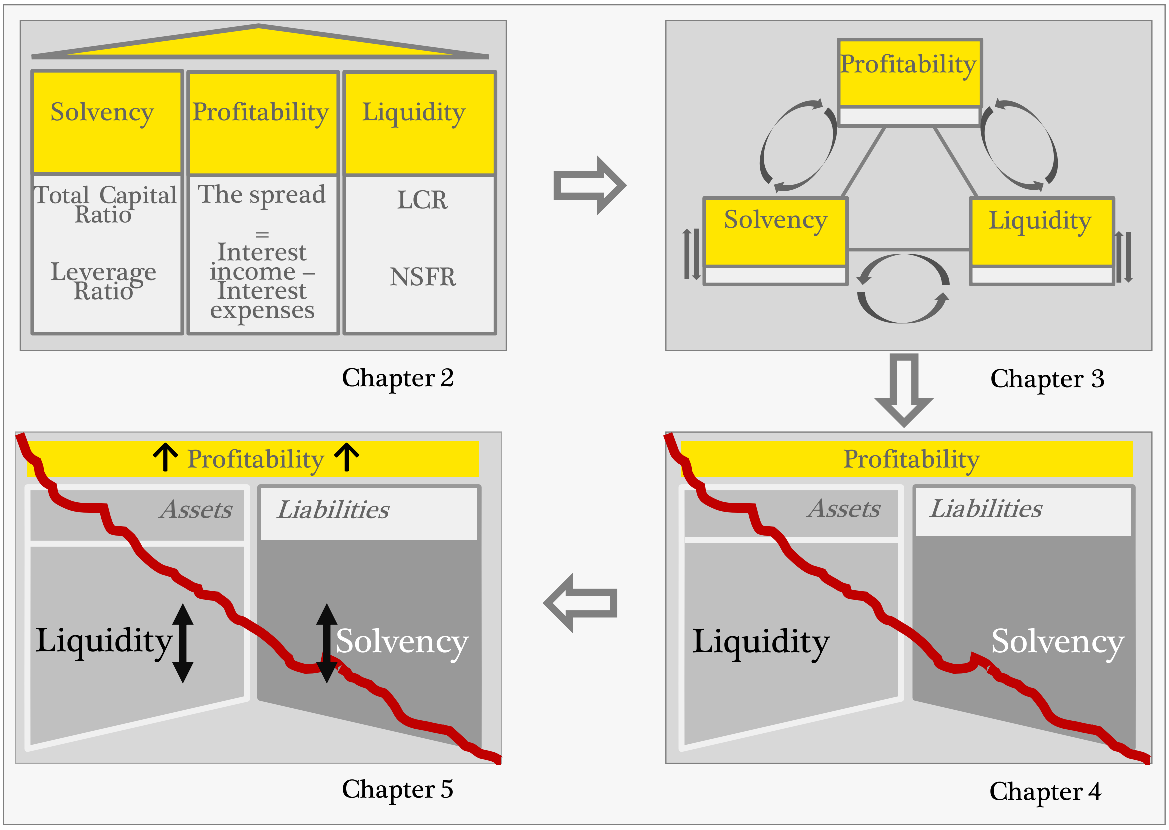


Figure 1.2: Thesis's outline

Chapter 2

Context Analysis

This chapter begins with a short description of how a bank works. Next, the concepts of solvency (risk) and liquidity (risk) are briefly explained, more background and technical information may be found in Appendix A. The chapter concludes with the linkage of the concepts to the subprime crisis.

2.1 Solvency and liquidity

2.1.1 The banking model

We distinguish, on a general level, three traditional roles that banks play in the economical system. First, they provide credit by funnelling numerous short-term deposits to sizeable long-term loans. Secondly, they provide payment services to retail and corporate clients. Lastly, they assist clients to manage their risks.

The focus of this thesis is concerned with the first role; the transformation process of transforming a large number of relatively short-term funding sources (e.g. retail deposits) in (through, at least in first instance, the cash position) relatively long-term interest bearing assets (e.g. mortgages), see figure 2.1. The possession of more short-term liabilities than short-term assets, the so-called maturity gap, creates interest rate risk. This means that a rise in interest rates (and therefore funding costs) cannot easily pass through to the interest bearing assets. Future interest income is locked-in contracts. Further, short-term liabilities can easily withdraw their funding which makes a bank vulnerable for changes in the market perception of the bank's viability.

The presence of solvency risk and liquidity risk is inherent in this transformation process. A bank can default due to one, or a combination of both sources of risk.

First, we discuss shortly the concepts of both sources of risk. A fierce debate is

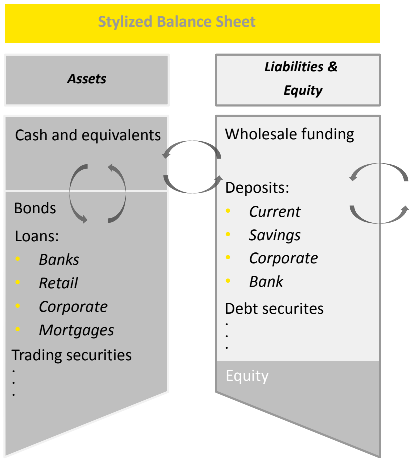


Figure 2.1: The Banking model

going on about whether the latest financial crisis was a liquidity crisis, or a solvency one. In the next section, both schools are briefly discussed.

2.1.2 Solvency

Corporate solvency is the ability to cover debt obligations in the long run (Gryglewicz, 2010). *Solvency refers to a company having more assets than liabilities, so that the value of its equity is positive* (Hull, 2010).

Equity is a cushion to absorb asset losses. If credit risk materializes (e.g. when a borrower is unable to repay his loan), the equity position suffers an equivalent amount. Solvency is the size of the cushion, it is the difference between the value of the assets and the sum of liabilities. The difference can be considered the bank's own funds, it consists of common shares, share premium and retained earnings. The bank must pay for, and repay in full, other types of funding (e.g. deposits), but equity is perpetual (Farag, Harland & Nixon, 2013). Further, the distribution of dividends is the cost of equity, and distribution is not obligatory, its varies with the bank's profits. However, in case of default, equity holders suffer first losses. Therefore, equity holders receive generally a higher return compared to other types of funding.

Figure 2.2 shows the situation in which a bank suffers from risky loans, the capital base is depleted with an equivalent amount as the asset impairment. If the impairment is greater than the capital cushion, the bank is insolvent and technically in default.

Capital requirements imposed by central banks are put in place to ensure fi-

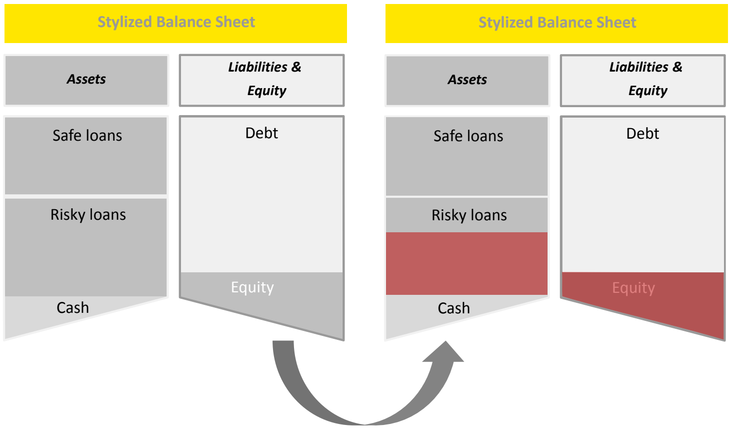


Figure 2.2: *A presentation of an insolvent balance sheet: on the left a balance sheet under normal conditions. On the right an insolvent balance sheet, the capital cushion is insufficient to withstand the asset impairment.*

nancial stability, the solvency of the financial system and to prevent banks taking excessive leverage. Capital requirements (also known as capital adequacy or regulatory capital) implies a minimum level of equity a bank should have to absorb unexpected losses. The riskier the assets, the more equity a bank should have. The capital ratios discussed in Basel III are metrics to assess the solvency of banks.

Section A.3 discusses the capital requirements imposed by Basel III:

- The capital ratio's. The *risk-weighted* capital measures. Are measures of different definitions of a bank's capital expressed as a percentage of the sum of its risk-weighted assets.
- The leverage ratio. The *un-weighted* capital measure. The bank's capital position expressed as a percentage of total assets.
- The capital conservation buffer. Designed to ensure that banks build up capital buffers outside periods of stress which can be drawn down as losses are incurred (BIS, 2011).
- The countercyclical buffer. Imposed in times of excessive credit growth.

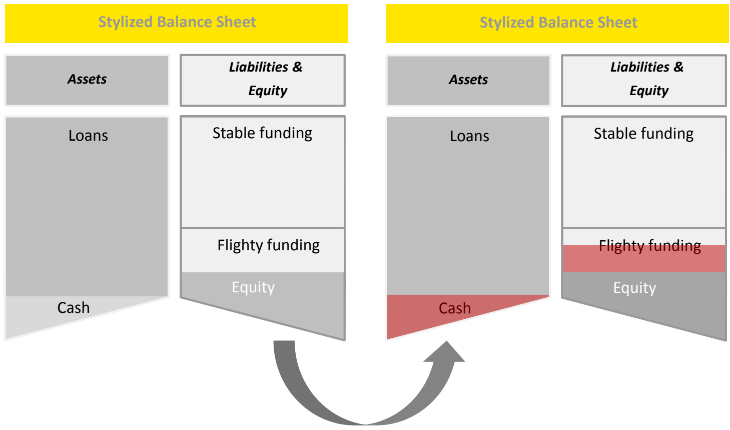


Figure 2.3: *A presentation of an illiquid balance sheet: on the left a balance sheet under normal conditions. On the right an illiquid balance sheet, the cash cushion is insufficient to meet all cash withdrawals and/or unable to meet demand in the event that its short-term loans are not rolled over.*

2.1.3 Liquidity

Liquidity is the ability of a bank to fund increases in assets and meet obligations as they come due, without incurring unacceptable losses (BIS, 2008).

Liquidity risk is inherent to the fundamental role of banks to transform short-term deposits into long-term loans. Without this mismatch, and as long as the assets pay off, it would not suffer from liquidity problems. Liquidity risk can either evolve from funding problems (inflow), unexpected and extensive withdrawals (outflow) or the illiquidity of assets. Section A.4 discusses *funding liquidity* and *market liquidity* more thoroughly.

Some cash flows are predictable, for instance the pay-off structure of a bond. Some cash flows are more challenging to predict, like deposit withdrawals. A bank can experience unexpected and extensive cash out-flows due to a downgrade in the credit rating or a sudden shift in the market perception about the bank's continuity. The bank-run on Northern Rock in 2007 is classical example of a bank-run. In such an event, debtors try to withdraw and secure their deposits simultaneously. But the deposits are invested in illiquid assets (e.g. mortgages). Liquidation is impossible or costly. Hence the bank is unable to meet demand, and default is inevitable.

Figure 2.3 shows the situation in which funders withdraw their funds simultaneously, or/and when short-term funders stop rolling-over their funds. Then, the pool of liquid assets (cash and assets that can be converted into cash with minimal costs) is quickly depleted. The bank is unable to meet all obligations and is regarded as defaulted.

Liquidity risk was neglected in recent decades. The absence of considering liquidity risk in Basel I affirms this disregard. It was a common belief that proper capitalized banks always had access to funding. But since, banks became more and more reliant on the relatively inexpensive short-term funding enhanced by the prosperity of technology. Now, the regulators' aim is to avoid pre-crisis circumstances of extensive reliance of short-term (unsecured) funding. Banks must assess a worst-case scenario, and prove being capable to survive such adverse event. Basel III introduces two liquidity standards; the Liquidity Coverage Ratio (LCR) and the Net Stable Funding Ratio (NSFR). The first standard however conceptually resembles the Liquidity Balance ratio operative since 2003 in the Netherlands (de Haan & van den End, 2012). This study shows that most Dutch Banks have held more liquid assets in the period of January 2004 to March 2010 than required by the Dutch regulator. Therefore, one could expect that the imposed LCR is not truly restrictive.

A technical description of the two liquidity standards is added in Section A.4.

2.2 Views on crisis' causes

A fierce debate is going on about whether the latest financial crisis was a *liquidity crisis* or a *solvency crisis*.

According to i.e. Gorton & Metrick (2012) at the nexus of the financial crisis in 2007-2008 there was a run on so called Repurchase Agreement Products (Repo's), a type of wholesale funding[1]. This short-term funding market is a key source of financing. But, stress in this market could cause severe liquidity deficiencies for banks. This phenomenon showed many similarities with an old-fashioned bank-run, in which depositors withdraw their funds simultaneously. This occurred during the latest crisis in September 2007 at Northern Rock in the United Kingdom (Goldsmith-Pinkham, Yorulmazer, 2010). The bankruptcy of Northern Rock is not the only example of an illiquid bank. Liquidity shortage killed Lehman and Dexia and almost Morgan Stanley if the bank did not receive a bailout of $107.3 billion (Keoun, 2011).

Many problems derived from the maturity mismatch risk of banks balance sheets (de Haan & van den End, 2012). The mismatch in a balance sheet is a consequence of the possession of more short-term obligations compared to the amount of short-term assets and more medium-term and long-term assets than liabilities with the same maturity, this mismatch is inherent to banks. The maturity profile of a bank is a proxy for the degree of liquidity risk. If a bank relies deeply on short-term funding and if doubts among the short-term funders arise about the roll-over abilities of the bank's short-term funding from remaining sources, the stimulus to run (and not roll-over the funds) could lead to serious instant liquidity problems.

Pre-crisis, it was more profitable to finance long-term assets with short-term funds. The supply side was exposed only for a short period of time and concerning Repo's, secured by collateral. So the long-term assets were strongly dependent on the ability to roll over short-term loans. Moreover, many banks had difficulties attracting deposits for funding the bull market (Babihuga & Spaltro, 2014). Therefore, banks supplemented deposits with wholesale funding.

The reliance on short-term funding to finance long-term assets increases the liquidity risk of banks. During the crisis, banks became eager for high quality liquid assets, for the mismatch risk and the roll-over risk of short term interbank borrowing (de Haan & van den End, 2012). The rising dependencies on short-term funding and the decreasing liquidity of assets (they proved to be mis-valued) had an impact on the volume of term borrowing and inter-bank rates (Acharya & Skeie, 2011). Wholesale funding became prohibitively expensive in 2007-2008, or even unavailable. The

[1] In repo transactions, securities are exchanged for cash with an agreement to repurchase the securities at a future date.

inter-bank markets dried up (Babihuga & Spaltro, 2014).

Contrarily, the solvency school argues that the liquidity shortage is a consequence of a lack of faith about which bank is solvent and which balance sheet is not credible. The complexity of the structured products caused legitimate doubt about the true value of mortgage-related assets and therefore the size of equity. In August 2008 the 500 billion dollar mark of asset write-downs was reached (Keoun, 2011). The solvency school argues that the fundamental issue is not liquidity, but rather solvency.

The two sources of financial distress are not independent, but intertwined (Jarrow & Turnbull, 2000; de Haan & van den End, 2012). These authors argue that the more solvent banks, have relative less liquid assets against their liquid liabilities. Furthermore, stressing one source, has implications on the other. Banks with impaired capital, experience a decline in funding sources causing increasing funding costs, which will erode capital even further. However, liquidity and solvency risk are often treated separately in stress test (Basel Committee on Banking Supervision, 2013, p.1; Morris & Song Shin, 2009). Banks, regulators and supervisors are aware of the significance of both sources of financial distress, but due to the number of models available the sources are treated separately (Drehmanna *et al.*, 2009). Furthermore, the Basel work-group argues that integration of stress-test results into banks' business practices should be further intensified (BIS committee, 2013).

Chapter 3

Literature Review

This chapter begins with the concept of stress testing. Stress testing encompasses three elements: a scenario, a model and an outcome. The same modular structure is used for the thesis' model. The previous chapter introduced the concepts of solvency and liquidity. In this chapter, we will discuss the interaction between solvency, liquidity and profitability.

3.1 Stress Testing

Stress testing is not restricted to the economical and financial environment. Stress Testing has a long history in engineering and computer science. Basically, stress testing is a method to identify the breaking point of a system by deliberately putting a system under intense stress. In finance, stress testing methods are quite new and applied initially in data rich environments for instance in trading operation (Schuermann, 2013). Stress test outcomes answer the elementary question of risk managers, *how resilient is my portfolio during severe scenarios?* The subject of exposure was often limited to single loans or to a portfolio.

The Market Risk Amendment of 1995, a supplement of the Capital Accord of July 1988, introduced stress testing as a complement of other risk measures. Stress testing is since this amendment mandatory for banks that use the internal model method for meeting the market risk requirements (BIS, 1995). Since then, stress testing is embedded in the regulatory environment. In Basel II, banks using the Internal Rating Based (IRB) approach, are obliged to have a sound stress test methodology in place to assess the capital adequacy (BIS, 2006). Under the new Basel III the methodology is also embedded and a prerequisite when banks use the internal model method to set the liquidity coverage ratio (LCR). The level of liquidity banks should have on hand should be sufficient to overcome a 30 day stress scenario. Banks have to construct their own stress scenario in order to combine idiosyncratic and market risk components (Basel Committe, 2013). The EBA wide stress test is

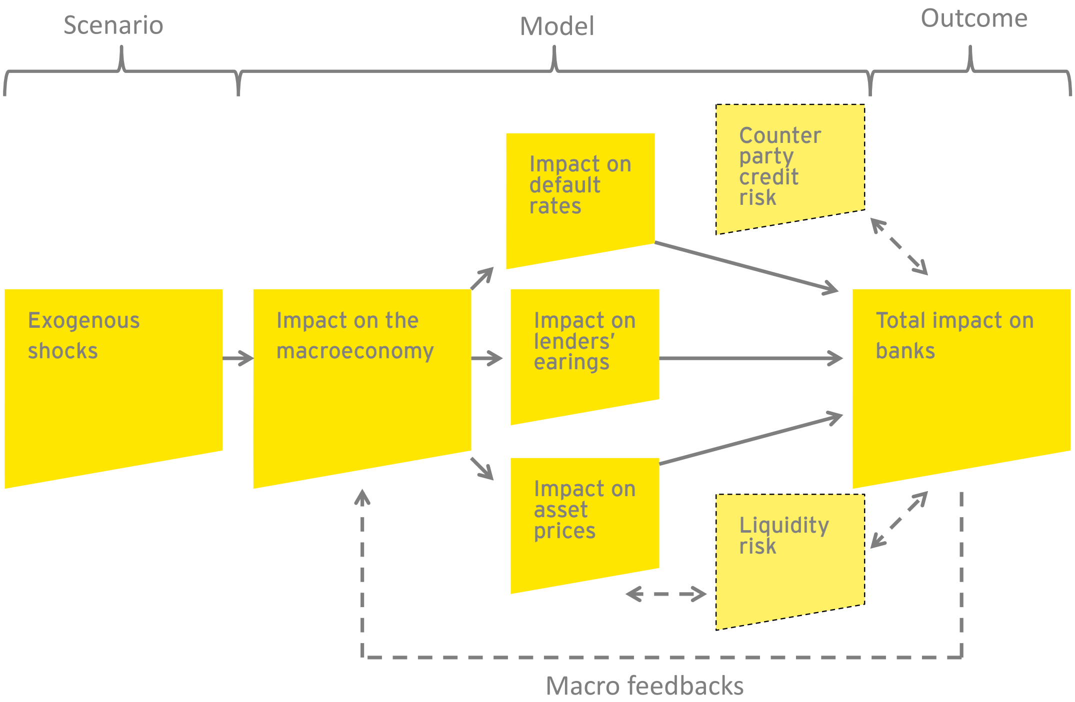


Figure 3.1: *Structure of a macro stress test, (Borio et al., 2014)*

a macro-stress test, which will assess the soundness of the European banking system.

Generally, the structure of a stress test model has a modular fashion and encompasses three elements; a scenario, a model and an outcome. See figure 3.1(Borio *et al.*, 2014)

The scenario In this phase the aim of the exercise is to define a set of exogenous shocks, a shock example could be: *a rise in investor aversion to long-term fixed income securities.* The type of shocks differ per exercise, it depends on the objective of the stress test. In case of the EU wide stress test, the scenario is a story line how the economical and sovereign crisis could evolve in an adverse manner. The standard rule for defining scenarios is that constructed scenarios should be 'severe yet plausible' (Quagliarello, 2009). Severe to be meaningful, plausible to be taken seriously by market participants. The scenario constructed by the EBA can be found in the appendix A. Scenarios could be modelled as well (e.g. using the tail of a distribution of historical data). Foglia (2008) summarizes different kind of models available, and Hilbers, Jones and Slack (2004) the considerations when using a macro model to simulate macroeconomic scenarios, including baseline assumption, policy responses, time horizon, which variables are assumed fixed and which are shocked and the size of the shock. Another type of approach is the use of historical crises. First, a risk manager can replicate for instance the Black Monday or the dot-com bubble. The latest episode, the crisis of 2008, will likely become a standard scenario is stress testing. Secondly, if enough data are provided, a risk manager can use the tail of a distribution of a certain risk factor, to identify severe yet plausible events. But, depending exclusively on historical data could be problematic. Each crisis evolves differently and each crisis begins with another type of 'shock'.

The Model The model consists of several parts. First, a macro model translates the effects of the exogenous shocks into relevant risk factors for banks[1](e.g. GDP decline). Is case of the EU wide stress test, both the exogenous shocks and the impact on various risk factors is given. Secondly, the output of the macro model serves as input for satellite or auxiliary models (Borio *et al.*, 2014). These models impose the risk factors (e.g. GDP decline) to banks asset classes. There are many credit-quality models, Foglia (2008) published a few, these models link the loan performance to macroeconomic conditions. Other satellite models link the macroeconomic conditions to market risk or income risk.

Outcome In the last phase, the impact on banks' balance sheet and/or profit&loss account is assessed.

More sophisticated models incorporate feedback effects. In case of the financial crisis of 2008 we can clearly perceive these 'loops' where the financial sector had an amplified effect on the macro-economic conditions (respectively, the original macro-economic stress scenario). Many stress tests are modelled from a micro-prudential perspective and disregard the endogenous characteristic and dynamics of systematic risk. The common models assume only first round effects and ignores negative contagion effects. In figure 3.1 the dotted lines indicates possible feedback effects. A common reaction during the recent financial crisis of a bank facing capital shortfall is adjusting the amount of loan issues (Schepens & Kok, 2013), which could have further negative economic implications. In case of supervisory macro-prudential stress tests the majority of the tests are restricted to first round effects, because there are practical reasons (Henry & Kok, 2013). Feedback loops are accompanied with (behaviour) assumptions which affects the validity of the test. Furthermore, the dynamic nature of the test is time consuming and has a burdensome for involved banks.

The 2014 EU wide stress test has the same modular structure. The EBA constructed a hypothetical adverse scenario, see for the scenario Section A.1. Banks are expected to translate this scenario, with the use of satellite models, into risk parameters (e.g., PDs (probability of default) and LGD (lost given default)). For small

[1]some literature include this step in the scenario phase

banks, or for benchmark purposes, the EBA published benchmark risk parameters, see Section A.1.

In Section A.2 more information is given about the two different approaches of stress testing: top-down and bottom-up stress test approaches. The top-down approach uses aggregated data to estimate the scenarios' impact into banks' balance sheets, and subsequently aggregates the results. The bottom-up approach uses banks' individual data (highly disaggregated) *and* models the resilience of the bank to adverse shocks (given by a central authority). The central authority aggregates the results.

3.2 Interaction of liquidity and solvency

The core metrics of a bank's financial strength are solvency, liquidity and profitability, see figure 3.2. All metrics are interrelated, and serve one or more stakeholders in different degrees. Shareholders want to maximize profits, depositors request safety and an attractive rate and the regulator demands a prudent risk profile.

As stated earlier, solvency and liquidity are two measures of the financial soundness of a bank. One of the core principles of finance states that there exists a trade-off between the soundness of a bank (risk) and the expected return. Expected returns can only rise, if it is subjected to a higher probability of loss. The trade-off between risk and return depends on the risk tolerance of the risk taker. A good illustration of this trade-off is the efficient frontier, introduced by Markowitz (1952).

Profitability is in our thesis equal to the spread between interest bearing assets instruments and interest bearing liability instruments. Clearly, some income and expenses are excluded from this equation. In particular, banks earn (or loose) money on their assets held for trading and banks face the inevitable presence of non-performing loans and bonds. The risk of non-performing loans is called credit risk, the risk that a borrower is unable to make the required payments. The amount of cost of write-downs of non-performing loans is related to the type of assets a bank posseses, considering the risk associated with the asset portfolio. Other costs are fees and other (staff) expenses and are regarded as independent of the risk profile of the bank during this thesis.

The composition of the asset portfolio affects the profit. Risky assets yields higher returns as explained earlier. But, if the credit risk materializes, the solvency position of a bank is also effected. A write-down has a direct impact on the equity position of a bank, as the write-down is paid by equity.

A banks' access to the short-term funding market is particularly sensitive to the

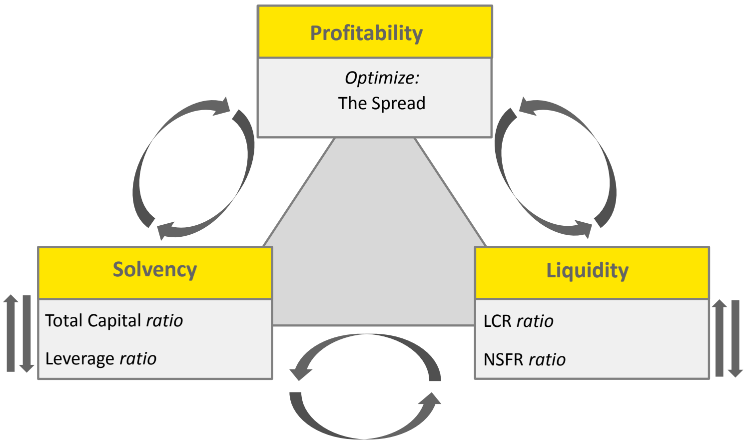


Figure 3.2: The Trias Perspective

expectation of the market about the solvency of a bank (Schmieder *et al.*, 2011). One of Pierret (2014) results suggests that in case of a systemic crisis, the solvency position is a explanatory variable for a bank's access to short-term funding[2] . However, this statement does not hold for banks experiencing a crisis in isolation. These findings are confirmed by Babihuga & Spaltro (2014). First, they found a strong relation between bank's credit quality (Tier 1 capital) and funding costs. Secondly, they found that equity returns are negatively correlated to funding costs and the probability of default.

Furthermore, the degree of exposure to short-term funding effects the expected amount of capital a bank should have in order to remain solvent during times of stress (Pierret, 2014). Reliance on short-term funding effects the bank's vulnerability to runs. To convince creditors that the bank is sufficiently robust to withstand stress events, a bank should raise adequate levels of common equity. These findings signify that bank's the creditors define the creditworthiness of a bank, reflected in the funding costs, both by the liquidity position and the capital levels of a bank. Ultimately, the impact of the increased funding costs on the profit depends on the ability to pass on the increased cost.

A credit rating agency rates the debtor's ability for making timely payments on their debt. A rating, subject to a comprehensive quantitative and qualitative analysis by an agency, affects the borrowing costs. A high rating means cheaper borrowing. Figure 3.3 shows the relation between the rating of a bank and the

[2]The solvency position is measured by the leverage ratio

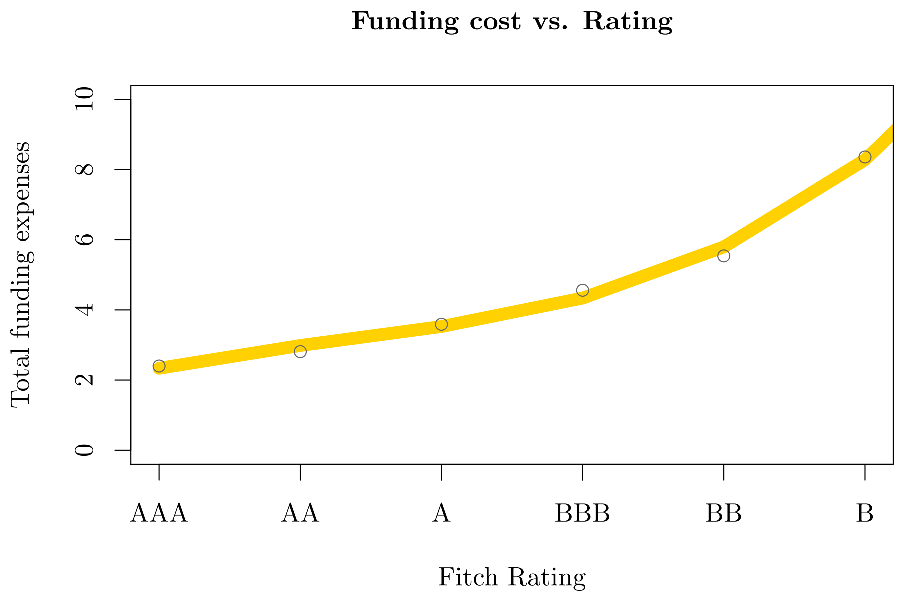


Figure 3.3: *Fitch credit ratings vs. total funding expenses. Data is extracted from the world banking information source: Bankscope. The 'total funding expenses' is the sum of all interest expenses divided by the sum of all liabilities, in percent.*

funding costs[3].

In summary, the bank's solvency position acts as a loss absorbing buffer in case of asset devaluations, and is able to create confidence amongst creditors to continue to provide funding (Pierret, 2014). However, not only funders can decide to stop reinvesting, depositors can withdraw their deposits if they think this is better from their perspective.

There are two traditional views of banking panics, so called bank runs (Allen & Gale, 1998). One school sees these events as random events, the other as self fulfilling prophecies. The former is unrelated to changes in the real economy. The latter is triggered by an extrinsic random variable, what Franklin Allen and Dougles Gale calls 'the sunspot view' The trigger evokes depositors to withdraw their deposits simultaneously, based on the assumption of first-come, first-served. Since a bank has a limited amount of liquid assets, it is optimal for each depositor to withdraw their deposits instantly. Another view than the *sunspot*, is that panics are part of the business cycle. Economic forces can impair the value of assets. If the impair-

[3]Data comprises Fitch ratings and total funding expenses (total funding expenses divided by total assets) of 10 Dutch Banks (ING, RABO, Bank Nederlandse Gemeenten, SNS, RBS, NIBC, Friesland Bank, Credit Europe Bank, GMAC) from 2004 to 2013, datasource: Bankscope

ment effects the bank's solvency and future obligations, depositors will anticipate by withdrawing their funds. Bank runs evaporate the liquidity position of a bank, triggered by observed information about the solvency position of a bank. If the run is greater than the liquidity position of the bank, the bank is forced to liquidate additional assets at discounted prices affecting the solvency position.

A bank has inherently insufficient liquid assets to meet all commitments if due simultaneously. But the size of the position must be sufficient to meet all debtors demands under normal circumstances. Highly liquid assets, cash and cash equivalents, and marketable assets, serve as the liquidity cushion of a bank. Unfortunately, liquid assets are "expensive" in the sense that they bear relatively little to zero interest. Those idle funds do not fetch any real profit for the bank. The crux of determining the size of the liquidity position is the assessment of the exposure to liquidity outflow and the availability of the counterbalancing capacity.

The funding costs can be derived from econometric models which are able to translate effects on the earning side to funding costs on the liability side. Such a model is based on empirical evidence (Schmieder *et al.*, 2011). The overall cost of funding is quite complex and difficult to obtain however (Babihuga & Spaltro, 2014). Furthermore, the dynamics between the asset composition and the funding cost differs between countries and banks. For instance, the fiscal and regulatory environments influences the sensitivity and level of funding costs. Data, necessary to reveal the dynamics, is barely available for Dutch banks. Other methods derive funding costs from credit default swap (CDS) spreads, credit ratings and equity prices.

CDS spreads are a proper indication of the default probability of the underlying. Babihuga & Spaltro (2010) used the 5Y CDS spread (plus LIBOR) to estimate bank's funding costs. However, Tang & Yan (2012) write that changes in CDS spreads, according to the Merton model, are mainly driven by "leverage, asset volatility, and market conditions such as interest rates". Another factor in CDS spread changes is risk aversion of investors in the market, making the spreads potentially increase when investors becoming more risk averse (Tang & Yan 2012).

The latter we clearly witnessed during the supreme crisis, see Figure 3.4. On September 15, 2008, Lehman Brothers filed for bankruptcy. Figure 3.4 clearly demonstrates the contagion effects in the CDS spreads of four Dutch banks. Prior to the fall of Lehman Brothers, all CDS spreads were almost fixed around zero percent, i.e. the financial market thought the probability of default of these banks was near zero.

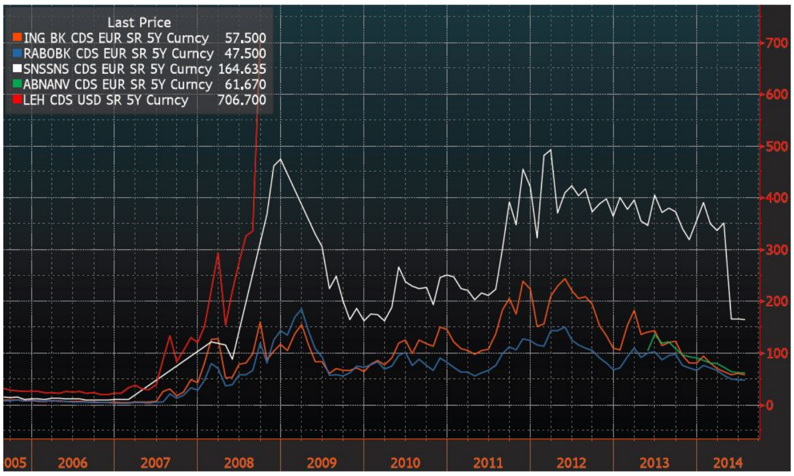


Figure 3.4: 5Y CDS spreads, source: Bloomberg

The use of credit ratings to estimate funding costs, in itself an obvious and quite practical one, is difficult to integrate with asset impairments. A rating, is not solely based on quantitative elements.

At last, Merton, 1974 [4], applies option pricing theory to loan valuation. Figure 3.5 shows the pay-off function of a writer of a put option conditional to an underlying stock price. The function shows clearly similarities with the pay-off function of a debt holder of a firm conditional to the asset value of the firm. The model developed for this thesis uses Merton's theory for determining funding costs.

It is assumed that a debt holder receives title to the remaining (liquidated) assets, in case of a default, but does not participate in the firm's fortunes. They only receive a yield. A writer of a put option receives a premium (p)(the yield), and keeps this premium if the stock price exceeds the strike price (K) (shaded green area in 3.5). But if the stock price falls under the strike price, the writer of the option looses the premium (shaded orange area in 3.5) and the difference between the strike price and stock price (shaded red area in 3.5).

Merton noted this equivalence, and considers the pay-off function of debt holders as a put option on a firm's assets with strike equal to the value of the debt. Likewise, the pay-off function of equity holders matches a long position in a call option on a firm's assets, with the same strike. The seller of the put, the debt holder, receives a option premium (the yield), with the risk of default. The holder of the call, the equity holder, pays a option premium (market value of share price), with the risk of default but with unlimited potential.

[4]See R. Merton "On the Pricing of Corporate Debt: The Risk Structure of Interest Rates", Journal of Finance, 29, (1974): 449-70

Section A.5 gives a technical description about the use of Merton's model. We should be aware that the use of Merton's model for estimating funding costs is purely theoretical, in practice this cost could diverge significantly.

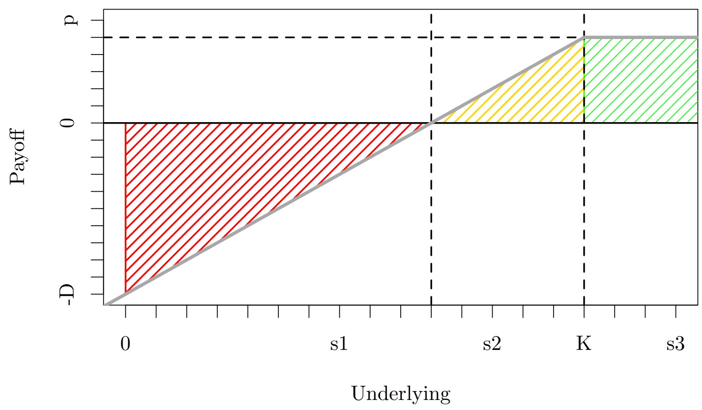


Figure 3.5: Long Put Payoff Function

Chapter 4

Balance Sheet Simulation

This chapter comprises four parts. First, the stylized balance sheet we use for our simulation is presented, including the different asset and liability components. Secondly, we show how we stress the asset side of the balance sheet. In the previous chapter we elaborated on the relation between the solvency position and the consequences regarding the funding costs and cash withdrawals. Here, we explain how we stress and relate the solvency position to these consequences in our model. Thirdly, we present the optimization techniques and restrictions. At last, we show which data we used for our simulation, concerning the interest rates corresponding to the different asset and funding classes, the balance sheet structure and the imposed shocks.

4.1 The model

4.1.1 Model components

The stylized Balance Sheet	
Assets	Liabilities & Equity
Retail:	*Retail:*
- (i=1) Residential Mortgage Loans - (i=2) Other Retail Loans	- (j=1) Customer Deposits - current - (j=2) Customer Deposits - savings - (j=3) Customer Deposits - term
Corporate & Commercial:	*Corporate & Commercial:*
- (i=3) Corporate & Commercial Loans - (i=4) Loans and Advances to Banks	- (j=4) Corporate deposits - (j=5) Bank deposits
- (i=5) Bonds - (i=6) Trading securities	- (j=6) Debt securities - (j=7) Subordinated borrowings - (j=8) Trading liabilities
- (i=7) Cash and equivalents	- (j=9) Equity

Table 4.1: The Balance Sheet

Table 4.1 shows our stylized balance sheet. The different classes are common generic classes in annual statements of the ING bank, Rabobank, ABN AMRO bank and the SNS bank, hence aggregates of many sub-classes. We distinguish 7 ($i = 1..7$) generic asset classes and 9 ($j = 1..9$) generic liability classes. We want the stylized balance to be a reflection of a real average Dutch balance sheet, therefore we included multiple sub-classes. If we add up all sub-classes, we have 43 asset classes and 18 liability classes.

A generic class is subdivided (if possible) by:

- different *loan to value* classes, if collateral is used (e.g. with residential mortgage loans), see table B.7;
- different credit rating classes, see table B.6,
- and different maturity classes, see table B.8.

It was a time-consuming study to allocate all assets and liabilities of all Dutch banks to each sub-class. The results are presented in the appendix.

We use the *residential mortgage loans* portfolio, the largest portfolio of an average Dutch bank, as an illustrative example. Within this portfolio, all mortgage products are allocated to 4 *loan to value* classes (NHG [1], 60%, 80% and 115%), to 2 *credit rating classes* (PD of 0.64% and PD of 6.15%) and to 2 maturity classes (3.5 year and 10.0 year). Therefore, within the residential mortgage portfolio we have $4 \cdot 2 \cdot 2 = 16$ sub-classes.

4.1.2 Asset shocks

The horizon of the stress is 36 months ($t = 1..T$), equal to the time horizon of the EU-wide stress test.

The model is an interplay of asset movements and reactions of the liability-side (variable funding costs, conditional to the size of the impairment of the asset portfolio and withdrawals of depositors). Brunnermeier (2009) argues that "failures are generally triggered by a decline in the value of the assets held by the bank, and by a run on the bank, itself usually primarily caused by a perceived decline in the bank's asset values." It that light, we model the balance sheet as a process of interaction between asset impairments and variable funding costs and withdrawals. In this section we discuss the asset shocks.

The part of the model which generates the shocks, derives the severity of the shock from three points given by the EBA: values for $t = 12, 24, 36$ which corresponds to the end of 2014, 2015 and 2016. In case of, but not restricted to, the residential property prices, $t = 0$ corresponds with an index value of 100. The EBA published deviations from this baseline level for the upcoming years. For Dutch residential property prices these values are: 90.7, 85.4, 83.3 (i.e. the Dutch house prices will fall with 16.7 percent in 3 years in this scenario). Figure 4.1 shows our method.

The model estimates using a third degree polynomial the index values between the four given points, see again figure 4.1. The impairment per day is then:

$$\frac{\text{Index value}_t}{\text{Index value}_{t-1}} \tag{4.1}$$

All asset classes, excluding the cash position ($i = 7$) are all exposed to shocks.

[1] A mortgage under the "The Nationale Hypotheek Garantie" (NHG), is guaranteed by a fund. The fund guarantees the payments if someone is unable to repay the loan or interest. Therefore, the bank faces limited risks.

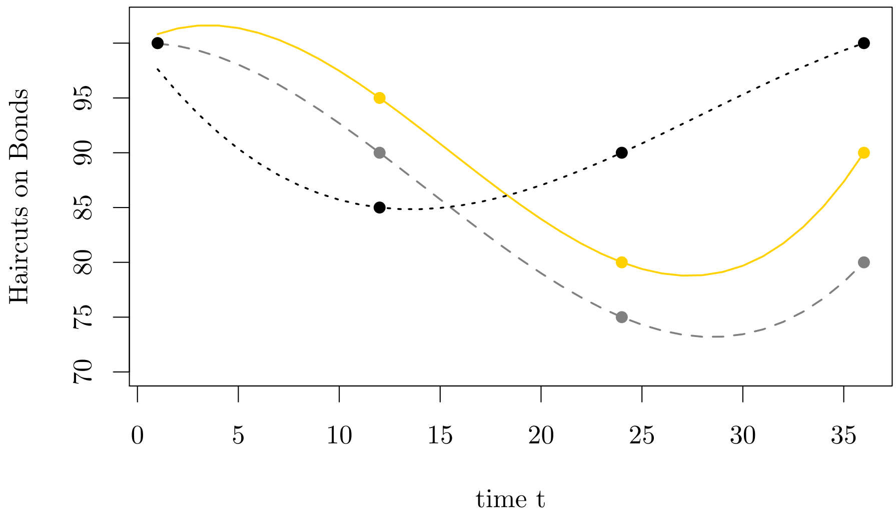


Figure 4.1: *Asset haircuts. At time t=0, all assets are indexed at 100. At t=12, t=24 and t=36 the index values deviates from the index value of 100 (e.g. a AAA rated bond with an index value of 95 at t=12, lost 5 percent of its value during the first year of the stress period.)*

The model distinguishes two kinds of different asset shocks. Shocks for (un)secured loans ($i = 1, 2, 3, 4$), and shocks for the *Bonds* and *Trading Securities* portfolios ($i = 5, 6$).

Typically, the movement of an assets' value is modelled with Brownian motion models. However, stochasticity is not included in this model. The model simulates a balance sheet under predefined stress levels for each asset class, we do not deviate from these levels. Generally, volatility increases in times of stress. These characteristics are out of scope for this thesis.

(un)Secured Loans, i=1,2,3,4

For ($i = 1, 2, 3, 4$) this shock is equal to 1 minus the multiplication of the PD with the LGD corresponding to a specific (un)secured loan sub-class. The severity of the shock differs per subclass.

The PD and LGD shocks are derived from the PD and LGD path generators provided by the EBA to central authorities, and based on the EU-wide stress scenario. The EBA published a PD and a LGD path generator for benchmark purposes or for small banks (without in-house knowledge of credit risk models).

The EBA generators generate three future PD's and LGD's for different types of loans, the same as figure 4.1. The index value at $t = 0$ is changed to the current PDs or LGDs, these are derived from all annual reports, see table B.6.

The LGD of the loans depends on the subclass *loan to value* and the shock on the collateral (in case of mortgages, the residential property prices).

Bonds and Trading securities, i=5, 6

For the sovereign bond portfolio (i=5), the model applies valuation haircuts to sovereign exposures. The EBA published a document stating the valuation haircuts for sovereign exposures, classified by maturity and sovereign state. With the use of Bloomberg a sovereign state is linked to a credit rating, since our generic bond class is subdivided by different *credit ratings* and not by sovereign state.

The trading securities are impaired by a market shock. The shock is published in accompanying document of the EBA (EBA, 2014).

4.1.3 Liability shocks

We distinguish two kinds of reactions of funders. A change in funding costs and withdrawals of deposits. The latter is restricted to the deposit holders.

Changing funding costs

The model determines for each funding class the funding cost at time t. The funding cost depends on: the volatility of the asset portfolio, the maturity of the funding class and size of the 'buffer' of the funding class. The buffer is the size of funding classes which have a later claim on assets in case of a default, we refer to Equation A.13 for the determination of the funding costs per funding source at time t. Only matured funding sources can receive new rates, else the rate is equal to the rate of $t-1$. The total funding cost for the bank at time t is:

$$\text{Total funding cost time } t = \sum \left(\vec{f_t} \cdot \vec{y_t} \right) \qquad \text{for all } t \tag{4.2}$$

where $\vec{f_t}$ is the vector of interest rates corresponding to the funding sources at time t, excluding the costs of equity which is determined differently. $\vec{y_t}$ is the vector of liability exposures at time t.

Withdrawals

Withdrawals are triggered by observed information about the solvency position of a bank. The actual trigger, the point were depositors decide to withdraw their funds, is hard to predict. In this model, withdrawals are limited to the depositors classes of the bank. However, withdrawals of other types of funding are well conceivable. In this model, other types of funding do not withdraw their funds, but demand higher rates, which has the same effect. Deposit rates are less volatile than wholesale funding rates. A bank suffers much more of immediate withdrawals than slowly rising deposit rates.

The model assumes, that withdrawals are triggered by a perilously low leverage ratio of the banks' balance sheet. We assume run off rates, on average, of 10% per year, when the leverage ratio decreases with more than 0.5 percent in 12 months. These numbers are based on run-offs rates (cash outflows) of the LCR, see table B.2.

4.1.4 The Profitability Criterion

The interest income, denoted by $\vec{a}_t$, from assets is assumed fixed. A bank is able to, but restricted to a certain extent, pass through changes of funding costs to the clients. The fixed income assumption is conservative.

The spread at time t, our profitability components from the bank's Trias is denoted by S_t:

$$S_t = \left[\left(\vec{a}_t \cdot \vec{x}_t \right) - \left(\vec{f}_t \cdot \vec{y}_t \right) \right] \qquad \text{for all } t \tag{4.3}$$

$\vec{x}_t$ is the vector of asset exposures at time t. First, fixed expenses are substracted from the spread (such as staff expenses and other operating expenses, denoted by E_t). Tax (δ) is paid on the the remainder. Which is equal to 40% in our model (which is a common tax rate in literature), if the remainder is positive, else zero.

Then, dependent on the dividend policy, divided (ψ) is paid to the banks' shareholders, which is the cost of equity in our model. We assume a dividend policy of 40% of the residual (after tax). Again, if the residual turns out to be negative, dividends are not distributed. The remainder is classified as retained earnings (RE_t) and added to the capital position. An equivalent amount is added (or subtracted if $S_t < 0$) to the cash position of the bank.

$$RE_t = \left[\left(S_t - E_t \right) \left((1-\delta)(1-\psi) \right) \right] \qquad \text{for all } t \tag{4.4}$$

4.2 Restrictions

While optimizing the total spread, which is:

$$S = \sum_{t=1}^{T} \left[\left(\vec{a}_t \cdot \vec{x}_t \right) \left(\vec{f}_t \cdot \vec{y}_t \right) \right] \qquad \text{for all } t \tag{4.5}$$

We assume a set of six restrictions. The first four were discussed in chapter 3.

- The Total Capital Ratio (TCR) $\geq 10.5\%$; we refer to Equation A.1 and figure A.1 for the regulatory composition of 10.5 percent. For the risk weights (denoted by $\vec{RW}$) we refer to table B.5. Additionally, a capital charge is imposed of 15 percent of the average gross income for the last three years.

$$\frac{y_{9,t}}{\sum \left(\vec{x}_t \cdot \vec{RW} \right) + \left((S \cdot 0.15)/3 \right)} \geq 0.105 \tag{4.6}$$

- The NSFR $\geq 100\%$; we refer to subsection A.4.2 for more information about the NSFR. For the weighting scheme of 'stable' assets ($R\vec{S}F$) and liabilities ($A\vec{S}F$) we refer to table B.4 and table B.3.

$$\frac{\sum \left(R\vec{S}F \cdot \vec{x}_t \right)}{\sum \left(A\vec{S}F \cdot \vec{y}_t \right)} \geq 1 \tag{4.7}$$

- The LCR $\geq 100\%$; we refer to Equation A.5 for more information about the LCR. For the weighting scheme denoting the liquidity of assets ($H\vec{Q}LA$) we refer to table B.1, and table B.2 for the weighting scheme denoting the outflow of funding classes in a 30 day stressed period ($\vec{CO}$).

$$\frac{\sum \left(H\vec{Q}LA \cdot \vec{x}_t \right)}{\sum \left(\vec{CO} \cdot \vec{y}_t \right)} \geq 1 \tag{4.8}$$

- The leverage ratio (LR) $\geq 3\%$; for more information about the leverage ratio we refer to Equation A.4.

$$\frac{y_{10,t}}{\sum \vec{x}_t} \geq 0.03 \tag{4.9}$$

The latter two restrictions are the Markowitz restriction, and the maximum shifts in both asset and funding portfolios.

- The basic concept of Modern Portfolio Theory (MPT) is that given a set of n risky securities with expected return of asset i ($i = 1..n$) denoted by E_i ($E_i = \bar{r}_i$), the risk denoted by the variance of return σ_i^2 and the covariance of returns between two securities denoted by σ_{ij}, we can construct a frontier which describes the set of portfolios consisting of n securities, were each portfolio has the smallest variance possible for a prescribed expected return (Markowitz, 1952).

  It attempts to maximize the expected return of a portfolio, denoted by E_p, given an amount of risk tolerance, denoted by $\widetilde{\sigma_p^2}$

  Let w_i be the weight of the ith investment in the portfolio, $\sum_{i=1}^{n} w_i = 1$, then the set of efficient portfolios with constrained portfolio variance, satisfies:

$$\sigma_p^2 = \sum_{i=1}^{n}\sum_{j=1}^{n} w_i w_j \rho_{ij} \leq \widetilde{\sigma_p} \tag{4.10}$$

  The variance per asset class is added in table B.9. The covariance derived from data analysis, see section 4.4.

- The optimal balance sheet could deviate substantially from the current balance sheet (which is to be expected). Banks are not able to divest large parts of their portfolio, or change their funding profile considerably. Therefore, we include a maximum allowed shift (MAS_p) in both the asset and funding portfolio of the bank. Further, we include a maximum allowed shift per asset sub-class and per liability sub-class denoted by (MAS_c), see figure 4.2. The solution is conditioned on these restriction, the model allocates all asset and liability classes till it is impossible to attain a higher spread.

$$\sum_{i=1}^{n} \mid \vec{x}_0 - \vec{x}_{Optimal} \mid \leq \text{maximum allowed shift} \tag{4.11}$$

$$\sum_{j=1}^{m} \mid \vec{y}_0 - \vec{y}_{Optimal} \mid \leq \text{maximum allowed shift} \tag{4.12}$$

  Set of all restriction:

$$\text{Set} = [\text{TCR, NSFR, LCR, LR}, \ \widetilde{\sigma_p}, \ \text{MAS}_p, \text{MAS}_c] \tag{4.13}$$

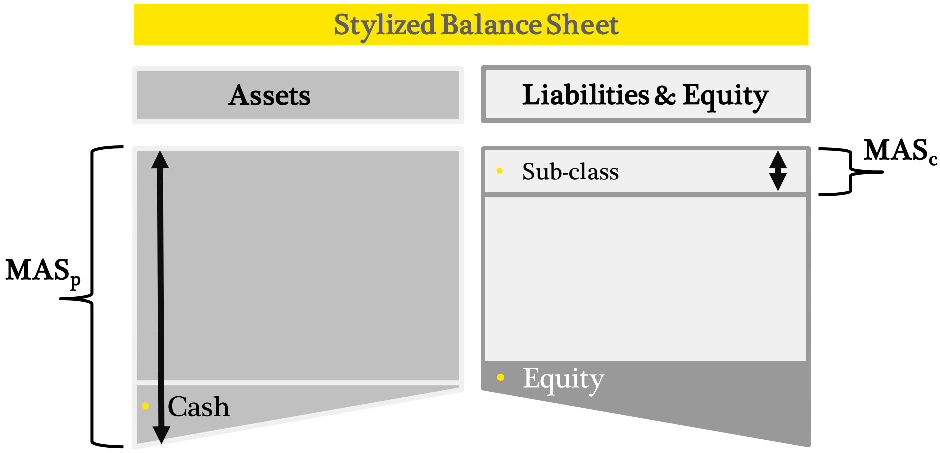


Figure 4.2: *The maximum allowed shifts.* MAS_p *is the restriction in the optimization of the maximum allowed shifts of the total asset and liability portfolio.* MAS_c *is the maximum allowed shift of each sub-class within the asset and liability portfolio.*

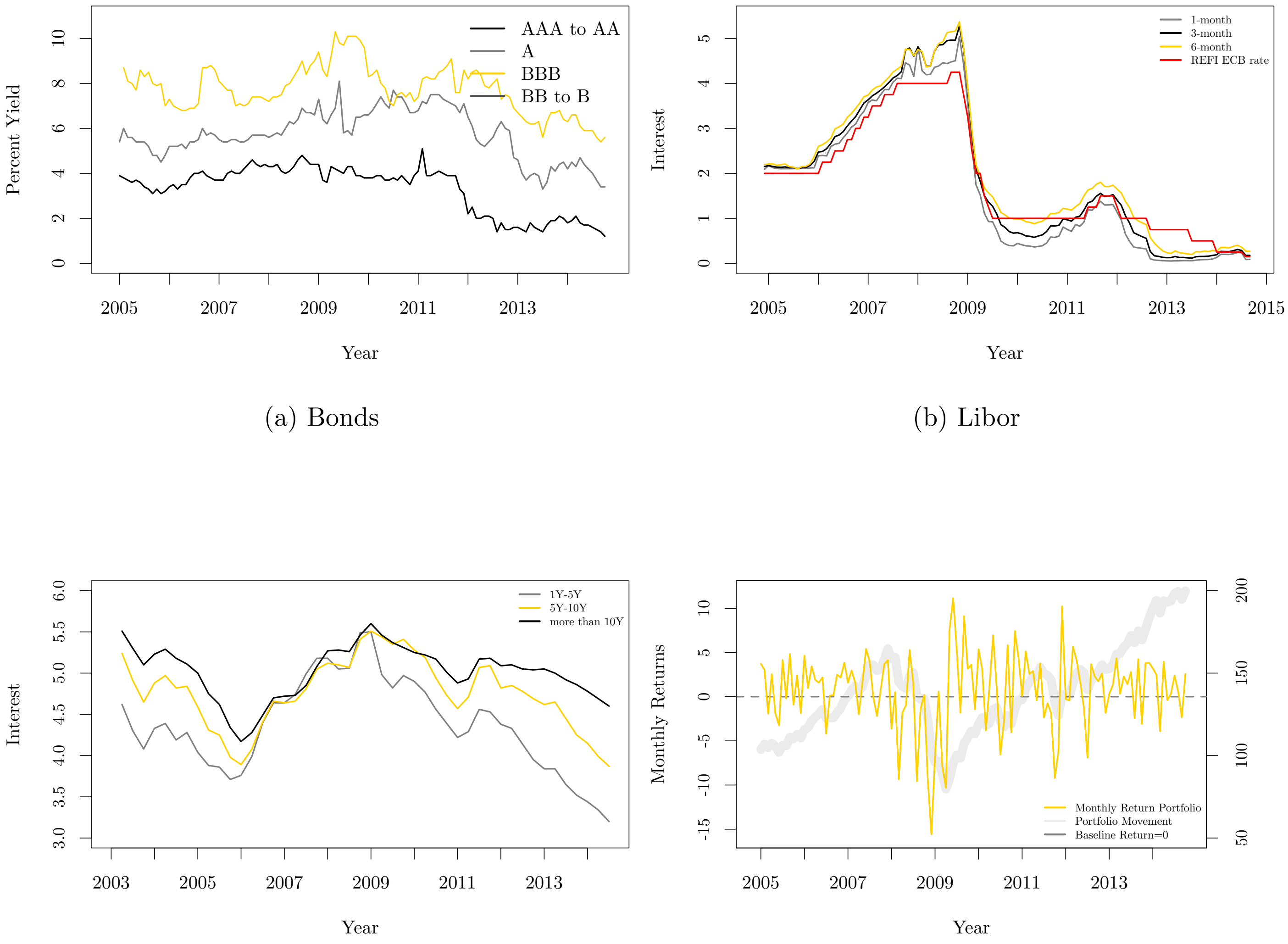
4.3 Improving the balance sheet

The optimization of the spread, while maintaining a prudent risk profile during the stress period of three years, is implemented with the use of the sequential quadratic programming (SQP) algorithm for non-linearly constrained gradient-based optimization (supporting both inequality and equality constraints), based on the implementation by Kraft (1994), and is a part of NLOPT package of R.

4.4 Input Data

Interest rates per class are shown in table B.9 and table B.10 in table form. In figure 4.3 the interest motion of the different classes is shown (extracted from Bloomberg, DNB, ECB and Bank of England documentation). We used the average interest rate as input, and used the standard deviation and correlation for the Markowitz restriction.

The distribution is set to the average distributions of the ING bank, Rabobank, ABN AMRO bank and the SNS bank (The structure of the portfolios is visualized in B.1 and B.2). The data is extracted from annual reports.



(a) Bonds

(b) Libor

(c) Mortgage rates

(d) Trading securities

Figure 4.3: Illustration of various interest rates

Chapter 5

The Results

In this chapter the findings are presented.

Impact and Improvement. In the first part of the analysis an average Dutch bank is subjected to the stress scenario identical to the EBA EU-wide stress test of 2014 regarding the asset shocks. A close look is given to the movement of various prudential ratios and other bank's fundamentals while being subjected to severe stress. Then, we show that a small change in the balance sheet structure can improve the bank's Trias (the resilience components: solvency and liquidity, and the profitability component) under this scenario.

Decision Space. Secondly, the improved balance sheet is restricted to a maximum deviation from the starting balance sheet. While we increase the allowed shift, we construct a frontier of possible solutions. We have shown the inevitable trade-offs present within the bank's Trias in previous chapters. The first part concludes with an analysis of the decision space a bank has regarding the bank's Trias under the EBA EU-wide stress scenario.

A Comparison. In the third part of this chapter we compare the resilience of different types of banks under the stress scenario regarding the maturity profile. We compare a bank which is highly dependent on short-term funding (flighty funding) with a bank which is funded with relative longer term funding products.

The majority of the results are shown by graphs. Because of the stylized nature of our model, we give consideration to movements in the balance sheet structure and directions of improvement.

5.1 Impact and Improvement

In this subsection we show the impact of the EBA EU-wide stress scenario on an average Dutch bank balance sheet. We look to the spread, interest expenses, the total capital position, the LCR, the NSFR and the leverage ratio of the bank. Subsequently, we try to answer one of the thesis' main questions: whether is it possible to improve the balance sheet and make the balance sheet more resilient for the adverse scenario and which changes are required.

A balance sheet change for both the asset and funding portfolio of 5.8 percent is required in order to make the bank's solvency and liquidity position during the time of stress equal to *pre-stress positions*.

$$\text{Set} = [\text{TCR, NSFR, LCR, LR}, \ \widetilde{\sigma_p}, \ \text{MAS}_p, \ \text{MAS}_c] \tag{5.1}$$
$$\text{Set} = [12.5\%, 114\%, 100\%, 4.1\%, 4.0\% \ 5.8\% \ , 0.75\%)] \tag{5.2}$$

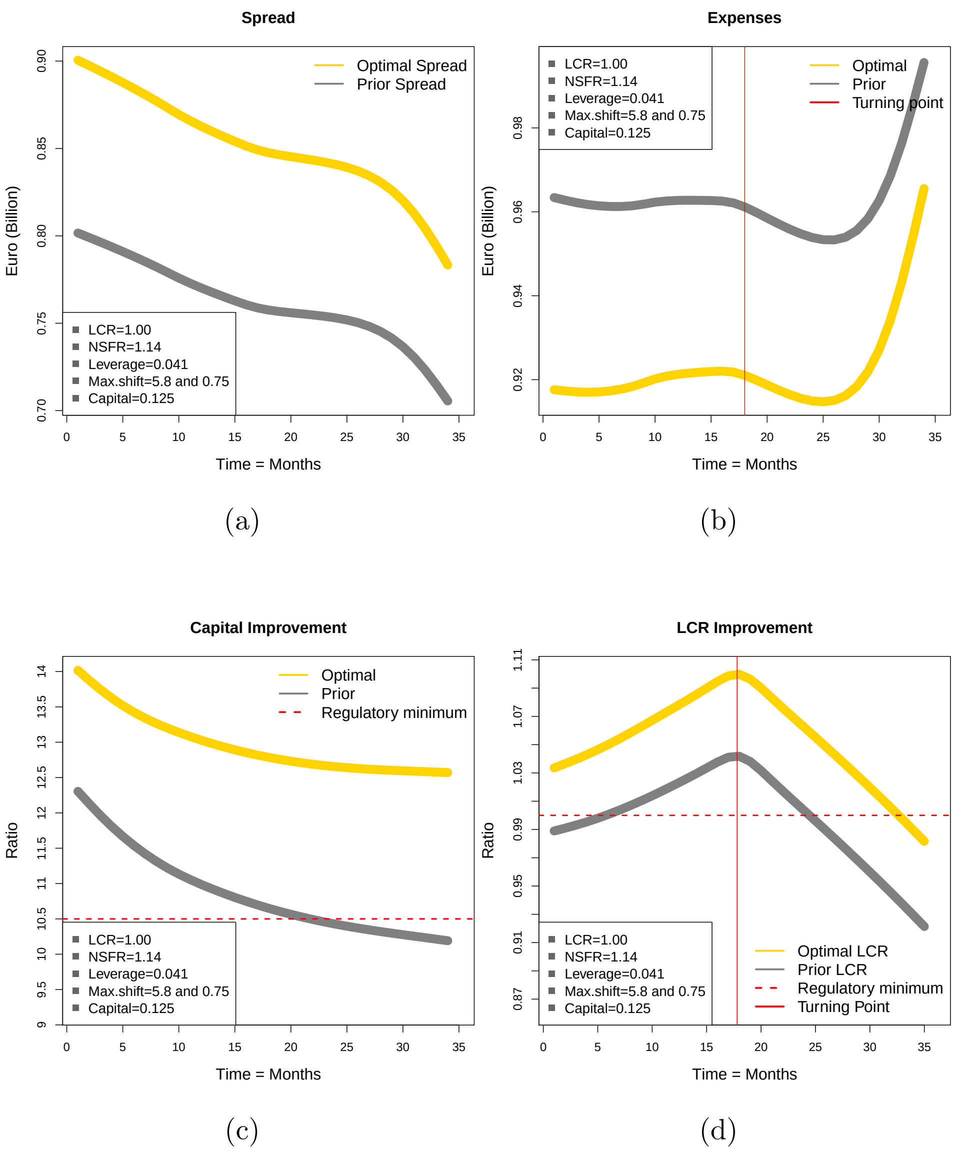
During this optimization the individual asset and funding classes are restricted to a maximum change of 0.70 percent of the total balance sheet size, an exemption is the *cash and equivalents* position, which is restricted to 1.2 percent. These values are the minimum values in which there is a feasible solution.

The model disinvest in the lowest category of bonds, and invest in AAA rated bonds. Further we see disinvestments in almost all loan categories with high risk weights. The *cash and equivalents* category has the largest increase of 1.2 percent, the maximum allowed shift.

The red vertical lines in figure 5.1b and figure 5.1d show the points where deposit holders begin to withdraw their funds. The model sets this point when the leverage ratio decreases with more than 0.5 percent in one year. In figure 5.1a this point is visible by the changing curve at $t = 17$. When deposit holders withdraw their funds, less interest expenses have to be paid (see figure 5.1b). After $t = 26$ the interest expenses increase significantly. The leverage ratio is at a dangerously low level at $t = 26$, the Merton model increases the interest rate for matured funding classes, especially for unsecured classes to compensate for the rising credit risk. The total capital ratio declines with 2.2 percent, from 12.5 to 10.3 during the stress scenario, slightly below the regulatory minimum of 10.5 percent (see figure 5.1c). The LCR (figure 5.1d) declines to levels below 100 percent, the regulatory minimum. The leverage ratio (figure 5.2b) and the total capital ratio figure 5.1c are visibly more stable in the improved balance sheet.

The output shows us, that both capital restrictions (the risk-weighted capital restriction and the unweighted leverage restriction) are both bindend. The same applies for the LCR and the NSFR liquidity restrictions. The results are noteworthy and suggest that the four metrics are a complementary set of restrictions and no single metric redundant. However, the Markowitz restriction i.e. the restriction which maximizes the portfolio variance, is not binding. Again, this result confirms that the set of restrictions is complete and retains banks from excessive risk taking.

The NSFR moves with the LCR constraint, the LR with the TCR constraint. These sets of constraints are intuitively related and this relation is apparent during this simulation.



(a) (b) (c) (d)

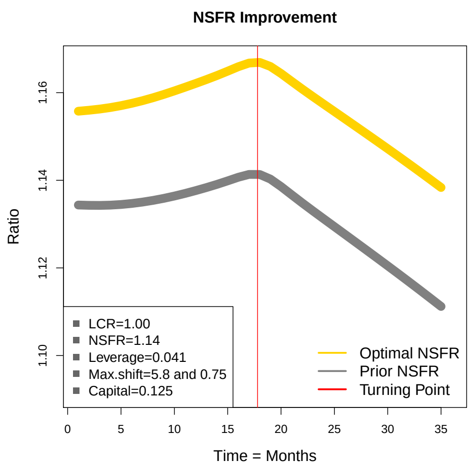
Figure 5.1

During this simulation, the restrictions were based on the solvency and liquidity positions of the bank prior to the stress event, i.e., the model looked for a solution where the solvency and liquidity positions stays above the current position during the entire horizon, even stressed conditions. This is a prudent assumption, since the solvency and liquidity positions are well above regulatory minima. However, a balance sheet shift of 5.8 percent is near impossible for a bank, particularly on short notice. Due to the allowed shift of 5,8 percent, the spread improved significantly in the improved balance sheet. Therefore, we ease the restrictions to regulatory minima.

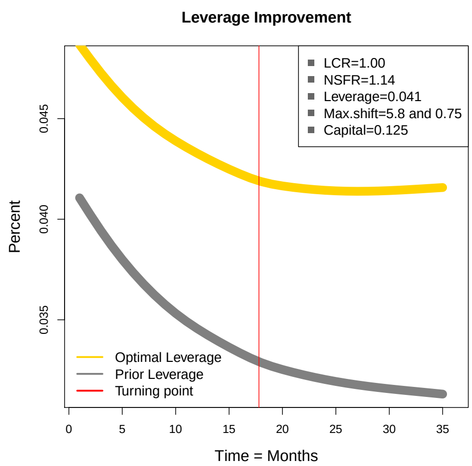
If we loose the restrictions to regulatory minima, then a balance sheet change for both the asset and funding portfolio of 1.60 percent is required, with a maximum allowed shift of 0.40 percent per class. With these changes the bank satisfies all requirements during the stress horizon.

The output shows us that the spread is slightly less, due to the cost of improving the solvency and liquidity positions. Further, the results shows us that the LCR and the total capital ratio constraint are binding and affect the optimal solution. The introduction of the LCR ensures that banks hold more liquid assets, but at a cost since it affects the optimization. Both the leverage and the NSFR restrictions are suffice enough, since the initial levels are far above regulatory minima.

At present, banks must maintain a buffer of at least 3 percent regarding the leverage ratio. However, banks expect a tightening of the requirement since the Dutch government and the Dutch Central Bank want to increase the buffer to 4 percent in the near future. Further, systemically important financial institutions (SIFIs) have to hold extra capital (TIER1), ranging from 1.0 to 3.0 percent, with the aim to reduce system wide risks stemming from such institutions. This systemic buffer will be 3 percent of risk-weighted assets for ING Bank, Rabobank and ABN AMRO Bank, and 1 percent for SNS Bank (DNB , 2014). First, we increase the leverage ratio to 4 percent (and keep other restrictions at regulatory minima). Secondly, the total capital ratio is increased with 2 percent (the average of the sample above) while the leverage ratio is kept at 3 percent and liquidity ratios at regulatory minima.



(a)



(b)

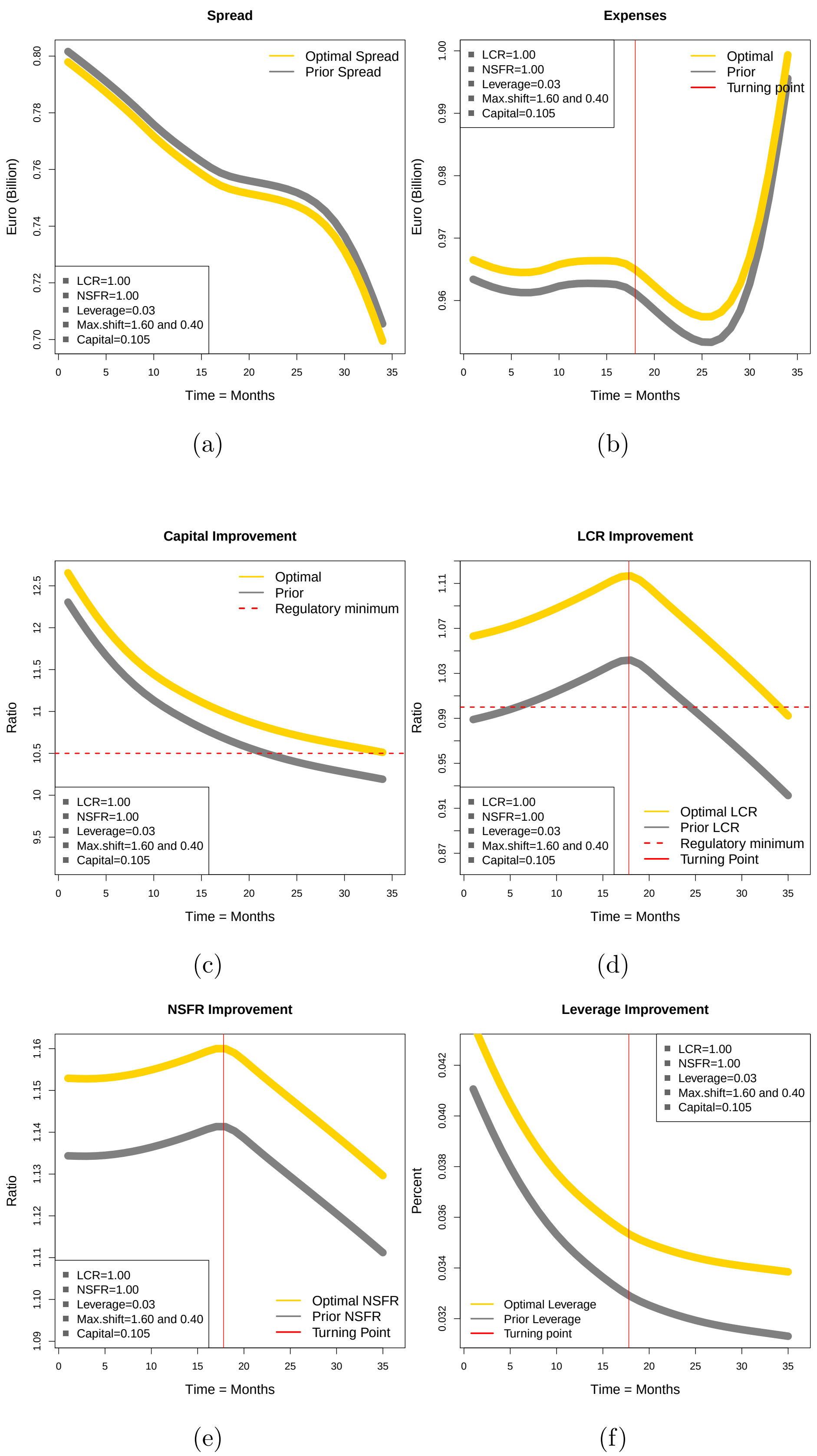
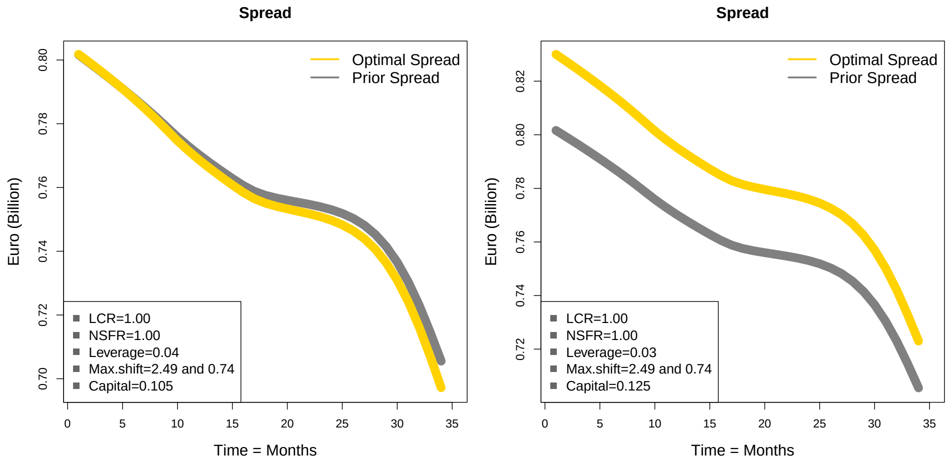

Spread
Euro (Billion)
Optimal Spread
Prior Spread
LCR=1.00
NSFR=1.00
Leverage=0.03
Max.shift=1.60 and 0.40
Capital=0.105
Time = Months
(a)
Expenses
Euro (Billion)
LCR=1.00
NSFR=1.00
Leverage=0.03
Max.shift=1.60 and 0.40
Capital=0.105
Optimal
Prior
Turning point
Time = Months
(b)
Capital Improvement
Ratio
Optimal
Prior
Regulatory minimum
LCR=1.00
NSFR=1.00
Leverage=0.03
Max.shift=1.60 and 0.40
Capital=0.105
Time = Months
(c)
LCR Improvement
Ratio
LCR=1.00
NSFR=1.00
Leverage=0.03
Max.shift=1.60 and 0.40
Capital=0.105
Optimal LCR
Prior LCR
Regulatory minimum
Turning Point
Time = Months
(d)
NSFR Improvement
Ratio
LCR=1.00
NSFR=1.00
Leverage=0.03
Max.shift=1.60 and 0.40
Capital=0.105
Optimal NSFR
Prior NSFR
Turning Point
Time = Months
(e)
Leverage Improvement
Percent
LCR=1.00
NSFR=1.00
Leverage=0.03
Max.shift=1.60 and 0.40
Capital=0.105
Optimal Leverage
Prior Leverage
Turning point
Time = Months
(f)

Figure 5.3



(a) (b)

Figure 5.4

An interesting finding from figure 5.4 is the difference in the maximum attainable spreads between the situation of a prevailing minimum leverage ratio of 4 percent and a minimum total capital ratio of 12,5 percent. Equity in relative expensive compared to other funding classes, especially during times of stress. A leverage ratio of 4 percent is only possible if the bank attracts more equity, or decreases the size of the total balance sheet. However, in our model it is not possible to choose to shrink the balance sheet size in order to increase the leverage ratio. To increase the total capital ratio, the bank can or increase the equity position, or decrease the sum of risk weighted assets (or a combination of both). Since risky assets impair the the capital position the most, a higher capital ratio is easily achieved by divestments in risky assets. The sum of risk weighted assets decreases, while the capital position is more stable during the stress situation.

5.2 Decision Space

In this section we loosen the maximum allowed shift (MAS_p and MAS_c) restriction for the asset and funding portfolios. The first feasible solution is found if the model is allowed to shift more than 1.60 percent of the asset and funding portfolio (with sub-classes maximized at 0.40 percent). First, we will construct a Pareto frontier. While we increase the MAS_p, the model will, by reallocation of assets and liabilities, improve the profitability of the balance sheet. It is Pareto efficient, since all constraints remain stable, see figure 5.5. The frontier is practically linear. If the frontier was concave upward sloping, then the incentive to change the balance sheet more than 1.60 percent was stronger.

Now, we change the MAS_p to 20 percent and increase the LCR and capital requirement incrementally. By doing so, we get a clear view how stricter restrictions effect the bank's profitability. In figure 5.6 and figure 5.7 we see the results. The shaded horizontal plane shows the fixed costs, which corresponds approximately to the ratio between fixed costs and the spread of data from annual reports of the four Dutch banks. .

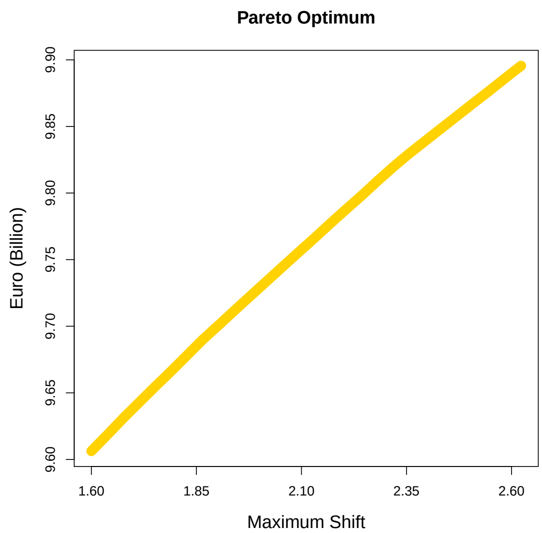


Figure 5.5: Pareto frontier

Two observations are notable referring to figure 5.6 and figure 5.7. Beyond a certain level of the capital (the total capital requirement) the maximum attainable spread decreases substantially. Higher capital requirements can be achieved by either increasing the capital base, or by decreasing the risk weighted assets. Generally, assets with a higher assigned risk weight, yield more interest. Decreasing the risk weighted assets is apparently less profitable than increasing the equity position. The

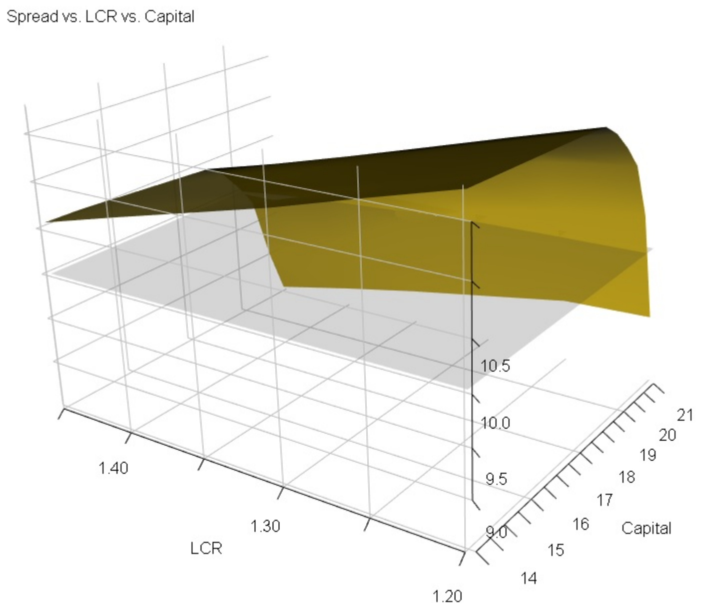


Figure 5.6: *The Bank's Trias. While stricter liquidity requirements have a linear effect on the bank's spread, the stricter capital requirement have a negative exponential effect on the bank's spread.*

restrictions concerning the maximum allowable shifts are in this particular simulation, intentionally, loosened. But the outcome clearly demonstrates that it is less costly to finance a higher capital ratio by attracting extra equity than by decreasing asset positions yielding high returns. But in the circumstance that a bank is unable to attract (more) equity (the red vertical lines in figure 5.9), then the maximum attainable spread decreases progressively, see figure 5.8a. First, the model increases the exposure of AAA rates bonds (yielding no to little interest). Then, the model sells mortgages financed at LTVs of 115 percent (risky assets, but profitable) after the AAA rated bonds reached the maximum allowed shift, see figure 5.9a. The same shifts are visible in the entire asset portfolio. Riskier assets are sold for assets regarded as safe havens.

Now we look closer to the funding side. In first instance, the cash position is reduced because the increase in the AAA bond portfolio (highly liquid) sets the LCR equal to one. But when the AAA bond and LTV 115 mortgage portfolios reached both the maximum allowable shift, only cash (virtually riskless) provides the required capital ratio, see figure 5.8b.

We witnessed recently the same shifts in balance sheet's structures. For instance, the ABN AMRO bank increased the equity position with 685 million euros from 2012 to 2013 and increased within the *financial investment* position OECD government bonds with 6.4 billion euros (ABN AMRO Annual Report, 2013). Partly

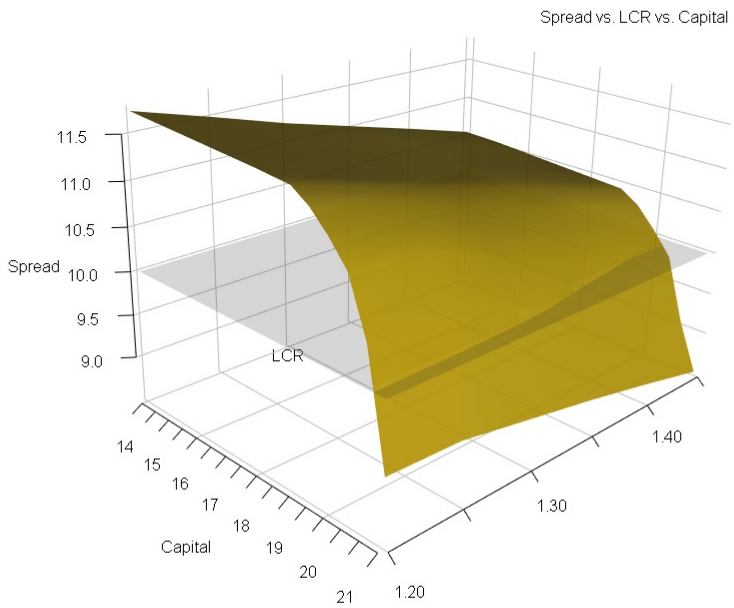
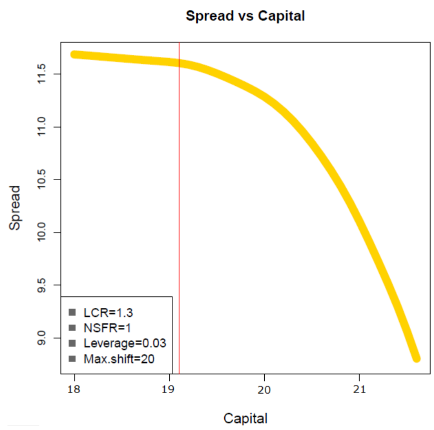


Figure 5.7: *The Bank's Trias. While stricter liquidity requirements have a linear effect on the bank's spread, the stricter capital requirement have a negative exponential effect on the bank's spread.*

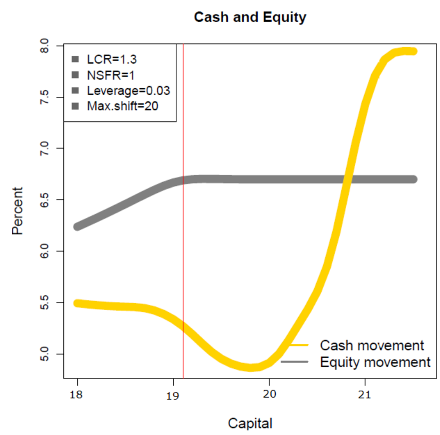
attributable to these shifts in the balance sheet structure, the total capital ratio (Basel 2) increases by 1.8 percent during the same period. In the model we observe the same behaviour.

For the liquidity ratio however, the maximum attainable spread decreases in a linear fashion. The main liquid assets are cash and bonds (rated from AAA to A). Eventually, these positions have reached the maximum allowed shift. Referring to the LCR ratio (Equation A.5), this is the stock of highly liquid assets. Then, the denominator, the possible net cash outflow of 30 days, should be decreased in order to satisfy higher LCR ratios. The model has for this denominator compared to the capital ratio's denominator, much more choices. In case of the capital ratio, the denominator's choice is limited to the capital position.

Furthermore, the increments of the LCR weights are much smaller compared to the capital ratio's weights. If an asset class (e.g. AAA/AA rated bonds with a risk-weight of zero) is full (reached the maximum allowed shift), the model should increase other asset classes with limited risk (e.g. A rated bonds). However, 'A' rated bonds are accompanied with a 20 percent risk weight. Regarding the LCR's increments, deposits considered as 'stable' receive a weight of 5 percent, and 'unstable' 10 percent. Therefore, in order to satisfy stricter LCR ratios, small shifts will do the job and numerous shifts are possible.



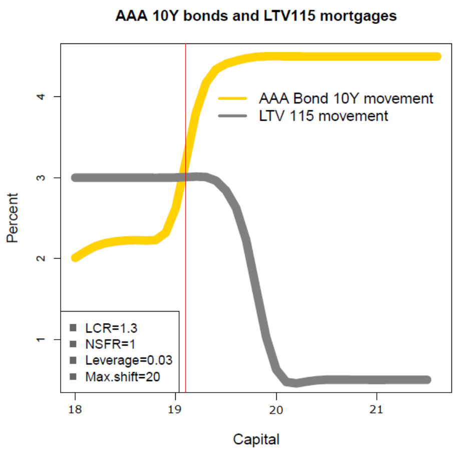
(a) *Stricter total capital requirements have an impact on the maximum attainable spread.*



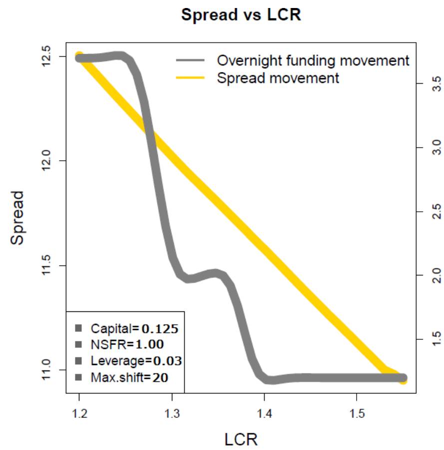
(b) *The equity and cash position increase, when stricter total capital requirements are put in place.*

Figure 5.8

Another argument explaining the minor impact on the maximum possible spread is the behaviour of the class *trading liabilities*. Generally, liability classes which are sensitive to information about the solvency position of a bank (flighty funding) receive a high LCR weight, but are relatively cheap in return. This class, typically designated as wholesale funding, became fairly expensive or even unavailable during the subprime crisis. The same happened during the simulation. Therefore, the LCR increases by limiting the class wholesale funding and the effect on the spread is moderate. The "easiness" of increasing the LCR is reflected in the considerable increase of LCR ratio's of the ABN AMRO bank (2013:100%, 2011:57% (ABN AMRO Annual Report, 2013)) and the Rabobank (2014:161%, 2013:126% (Rabobank Issuer Rating Report, 2014)) (not disclosed by other banks yet). The maturity of most funding classes is much shorter than the maturity of asset classes, the maturity gap is an inherent characteristic of a bank. This makes it 'easier' to change the funding structure, than the asset structure.



(a) *The AAA rated bonds position increases, while the LTV 115 percent mortgages position decreases, when stricter total capital requirements are put in place.*



(b) *The maximum attainable spread decreases and the position in overnight funding decreases, when stricter total capital requirements are put in place.*

Figure 5.9

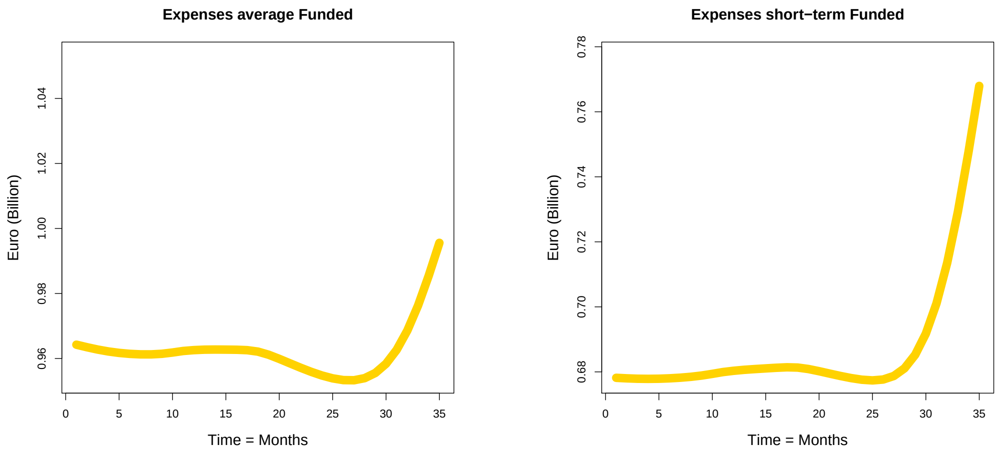
5.3 A comparison: Short-term vs. Long-term

Not only banks suffering from large asset impairments are exposed to expensive funding costs. During the heat of the subprime crisis all banks were subjected to higher interbank rates. In this section we shortly discuss this phenomenon.

The banking crisis had immense contagion effects. Interbank lending suffered from unprecedented distrust. Banks, and other funders, doubted the creditworthiness of nearly all banks. Here we compare two different banks. Both banks possess the same asset portfolio, but are funded differently. One is funded as an average Dutch bank, the other highly dependent on short-term funding (i.e. dependent on current deposits and wholesale funding), see figure 5.11[1]. The movement of funding cost of both banks, and the panic amongst deposit holders are the same. This is in alignment with the panic we witnessed end 2008. Figure 5.10 shows the results. The bank which is highly dependent on short-term funding, is exposed to funding costs which are more volatile to the bank's fundamentals than an average bank. Matured liabilities are rolled over, but at a new rate. Because of the short-term nature, the increases in costs are immediately apparent. Before the panic, the 'short-term' bank is able to attract cheaper funding. When doubt amongst funders strikes about the creditworthiness, the 'short-term' bank is much more vulnerable. Interest expenses increased with almost 13.5 percent in 4 months, compared to 3 percent for

[1]The distributions are in this instance not derived from real banks.

an average bank.



(a) *An average bank: the funding cost are relatively high, but the increase of funding cost is limited.*

(b) *A short-funded bank: the funding cost are relatively low, but the increase is significant.*

Figure 5.10

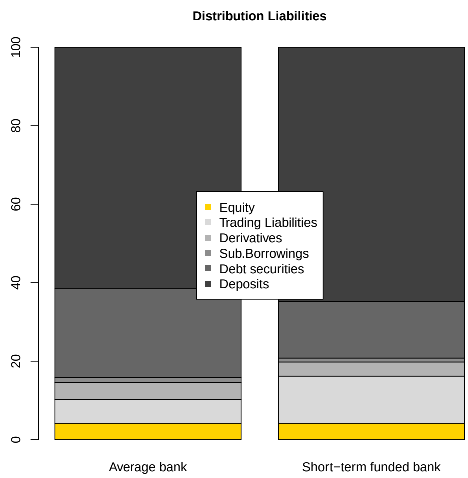


Figure 5.11: *An average and short-term funded bank. The short-funded bank is more dependant on deposits and 'trading liabilities' i.e. short-term funding.*

Chapter 6

Conclusion

In the aftermath of the subprime crisis we asked ourselves: "what went wrong"? Were those banks that got into trouble under-capitalized, given their exposure to highly risky assets? Or were banks to much dependent on short-term funding? Two questions, with two different underlying risks; solvency risk and liquidity risk. We have studied the concepts of solvency risk and liquidity risk, and their mutual relation. Moreover, we developed a model, which is able to simulate, in a stylized fashion, an average Dutch bank under stressed conditions containing both sources of risk. The model improves the balance sheet structure in anticipation of the same stressed scenario, while being subjected to a set of 6 types of restrictions. Now we are able to address the main research question: *'how could banks use stress test methods to improve the balance sheet in anticipation of a severe stress scenario, considering the solvency and liquidity position, while improving the bank's profitability?'*

First, we will discuss our findings, followed by possibilities for further research.

6.1 Conclusions

We showed how various prudential metrics evolve during stressed conditions and the valuable information it generates. The potential weakness of Basel metrics are the static and unconditional properties. The risk weights of the RWA, the denominator of capital ratios, are based on historical data and the numerator, the eligible capital, is based on a single point in time. A stress test generates valuable information of future state balance sheets based on a projection of a potential scenario. We showed that particularly the liquidity cushion is sensitive to stress from rising funding costs and/or the withdrawals of deposits triggered by asset impairments. The LCR decreased near 15 percent during the stressed conditions. Therefore, we conclude that the status quo of Basel metrics is insufficient to determine if a bank is well capitalized or whether the liquidity cushion is able the withstand particular scenarios.

Liquidity risk can materialize endogenously as a result of impaired capital. These second round effects should be taken into account when we test the resilience of a bank. Instantaneous increased funding cost, as a result of (over)reliance on short term funding, affect the retained earnings and therefore the change to strengthen the capital position after impairments. We showed that banks which are highly dependent on short-term funding are more likely to default, their funding costs increased more than three times as quickly compared to an average funded bank. Stressing the solvency and liquidity positions separately, would give overly optimistic results.

A balance sheet change for both the total asset and funding portfolio of 5.8 percent is required (and 0.7 percent shifts within sub-classes) in order to make the bank's solvency and liquidity position during the time of stress equal to pre-stress positions. We showed that both capital restrictions, the leverage ratio and total capital ratio, and both liquidity restrictions, the LCR and the NSFR, were binding in the optimization. This shows that the four metrics are a complementary set of restrictions and no single metric redundant. If restrictions are set to regulatory minima, the first feasible solution was found when 1.60 (and 0.40 percent shifts within sub-classes) of the balance sheet is changed. The binding constraints are the LCR and the total capital ratio, the leverage and NSFR restrictions were already sufficient. The total asset variance constraint proved to be redundant in both cases, which suggest that the regulatory requirements prevent excessive risk in the balance sheet structure. We constructed a Pareto frontier (profitability versus the maximum allowed shift) to assess whether it is optimal to shift more than 1.60 percent of the balance sheet, but the frontier turned out to be practically linear on the range of 1.60 to 2.60.

The surface in the three dimensional space provide banks information about the maximum attainable spread (and which changes are required) for each set of desired minimal solvency and minimal liquidity position during specific stress. There are some studies which link solvency and liquidity risk to assess the impact of scenarios on a balance sheet. But we included and optimized the profitability component, while the balance sheet is subjected to a stress test which incorporates both solvency and liquidity risk. We loosened the restriction on the maximum allowed shifts in the balance sheet structure to levels of 20 percent and maximum shifts of 2.5 percent per sub-class, while incrementally increasing the LCR (from 120 to 145 percent) and the total capital ratio (from 14 to 21 percent), we got a perspicuous view of all possible maximum attainable spreads for all solvency and liquidity profiles: *the bank's Trias*. Obviously, some important caveats and transition issues are not captured within our framework. But the outcome shows clearly that stricter liquidity requirements have a linear effect on the bank's spread, while the stricter capital requirement have a negative exponential effect on the bank's spread when the total capital ratio is greater than 19 percent. The model divest in the highest categories of risk weights (e.g., visible disinvestments in almost all loan categories) and investments in for instance AAA rated bonds, with limited returns. Banks can use this stress test model to get a holistic view of the impact of both sources of risk and the possibilities to anticipate on a certain scenario.

The ongoing conception is that banks should be much safer, our results shows the trade-offs between safety (improved solvency and liquidity positions) and economic costs, assuming that a declining profitability (the spread) is passed on to the borrowers and less new loans are issued due to the stricter imposed requirements. We assessed the impact of higher capital standards, since national supervisory authorities can raise (and probably will) the prevailing standards. We found out that the impact of a leverage ratio of 4 percent has a greater impact on the spread than the implementation of the buffer for systemically important financial institutions. In case of the stricter total capital requirement, the risk weighted measure, the model divests in risky loans (e.g., SME loans). Credit provision could therefore be hampered. Bank could shrink the size of the balance sheet to meet the stricter leverage ratio, which again could restrain the credit supply of banks to the economy.

6.2 Further Research

We have seen the dynamics between solvency and liquidity risk and applied the dynamics to a stylized balance sheet of an average Dutch bank under a severe stress scenario. We showed the impact of stress on various prudential ratios and other bank's fundamentals over time. Our model indicated a direction for improvement in the balance sheet structure. We showed, by increasing the restrictions, the impact on the maximum feasible spread for higher capital and liquidity requirements.

The point at which deposit holders begin to withdraw their deposits, together with the volume, is rather difficult to predict. But this point has a significant effect on the liquidity cushion of a bank, as we have seen. The same applies to the sensitivity of the funding costs to asset impairments. It may well be that the funding costs are less effected by the movements of the asset portfolio. In the structure of the balance sheet we distinguished 43 asset and 18 liability categories, which is for this research sufficient and suffice to construct different types of banks. The interest on assets is during this research assumed fixed and equal to the average of the last 10 years. This assumption is conservative, since banks are, in some degree, able to pass through the increased funding costs to the asset side of the balance sheet.

With this thesis we made one of the first attempts to integrate solvency and liquidity risk, while the profitability is improved. We clearly demonstrated the mutual forces while a balance sheet in exposed to stress. In addition we showed the decision space bank management has regarding the solvency, liquidity and profitability position of a bank (which we called the *bank's Trias*). This way of looking at a bank balance sheet will contribute to the public debate of bank's safety versus the impact of bank's profitability.

Appendix A

Reference topics

A.1 EBA 2014 wide stress test

Macro-economical stress tests became more important since the recent financial crisis. Macro stress test, like the EBA 2014 EU wide test, are promising tools. Regulators, and banks, use these methods to access the resilience of financial institutions to possible adverse world-wide market developments.

Unlike historical simulation methods banks have to ask themselves the *what if* question when severe but plausible macro-economical events materialize. A satellite model translates the macro-economical parameters (e.g. GDP, unemployment rates) into risk parameters (PD, LGD and EaD). The satellite model measures the sensitivity of the balance-sheet to shifts in macro-economical parameters.

The EBA 2014 wide stress test is a test to assess the resilience of financial institutions to adverse market developments and to assess the potential for systemic risk to increase in situations of stress (EBA, 2014). Systemic risk occurs when a significant number of financial institutions fails, and has contagion effects on the functioning of the financial system and undermining the real economy (Quagliarello, 2009). The EU wide stress test applies a macro bottom-up approach, and assess the resilience of individual financial institutions. The EBA aggregate the results, on a bank by bank basis. The test rest mainly on transparency and regaining confidence. The ECB wants to start with a clean sheet in preparation of the new prudential supervision task as part of the Single Supervisory Mechanism (SSM). The disclosure includes capital positions of banks, risk exposures and sovereign holdings (EBA, 2014). Market participants can draw their own conclusions from this disclosure.

The EBA 2014 wide assessment is threefold:

A supervisory risk assessment
Addressing key risks in banks' balance sheets.

An asset quality review (AQR)
Reviewing the adequacy of asset and collateral valuation.

A stress test
Examining the resilience of banks' balance sheets under severe stress.

The stress test (phase 3) follows the AQR (phase 2). The AQR is the starting point and prerequisite for the wide stress test. The AQR uses harmonised definitions, complying with accounting principles, to assess and correct, if necessary, the value of assets. This ensures a reliable basis for phase 3.

In phase 3, a bank should prove their Common Tier 1 ratio is resistant and greater than the hurdle rate of 5.5 percent under adverse stress.

If a bank fails, they have nine months to recapitalize their balance sheet. Banks want to avoid the humiliation of failing and prevent giving the market a reason to loose confidence with potential undesirable effects.

A.1.1 EBA wide stress test characteristics

The next enumeration summarizes the relevant EBA wide stress test characteristics[1]:

Time frame The scenario will cover a three year period from 2014-2016.

Capital : Capital adequacy will be based on Common Equity Tier 1 (CET 1).

Hurdle rates Minimum capital ratios: 5.5 percent for the adverse scenario.

Balance sheet assumptions The test will assume a static balance sheet. Asset and liabilities that mature during the time frame, should be replaced with similar instruments regarding type, credit quality and data of maturity. No capital measures regarding defaulted assets is assumed. During the exercise, the same business mix model (geographical, product strategies and operations) is assumed

Data The test will rely on 2013 year-end figures.

[1]From: EBA, Methodological note EU wide Stress Test 2014.

A.1.2 The hypothetical adverse scenario.

This subsection outlines the adverse scenario as constructed by the EBA. First, the EBA designed a severe but plausible story line. Then, the EBA translated the story line (presumably with macro models) into risk factors (bond yields, equity price shocks, currency shocks, Euro swap rates, house prices, GDP, price inflation, unemployment and commercial property prices).

- (i) an increase in global bond yields amplified by an abrupt reversal in risk assessment, especially towards emerging market economies (EMEs), and pockets of market liquidity;
- (ii) a further deterioration of credit quality in countries with feeble demand, with weak fundamentals and still vulnerable banking sectors;
- (iii) stalling policy reforms jeopardising confidence in the sustainability of public finances; and
- (iv) the lack of necessary bank balance sheet repair to maintain affordable market funding

A.1.3 The stressed macro-economical drivers of EBA wide stress test

Explanatory macro-economic variables for the risk parameters for each stylized balance sheet item.

The stressed macro-economical drivers	
Long-term EU government bond yields	Equity prices
Foreign currency shocks	Euro Swap Rates
House prices	(domestic) GDP
Price inflation	Unemployment rates
Residential property prices	Commercial property prices

Table A.1: The stressed macro-economical drivers

A.2 Top-down and Bottom-up approaches

We can distinguish different types of stress tests, first we make a distinction between top-down and bottom-up stress stress test approaches, later on micro and macro tests.

The top-down approach uses aggregated data to estimate the scenarios' impact into banks' balance sheets, and subsequently aggregate the results to estimate the resilience of the banking sector to adverse shocks. For instance, Espen Frøyland & Kai Larsen (2002) constructed a regression model for residential mortgages loan losses as a function of household debt, wealth and unemployment. With the use of this regression model, the central authority in Norway estimated the impact of shocks on the macroeconomic parameters to estimate loan losses of all Norwegian banks. Banks are usually not directly involved in top-down approaches, the central authority performs the stress test on aggregated system- wide data. But the precision of the test is highly dependable on the quality and granularity of data availability. The outcome is often the resilience of the banking sector to adverse shocks.

The bottom-up approach uses banks' individual data (high disaggregated) *and* models the resilience of the bank to adverse shocks (given by a central authority), the central authority aggregates the results. An advantage of this approach is the availability of data and the consistency of the method, this method tends to be more tailor-made. A disadvantage of the approach is the use of different models with different assumptions to assess the impact of macroeconomic shocks on asset classes. This undermines cross-section comparability.

The methods are complementary regarding consistency, benchmarking and learning opportunities.

A.3 Solvency

$$\frac{\text{Eligible Capital}}{\text{Risk Weighted Assets (RWA)}} \geq \text{ Capital BIS Ratio (10.5 percent)} \tag{A.1}$$

The *risk-weighted assets* is a measure of the total credit risk, market risk and operational risk exposure of a bank. In case of credit risk, each asset class is assigned a risk weight. The weight per class depends to the credit risk exposure of that class, see table table B.5. The risk weighted assets are the sum of the banks' asset exposures multiplied by the specific risk weights, see equation Equation A.2. i is the asset class (e.g. a AAA bond or a certain retail loan). n is the total number of classes. For operational risk, under the Basic Indicator Approach, a bank must hold capital of at least 15 percent of the average three year gross income (ignoring negative values in both numerator and denominator, see Equation A.3).

$$\text{RWA-Credit Risk} = \sum_{i=1}^{n} \text{asset exposure}_i \ \cdot \ \text{risk weight}_i \tag{A.2}$$

$$\text{RWA-Operational Risk} = \Big[\sum_{i=1}^{n} \Big(GI_i \cdot 0.15\Big)\Big]/n \tag{A.3}$$

This requirement applies since the end of 1992 (Basel Committe, 2014), the execution of the Basel Capital Accord (also known as *the 1988 Accord*). The Basel Capital Accord included a minimum capital ratio of capital to risk-weighted assets of 8 percent. Since the Basel Capital Accord, the details developed and expanded, for instance in the Revised Capital Framework (also known as Basel II), but the essence remained the same. Banks should have *sufficient* equity compared to assets, the equity should be of high *quality* and *available* if losses materialize.

The financial crisis showed that the framework under Basel II was insufficient. Basel III (issued mid-December) surpasses that deficit by a fundamental strengthening of the framework. In 2008 it came apparent that banks took to much leverage, held inadequate levels of liquidity, applied poor governance and risk management, as well as inappropriate incentive structures (Basel Committe, 2014).

Under the new capital regime, the measure of capital is composed of two parts, Tier 1 and Tier 2, in contrast with three Tiers under Basel II. The new accord proposes new definitions of capital to increase the quality and transparency of the capital base, while capital ratio's are increased. The eligible capital in Equation A.1 is composed of Tier 1 capital (Common Equity Tier 1 and Additional Tier 1) and Tier 2 capital, see page 62. The total capital (Tier 1 plus Tier 2) must be at least 8% of risk weighted assets.

Apart from these changes, Basel III introduced two other capital buffers. The static Capital Conservation Buffer (CCB) and the variable Countercyclical Buffer (CB), see figure A.1.

The **Capital Conservation Buffer** is designed to ensure that banks build up capital buffers outside periods of stress which can be drawn down as losses are incurred (BIS, 2011). The Capital Conservation Buffer is 2.5% of RWA to be met with CET1 capital. When the Capital Conservation Buffer is depleted, the bank should rebuild the buffer through reducing discretionary distributions of earnings (dividend payments, bonuses ect.) or by raising new capital (BIS, 2011). The more the buffer is affected by periods of stress, the tighter the imposed constraints on capital distributions to conserve and rebuild the deficit, this is reflected in the next table. These imposed constraints should avoid:

- breaches of minimum capital requirements, and
- distribution of dividends and compensations showing the creditworthiness of the bank.

Individual bank minimum capital conservation standards	
Common Equity Tier 1 Ratio	Minimum Capital Conservation Ratios (expressed as a percentage of earnings)
>4.500% - 5.125%	100%
>5.125% - 5.750%	80%
>5.750% - 6.375%	60%
>6.375% - 7.000%	40%
>7.000%	0%

Table A.2: Capital Conservation Standards

The Countercyclical Buffer takes the macro-financial environment into account. The excessive credit growth prior to the eruption of the financial crisis led to an increase in system-wide risk, which sparked a vicious circle. The downturn affects in the financial system effected the real economy, which led to second round effects in the financial system. The buffer level is set by Member States (MS) and ranges from 0% - 2.5% of RWA met by CET1 capital. The Countercyclical Buffer is

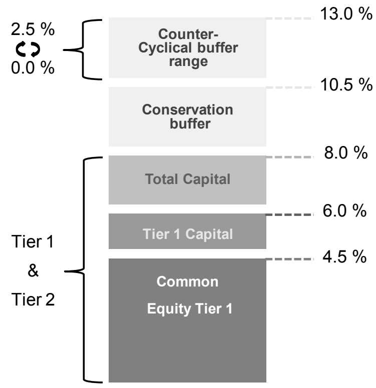


Figure A.1: Capital Requirements

deployed by MS, if MS judge that excessive credit growth in a boom-phase affects the system-wide risk. The restraint is released if system-wide risk crystallises or dissipates (BIS, 2011).

Leverage ratio

The excessive build-up of leverage (assets to capital on a bank's balance sheet, and off-balance exposures) was one of the features which led to the cliff edge in 2008.

$$\text{Leverage Ratio} = \frac{\text{Tier 1 Capital}}{\text{Total Exposure}} \geq 3\% \tag{A.4}$$

For **systemically important banks** a loss absorbency capacity applies and should hold extra capital.

A.4 Liquidity

The causes and types of liquidity risk

From the liability side; funding liquidity

- Wholesale or retail funders can avoid lending to a bank, due to changes in the market perception of the bank's viability for instance. The banks' ability to roll-over the short-term funding in the wholesale market is hampered and becomes more expensive. The bank faces liquidity problems. In case of retail deposits, agents try to secure their money by withdrawing it. To reduce the impact of such a scenario, is to ensure a proper diversification of funding sources (Dermine and Bissada, 2002). If a bank is less reliant on (secured) short-term funding and the funding sources are well diversified, it is less susceptible to bank runs.
- Systemic liquidity. Systemic shocks can shut down the liquidity market, like the liquidity shock banks experienced in 2008. Mutual confidence in the interbank lending market reached unprecedented levels. During a systemic crisis, many other banks are in a similar position, all eager for highly liquid assets. In such an event, the pledging of assets as collateral is fairly costly (increasing margins) in case of secured funding. Unsecured funding will be the first to evaporate. It is a vicious circle, because potential funders of the bank are unable to find funding to buy the assets. It is even more detrimental when assets need to be liquidated in an illiquid market to pay-off the creditors.

From the asset side, market liquidity

- Liquidation of an asset concerns a trade-off, the speed of the sale of the asset and the price for which it can be sold. Liquidity risk arises when assets, thought to be liquid, are difficult (or even impossible) to liquidate or at fire-sale prices. This is probably not the case if a bank fails in isolation, but is typical for system crises. Unsuccessfully pledging an asset as collateral or unable to securitize illiquid assets (the attractive "originate to distribute" model) are other examples of market illiquidity. Liquid assets are more expensive than illiquid assets. This is because interest earned on liquid assets, such as liquid bonds, is less than the interest earned on assets not readily convertible into cash. Here is a trade-off for banks, liquidity vs. profitability. As one can see, in a systemic liquidity shock, funding liquidity and market liquidity compound each other. This is also evident in the regulatory liquidity ratio's described later on in this section were the regulator applies weights on assets, liabilities and cash flows. The weights reflect haircuts on assets or probabilities of withdrawals of liabilities, reflecting market disruptions.

A.4.1 LCR

The introduction of the LCR is a key reform of the Basel Committee. Many banks experienced difficulties during the financial crisis despite adequate capital levels (Basel Committee on Banking Supervision, 2013). The LCR promotes short-term resilience. Banks should have sufficient levels of high-quality liquid assets to withstand a 30-day stress period. High-quality liquid assets are characterized by their low risk, ease and certainty of valuation, absence of wrong-way risk and are traded on developed and recognised exchanges. The committee assigned risk-weights to each asset class which reflects the marketability of each class, see table table B.1. The stock of HQLA is the multiplication of the weights with the total amount of the asset on the balance sheet, this is the amount with can easily be converted into cash.

The 30-day stress period is defined by the committee. Likewise, the committee assigned run-off rates to each liability class to defines the cash outflow of a 30 day period, see table table B.2. The bank subtracts the cash inflow (to a maximum of 75% of the cash outflow), to find the *net* cash outflow over the stressed period. Double counting is not permitted, cash inflows from assets assigned being HQLA are not allowed. The amount of HQLA should cover the net cash outflow of a 30-day stress period, see Equation A.5. The LCR is stepwise implemented, see table table A.3.

$$\text{LCR} = \frac{\text{Stock of HQLA}}{\text{Total net cash outflows over the next 30 calendar days}} \geq 100\% \tag{A.5}$$

LCR implementation scheme					
	1 Jan. 2015	1 Jan. 2016	1 Jan. 2017	1 Jan. 2018	1 Jan. 2019
LCR	65%	70%	80%	90%	100%

Table A.3: LCR Implementation Scheme

A.4.2 NSFR

The NSFR promotes a stable funding profile in relation with the asset portfolio. It is defined as the amount of available stable funding (ASF), meaning liabilities and capital expected to be reliable over a year, relative to the amount required, see Equation A.6. Each capital and liability class is assigned a ASF factor, the factor depends on the broad characteristics of the stability of the funding source, see table B.3. The sum of multiplications of the ASF factors with each funding source is the ASF.

$$\text{NSFR} = \frac{\text{Available amount of stable funding}}{\text{Required amount of stable funding}} \geq 100\% \tag{A.6}$$

The required amount of stable funding is defined in a similar fashion, see table table B.4. The amount of stable funding should be at least 100 percent of the amount required.

A.5 Merton's model

Definitions in Merton Model	
V	Value of the firm, asset value.
D	Debt value
E	Equity value
k	required yield on risky debt.

Table A.4: Definitions

If $V_T < D$ the company defaults, in theory.

$$E_T = max(V_T - D, 0) \tag{A.7}$$

This is a call option with strike equal to the debt level. Black-Scholes-Merton gives E_0 and D_0:

$$E_0 = V_0 N(d_1) - De^{-rT} N(d_2) \tag{A.8}$$

$$D_0 = De^{-rT}\left[\left(\frac{1}{d}\right)N(d_1) + N(d_2)\right] \tag{A.9}$$

where :

$$d = \frac{De^{-rT}}{V_0} \tag{A.10}$$

$$d_1 = \frac{ln(V_0/D) + (r + \sigma_V^2/2)T}{\sigma_V\sqrt{T}} \tag{A.11}$$

$$d_2 = d_1 - \sigma_V\sqrt{T} \tag{A.12}$$

A.10 is the leverage ratio of the bank. The risk neutral probability that a company will default is $N(-d_2)$. Both V_0, σ_V and D we can observe in the model. r is LIBOR (the risk-free rate of equivalent maturity of T), T is time to maturity, the time the debt should be paid.

This equation also can be written in terms of a yield spread that reflects an equilibrium default risk premium that the borrower should be charged:

Equation A.9 can be written as:

$$k - r = \left(\frac{-1}{T}\right) ln\left[\left(\frac{1}{d}\right)N(d_1) + N(d_2)\right] \tag{A.13}$$

A.13 is the yield spread that reflects the equilibrium default risk premium Saunders & Lillen (2002).

Here we present the CDS spread before and after the fall of Lehman Brothers.

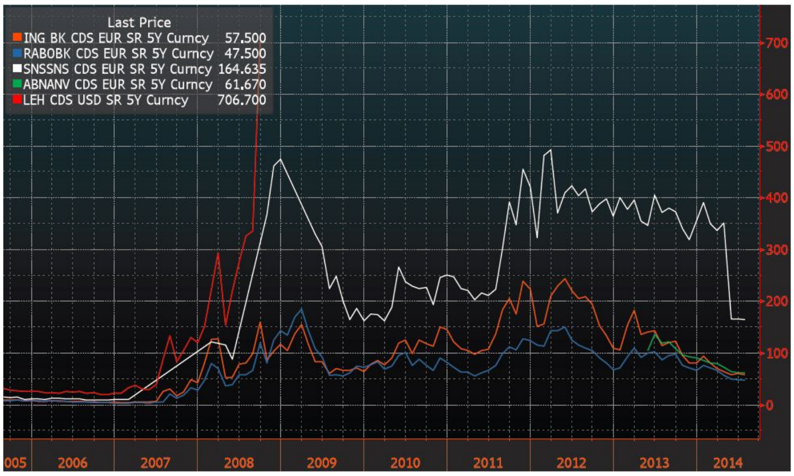


Figure A.2: 5 Y CDS spreads, source: Bloomberg

Appendix B

Graphs and Tables

B.1 Tier 1 and Tier 2 definitions

Tier 1 (going-concern capital) From 4% to 6% under Basel III

A. Common Equity Tier I capital (CET1)
The purest form of capital. From 2% to 4.5% under Basel III and consists of the following elements (BIS, 2011):

- Common shares issued by the bank.
- Stock surplus (share premium).
- Retained earnings.
- Accumulated other comprehensive income and other disclosed reserves.
- Common shares issued by consolidated subsidiaries.
- Regulatory adjustments applied in the calculation of Common Equity Tier 1.

B. Additional Tier I capital
Consists of the following elements (BIS, 2011):

- Instruments issued by the bank that meet the criteria for inclusion in Additional Tier 1 capital (and are not included in Common Equity Tier 1).
- Stock surplus (share premium) resulting from the issue of instruments included in Additional Tier 1 capital.
- Instruments issued by consolidated subsidiaries of the bank and held by third parties that meet the criteria for inclusion in Additional Tier 1 capital and are not included in Common Equity Tier 1.
- Regulatory adjustments applied in the calculation of Additional Tier 1 Capital.

Tier 2 (gone-concern capital) .
Consists of the following elements (BIS, 2011):

- Instruments issued by the bank that meet the criteria for inclusion in Tier 2 capital (and are not included in Tier 1 capital).
- Stock surplus (share premium) resulting from the issue of instruments included in Tier 2 capital.
- Instruments issued by consolidated subsidiaries of the bank and held by third parties that meet the criteria for inclusion in Tier 2 capital and are not included in Tier 1 capital.
- Certain loan loss provisions as specified in paragraphs 60 and 61.
- Regulatory adjustments applied in the calculation of Tier 2 Capital.

B.2 LCR

Stock of High Quality Liquid Assets	
Item	Factor
Level 1 assets:	
• Coins and bank notes • Qualifying central bank reserves • Domestic sovereign or central bank debt for non-0% risk-weighted sovereigns	100%
Level 2 (maximum of 40 % of HQLA):	
• Sovereigns qualifying for 20% risk weighting • Qualifying corporate debt securities rated AA- or higher • Qualifying covered bonds rated AA- or higher	85%
Level 2B assets (maximum of 15% of HQLA)	
• Qualifying corporate debt securities rated between A+ and BBB-	50%
• Qualifying common equity shares	50%

Table B.1: Weighting Scheme HQLA, *source: Basel III: The Liquidity Coverage Ratio and liquidity risk monitoring tools, 2013*

B.3 Asset definitions

Residential Mortgage Loans
This asset class includes loans secured by residential property. The class is divided into three sub-classes: value to loan, credit rating and maturity.

Other consumer Loans
Loans and leases to individuals, either unsecured or secured by assets other than residential property. Subclasses: Credit Rating, value to loan (if applicable), and maturity.

Corporate & Commercial Loans
Loans and leases to corporate and commercial enterprises. Subclasses: Credit Rating, value to loan (if applicable), and maturity.

Loans and Advances to Banks
Loans and advances to banks. Subclasses: Credit Rating, value to loan (if applicable), and maturity.

(Government) Bonds
Subclasses: Credit Rating and maturity.

Trading securities
Subclass: Risk profile in risk/return.

Cash and equivalents
Cash and non-interest-earning balances with central banks.

B.4 Liability and equity definitions

Customer deposits

Current: customer transaction accounts which can be withdrawn on demand or short notice. No subclasses.
Savings: customer savings accounts. No sub-classes.
Term: customer deposits for which there is a set maturity date. No subclasses.

Corporate Deposits

Deposits from corporates and commercial enterprises. Sub-classes: maturity.

Bank deposits

Deposits from banks. Sub-classes: maturity.

Debt securities

Issued bonds. Subclasses: maturity.

Subordinated borrowings

Subordinated loans and debt. Subclasses: maturity.

Derivatives

No Sub-class.

Trading liabilities

short-tem notes and other financial liabilities classified as held for trading. Sub-class: maturity.

Equity

Includes Common shares, premium and retained earnings.

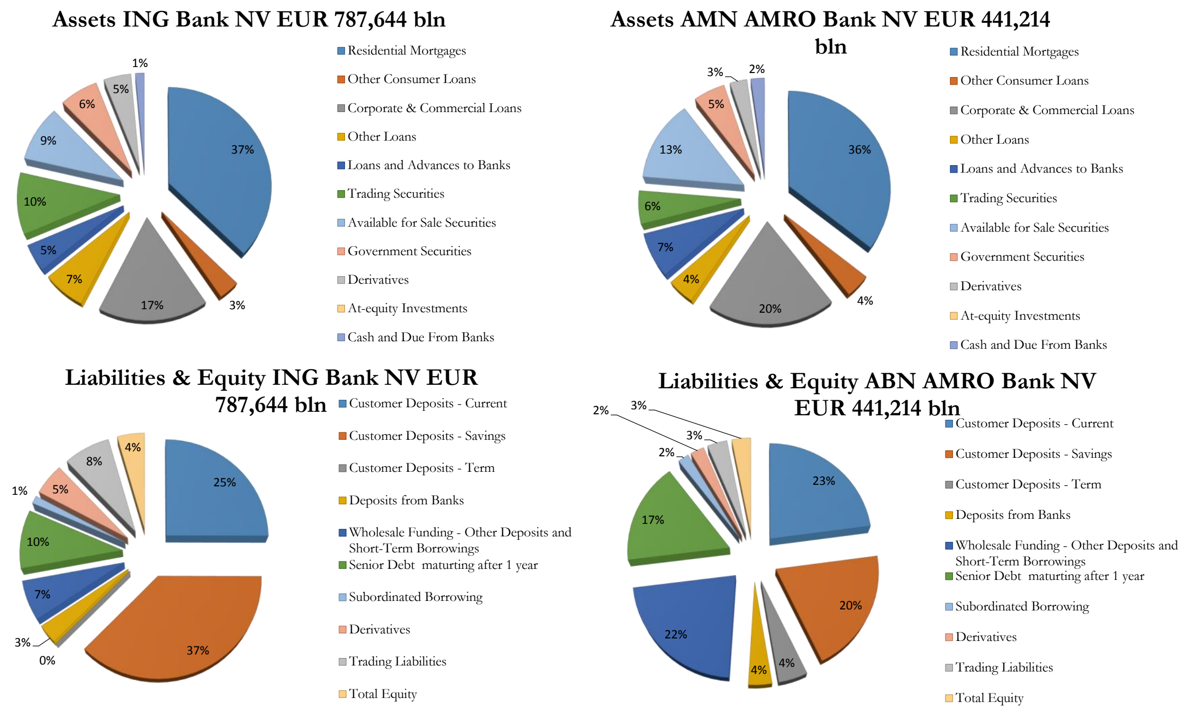


Figure B.1: Assets and Liabilities of ING and ABN AMRO

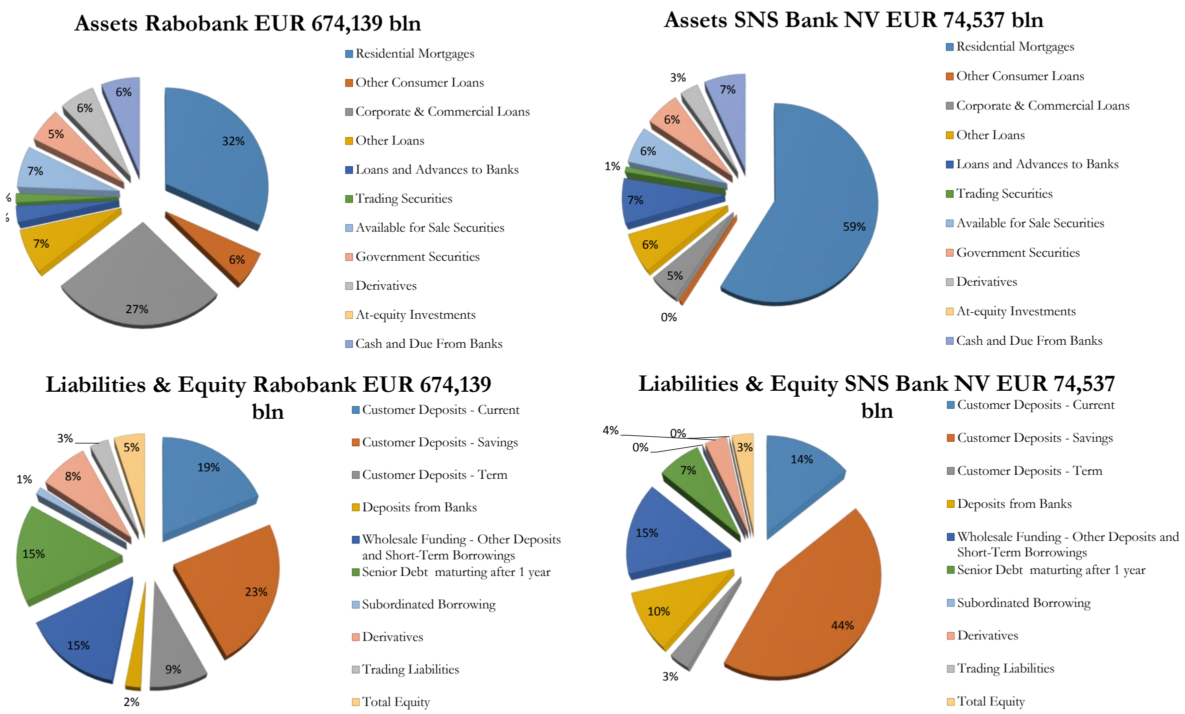


Figure B.2: Assets and Liabilities of Rabobank and SNS bank

Cash outflows	
A. Retail Deposits:	
• Stable deposits (with additional criteria)	3%
• Stable deposits	5%
• Less stable retail deposits	10%
B. Unsecured wholesale funding:	
• Stable deposits small business customers	5%
• Less stable deposits small business customers	10%
• Cooperative banks in an institutional network	25%
• Non-financial corporates, sovereigns, PSEs.	40%
• Other legal entity customers	100%
C. Secured funding:	
• backed by Level 1	0%
• backed by Level 2A	15%
• backed by Level 2B	25%
• backed by other than 2B	50%

Table B.2: Cash outflows under LCR, *source: Basel III: The Liquidity Coverage Ratio and liquidity risk monitoring tools, 2013*

ASF Liability and Capital factors
Liabilities and capital receiving a 100% ASF factor
• Total regulatory capital, excluding Tier 2 capital. • Other capital instruments and liabilities with effective residual maturity of one year or more.
Liabilities receiving a 95% ASF factor
• Liabilities receiving a 95% ASF factor comprise "stable", non-maturity (demand) deposits and/or term deposits with residual maturities of less than one year provided by retail and small- and medium-sized entity (SME) customers
Liabilities receiving a 90% ASF factor
• Liabilities receiving a 90% ASF factor comprise "less stable" , non-maturity (demand) deposits and/or term deposits with residual maturities of less than one year provided by retail and SME customers.
Liabilities receiving a 50% ASF factor
•Funding (secured and unsecured) with a residual maturity of less than one year provided by non-financial corporate customers. • Funding with residual maturity of less than one year from sovereigns, public sector entities (PSEs), and multilateral and national development banks. •Other funding (secured and unsecured) not included in the categories above with residual maturity of not less than six months and less than one year, including funding from central banks and financial institutions.
Liabilities receiving 0% ASF factor
• All other liabilities and equity categories not included in the above categories.

Table B.3: ASF factors, *source: Basel III: The Net Stable Funding Ratio, 2014.*

ASF Asset factors
Assets receiving a 100% ASF factor
• All assets instruments not assigned below.
Assets receiving a 85% ASF factor
• Other unencumbered performing loans that do not qualify for the 35% or lower risk weight under the Basel II Standardised Approach for credit risk and have residual maturities of one year or more.
Assets receiving a 65% ASF factor
• residential mortgages with a residual maturity of one year or more that would qualify for a 35% or lower risk weight under the Basel II Standardised Approach for credit risk.
Assets receiving a 50% ASF factor
• corporate debt securities (including commercial paper) with a credit rating of between A+ and BBB–. • exchange-traded common equity shares. • Deposits held at other financial institutions. • All other that have a residual maturity of less than one year, including: loans to non-bank financial institutions, loans to non-financial corporate clients, loans to retail customers and small business customers, and loans to sovereigns, central banks and PSEs.
Assets receiving a 15% ASF factor
• Markable securities representing claims on or quarenteed by sovereigns, PSEs and ECB which are assigned a 20% risk weight under under credit risk. • Corporate debt securities (including commercial paper) and covered bonds with a credit rating equal or equivalent to at least AA–.
Assets receiving 5% ASF factor
• Markable securities representing claims on or quarenteed by sovereigns, PSEs and ECB which are assigned a 0% risk weight under under credit risk.
Assets receiving 0% ASF factor
• Coins, banknotes and all central bank reserves.

Table B.4: ASF factors, *source: Basel III: The Net Stable Funding Ratio, 2014.*

Credit Risk – Standardized Approach					
	AAA to AA^-	A^+ to A^-	BBB^+ to BBB^-	BB^+ to B^-	Below B^-
Sovereigns	0%	20%	50%	100%	150%
Banks	20%	50%	100%	100%	150%
Corporates	20%	50%	100%	100%	150%
Retail-loans	75%				
	LTV<0.8	LTV>0.8			
Retail-mortgages	35%	75%			
Commercial-mortgages	100%	100%			
Cash	0%				

Table B.5: Credit Risk – Standardized Approach

Investments per risk class

Banks	Rating AAA	PD	Rating AA	PD	Rating A	PD	Rating BBB	PD	Rating BB	PD	Rating <B	PD
ABN			96%	0,10			4%	3,00				
ING	34%	0,10	51%	0,25	14%	2,80					1%	50,00
RABO	66%	0,50			34%	2,00						
SNS												
Corporates												
ABN			35%	0,01			65%	3,00				
ING	4%	0,10	43%	0,25	39%	2,80	3%	7,50	3%	15,00	8%	50,00
RABO	11%	0,50			84%	2,00	3%	5,00			3%	30,00
SNS												
Sovereigns												
ABN												
ING	80%	0,10	17%	0,25	3%	2,80						
RABO												
SNS	55%	0,10	32%	0,25	4%	2,80	8%	7,50				
Mortgages												
ABN			84%	0,01			16%	3,00				
ING	7%	0,10	56%	0,25	30%	2,80	2%	7,50	2%	15,00	3%	50,00
RABO	23%	0,50			75%	2,00	1%	5,00			1%	30,00
SNS	75%	0,50	14%	2,50	4%	5,50					7%	20,00
Retail												
ABN			40%	0,01			60%	3,00				
ING	7%	0,10	56%	0,25	30%	2,80	2%	7,50	2%	15,00	3%	50,00
RABO	5%	0,50			86%	2,00	7%	5,00			3%	30,00
SNS												

* The percentages correspond with the degree the four banks invest in the specific Credit Rating classes. Missing values are filled by averages of other banks values.

Table B.6: Credit Risk per asset class

Loan to value of mortgage loans				
LtV	NHG	60	80	115
ABN	24%	34%	17%	24%
ING	10%	9%	21%	59%
RABO	20%	43%	16%	21%
SNS	26%	28%	19%	27%

Table B.7: Loan to Value

Maturity distribution per asset class					
Banks & Asset Class					
ABN	<1 M	1-3 M	3-12 M	1-5 Y	>5 Y
Cash and balances at central banks	100	0	0	0	0
Financial assets held for trading	100	0	0	0	0
Financial investments	2	3	7	32	56
Loans and receivables to banks	72	3	4	1	21
Loans and receivables to customers	11	3	6	17	63
ING					
Cash and balances at central banks	100	0	0	0	0
Financial assets held for trading	45	8	13	17	17
Financial investments	5	5	11	42	38
Loans and receivables to banks	64	12	13	10	1
Loans and receivables to customers	12	3	6	24	54
RABO					
Cash and balances at central banks	36	64	0	0	0
Financial assets held for trading	1	35	10	34	19
Financial investments	0	8	7	25	59
Loans and receivables to banks	16	75	6	3	1
Loans and receivables to customers	6	7	7	20	60
SNS					
Cash and balances at central banks					
Financial assets held for trading					
Financial investments	8	2	5	24	61
Loans and receivables to banks	26	7	67	0	0
Loans and receivables to customers	4	1	0	2	92

* The numbers correspond with the degree the four banks invest in the specific Maturity classes. Missing values are filled by averages of other banks values.

Table B.8: Maturity distribution per asset class

Interest income per asset class					
Asset Class					
	Min	Max	Mean	SD	Last
Residential Mortgage Loans					
>1Y and <= 5Y fixed interest	3,20	5,50	4,37	0,56	3,20
>5Y and <= 10Y fixed interest	3,87	5,51	4,76	0,43	3,87
>10Y fixed interest	4,17	5,60	5,01	0,32	4,60
Other Retail Loans					
variable interest and <= 1Y	2,08	5,55	3,56	1,04	2,23
>1Y and <= 5Y fixed interest	4,17	6,21	5,17	0,56	4,29
>5Y fixed interest	4,13	6,51	5,22	0,57	4,69
Corporate & Commercial Loans					
variable interest and <= 1Y	2,93	5,82	3,83	0,79	3,33
>1Y and <= 5Y fixed interest	3,77	6,35	4,69	0,66	3,85
>5Y fixed interest	4,02	5,95	4,84	0,50	4,08
Loans and Advances to Banks					
1M	0,05	5,04	1,72	1,56	0,09
3M	0,12	5,27	1,91	1,59	0,18
6M	0,20	5,37	2,07	1,54	0,27
5Y Bonds					
AAA/AA	0,32	4,79	2,54	1,28	0,32
A	2,79	7,97	5,51	1,25	2,94
BBB	2,96	10,49	6,48	2,08	3,30
BB/B	3,37	17,15	6,35	2,47	3,90
<B	4,21	61,18	28,54	21,16	4,21
10Y Bonds					
AAA/AA	1,20	5,10	3,30	1,05	1,20
A	3,30	8,10	5.73	1,10	3,40
BBB	5,40	10,30	7,73	1,08	5,60
BB/B	4,40	22,00	10,23	3,90	4,90
<B	8,10	35,00	16,76	8,36	9,00
Trading Securities					
	-20,00	22,27	10,60	14,36	12,04
Cash and Equivalents					
	0,02	4,30	1,58	1,46	0,02

Table B.9: Interest income per asset class

Interest expenses per liability class					
Liability Class					
	Min	Max	Mean	SD	Last
Customer deposits - current	-	-	-	-	0,00
Customer deposits - savings	-	-	-	-	1,33
Customer deposits - term					
<= 1Y	1,67	4,60	2,77	0,73	2,01
>1Y en <= 2Y	1,99	5,07	3,13	0,95	2,17
>2Y (incl. longer terms)	2,02	4,29	3,21	0,53	2,64
Corporate deposits					
<= 1Y	0,16	4,54	1,81	1,38	0,25
>2Y (incl. longer terms)	2,19	5,15	3,56	0,70	2,19
Bank deposits					
1 M	0,05	5,04	1,72	1,56	0,09
3 M	0,12	5,27	1,91	1,59	0,18
6 M	0,20	5,37	2,07	1,54	0,27
Debt securities	-	-	3,82	1,58	3,82
Subordinated borrowings	-	-	4,53	2,00	4,53
Trading liabilities					
1 W	0,20	6,25	2,47	2,18	0,49
1 M	0,38	5,96	2,48	2,18	0,49
3 M	0,36	5,97	2,49	2,19	0,50
Equity	-	-	-	-	2,88

Table B.10: Interest expenses per asset class

Appendix C

The Model

The asset portfolio of a bank consists of n (i=1,..,n) classes. The exposure per class at time t (t=0,..,T) is x_{it}. So, the exposure per class at $t = 0$ (starting values) is equal to x_{i0}. T=36 (three year times 12 months), equal to the time horizon of the EBA stress test. Time-steps are set to one month for a good understanding of the evolvement of the balance sheet. Smaller steps are redundant, since the assets shocks are given per year (see **??**).

Equation C.1 shows each asset class.

$$i = \begin{cases} \text{i=1} & \text{Residential Mortgage Loans} \\ \text{i=2} & \text{Other Retail Loans} \\ \text{i=3} & \text{Corporate \& Commercial Loans} \\ \text{i=4} & \text{Loans and Advances to Banks} \\ \text{i=5} & \text{Bonds} \\ \text{i=6} & \text{Trading Securities} \\ \text{i=7} & \text{Cash and Equivalents} \end{cases} \tag{C.1}$$

Equation C.2 show the different subclasses for $i = 1, 2, 3$ and 4 regarding the *value to loan* for the residential mortgage portfolio and (un)secured loans. Equation C.3 shows subclasses for $i = 1, 2, 3, 4, 5$ regarding the *credit rating* and equation C.4 shows the different subclasses for $i = 1, 2, 3, 4, 5$ and 6 regarding the *maturity* of the subclass. We work with a static balance sheet assumption, meaning interim matured assets are reinvested under this assumption which is in alignment with the EBA stress test. However, knowledge about the maturity profile is necessary for the calculation of different ratio's and the assessment of interest rate risk. But most importantly, different maturities yield different returns, due to the yield curve slope.

$$v = \begin{cases} \text{NHG} & \text{v=1} \\ 60\% & \text{v=2.} \\ 80\% & \text{v=3.} \\ 115\% & \text{v=4.} \\ \text{No collateral} & \text{v=0.} \end{cases} \tag{C.2}$$

$$c = \begin{cases} AAA \text{ to } AA^- & \text{c=1.} \\ A^+ \text{ to } A^- & \text{c=2.} \\ BBB^+ \text{ to } BBB^- & \text{c=3.} \\ BB^+ \text{ to } B^- & \text{c=4.} \\ <B^- & \text{c=5.} \\ \text{not applicable} & \text{c=0.} \end{cases} \tag{C.3}$$

$$k = \begin{cases} \text{overnight} & \text{k=1} \\ 1/12 & \text{k=2} \\ 3/12 & \text{k=3.} \\ 6/12 & \text{k=4.} \\ 9/12 & \text{k=5.} \\ 1 & \text{k=6.} \\ 3.5 & \text{k=7} \\ 5 & \text{k=8} \\ 7.5 & \text{k=9} \\ 10 & \text{k=10} \\ \text{not applicable} & \text{k=0} \end{cases} \tag{C.4}$$

$$x_{i_{v,c,k}t} = \begin{cases} x_{1_{v,c,k}t} & \text{i=1.} \\ x_{2_{v,c,k}t} & \text{i=2.} \\ x_{3_{v,c,k}t} & \text{i=3.} \\ x_{4_{v,c,k}t} & \text{i=4.} \\ x_{5_{0,c,k}t} & \text{i=5.} \\ x_{6_{0,0,k}t} & \text{i=6.} \\ x_{7_{0,0,0}t} & \text{i=7.} \end{cases} \qquad \text{for all v, c and k.} \tag{C.5}$$

The liability and equity portfolio of a bank consists of m (j=1,..,m) classes. The exposure per class at time t (t=0,..,T) is $y_{j,t}$. So, the exposure per class at $t = 0$ (starting values) is equal to $y_{j,0}$.

Equation C.6 shows each funding class.

$$j = \begin{cases} \text{Customer deposits - current} & \text{j=1.} \\ \text{Customer deposits - savings} & \text{j=2.} \\ \text{Customer deposits - term} & \text{j=3.} \\ \text{Corporate deposits} & \text{j=4.} \\ \text{Bank deposits} & \text{j=5.} \\ \text{Debt securities} & \text{j=6.} \\ \text{Subordinated borrowings} & \text{j=7.} \\ \text{Derivatives} & \text{j=8.} \\ \text{Trading liabilities} & \text{j=9.} \\ \text{Equity} & \text{j=10.} \end{cases} \tag{C.6}$$

All liability classes are subdivided by their maturity, see Equation C.4. Therefore, $y_{j_k t}$ is the exposure per funding class for all k.

$\vec{x}_t$ is the vector of exposures of the asset classes at time t, and $\vec{y}_t$ is the vector of exposures of the funding classes at time t, see Equation C.9.

$$0 \leq x_{i_{v,c,k},t} \leq 1 \qquad\qquad 0 \leq y_{j_k,t} \leq 1 \tag{C.7}$$

$$\sum_{i=1}^{n} x_{i_{v,c,k},0} = 1 \qquad\qquad \sum_{j=1}^{m} y_{j_k,0} = 1 \tag{C.8}$$

Equation C.7 and Equation C.8 prohibit short selling and ensure that all assets and liabilities are distributed among the different classes at $t = 0$. The restriction of Equation C.8 is limited to $t = 0$, and is considerend the distribution scheme of all assets and funding classes at $t = 0$. For $t > 0$ it could well deviated from 1, the value is considered the balance sheet size, relative to 1 (the balance sheet size at $t = 0$).

$$\vec{x}_t = \begin{pmatrix} x_{1_{v,c,k},t} \\ \vdots \\ \vdots \\ \vdots \\ \vdots \\ x_{7_{v,c,k},t} \end{pmatrix} \qquad\qquad \vec{y}_t = \begin{pmatrix} y_{1_k,t} \\ \vdots \\ \vdots \\ \vdots \\ \vdots \\ y_{10_k,t} \end{pmatrix} \tag{C.9}$$

The familiar accounting rule states that the value of the assets should be equal to the value of the funding side (the sum of liabilities and the equity position). The equity position equals both sides for each t, therefore:

$$\sum_{i=1}^{n} x_{i_{v,c,k},t} = \sum_{j=1}^{m} y_{j_k,t} \qquad \text{for all } t \tag{C.10}$$

C.0.1 Asset shocks

The model is an interplay of asset movements and reactions of the liability-side (variable funding costs, conditional to the size of the impairment of the asset portfolio and withdrawals of depositors). Brunnermeier (2009) argues that "failures are generally triggered by a decline in the value of the assets held by the bank, and by a run on the bank, itself usually primarily caused by a perceived decline in the bank's asset values." It that light, we model the balance sheet as a process of interaction between asset impairments and variable funding costs and withdrawals. In this section we discuss the asset shocks.

The part of the model which generates the shocks, derives the severity of the shock from three points: the end of 2014, 2015 and 2016. In case of, but not restricted to, the residential property prices, bonds and trading securities, $t = 0$ corresponds with an index value of 100. The EBA published deviations from the baseline level (index value $t = 0$) for the upcoming years. For Dutch equity securities these values are: 79.6 80.0 and 74.1. The model estimates using a third degree polynomial the values between the shock points, see for an example figure 4.1. The impairment per day is:

$$\frac{\text{Index value}_t}{\text{Index value}_{t-1}} \tag{C.11}$$

All asset classes, excluding the cash position ($i = 7$) are all exposed to shocks. We define the shock for asset class $x_{i_{v,c,k}t}$ as $g_{i_{v,c,k}t}$. $\vec{g}_t$ is the vector of impairments of the asset classes at time t.

The model distinguishes three kind of different shocks. A shock is materialized by the multiplication of $x_{i_{v,c,k}t-1}$ with $g_{i_{v,c,k}t}$ with $g_{i_{v,c,k}t} \geq 0$, so:

$$x_{i_{v,c,k}t} = x_{i_{v,c,k}t-1} \cdot g_{i_{v,c,k}t} \qquad \text{for } t \geq 1 \tag{C.12}$$

Typically, the movement of an assets' value is modelled with Brownian motion models. However, stochasticity is not included in this model. The model simulates a balance sheet under predefined stress levels for each asset class, we do not deviate from these levels. Generally, volatility increases in times of stress. Including these characteristics into this model requires too much effort compared with the pay-off of the extra information it will give us.

(un)Secured Loans, i=1,2,3,4

For $(i = 1, 2, 3, 4)$ this shock $(g_{i_{v,c,k}t})$ is equal to 1 minus the multiplication of the PD $(PD_{i_{v,c,k}t})$ with the LGD $(LGD_{i_{v,c,k}t})$ corresponding to $x_{i_{v,c,k}t}$. The severity of the shock differs per subclass. The PD shock is derived from the PD path generator provided by the EBA. The EBA published a PD and a LGD path generator for benchmark purposes or for small banks (without in-house knowledge of such credit risk models). The EBA generators generates three future PD's and LGD's for different types of loans, as in figure 4.1. The index value at $t = 1$ is changed in the model to the current PD.

$$g_{i_{v,c,k}t} = 1 - \Big(PD_{i_{v,c,k}t} \cdot LGD_{i_{v,c,k}t}\Big) \qquad \text{for } i = 1, 2, 3, 4 \tag{C.13}$$

The LGD of the loans depends on the subclass v and the shock on the collateral (in case of mortgages, the residential property prices). The collateral on time t is denoted by C_t. The house price shock for the Dutch market equals: 90.7 , 85.4, 83.3 (with 100 in 2013). In case of a default, given the subclass v, the lost given default is equal to:

$$LGD_{i_{v,c,k}t} = \max\Bigg[\Big((v * \mathrm{C}_0) - \mathrm{C}_t\Big), 0\Bigg] \tag{C.14}$$

Bonds, i=5

For the sovereign bond portfolio (i=5) , the model applies valuation haircuts to sovereign exposures. The EBA published a document stating the valuation haircuts for sovereign exposures, classified by maturity and sovereign state. With the use of Bloomberg a sovereign state is linked to a credit rating, c.

$$g_{i_{(0,c,k)}t} = \frac{\text{Index value}_{t_{(0,c,k)}}}{\text{Index value}_{t-1_{(0,c,k)}}} \qquad \text{for i=5} \tag{C.15}$$

Trading securities, i=6

The trading securities are imposed by a market shock. The shock is published in accompanying document of the Methodological note EU-wide Stress Test 2014 from the EBA (EBA, 2014).

$$g_{i_{(0,0,k)}t} = \frac{\text{Index value}_{t_{(0,0,k)}}}{\text{Index value}_{t-1_{(0,0,k)}}} \qquad \text{for i=6} \tag{C.16}$$

C.0.2 Liability shocks

We distinguish two kind of reactions of funders. A change in funding costs and withdrawals of deposits. The latter is restricted to the deposit holders.

Changing funding costs

The model determines for each funding class the funding cost at time t. The funding cost depends on: the volatility of the asset portfolio ($\sum \vec{x}_t$), the maturity of the funding class and size of the "buffer" of the funding class. The buffer is the size of funding classes which have a later claim on assets in case of a default, we refer to Equation A.13 for the determination of the funding costs per funding source at time t. Only matured funding sources can receive new rates, else the rate is equal to the rate of $t-1$. The total funding cost for the bank at time t is:

$$\text{Total funding costs time } t = \sum \left(\vec{f_t} \cdot \vec{y_t} \right) \qquad \text{for all } t \tag{C.17}$$

were $\vec{f_t}$ is the vector of interest rates corresponding the funding sources at time t, excluding the costs of equity which is determined differently.

Withdrawals

Withdrawals are triggered by observed information about the solvency position of a bank. The actual trigger, the point were depositors decide to withdrawal their funds, is hard to predict. In this model, withdrawals are limited to the depositors classes of the bank. However, withdrawals of other types of funding are well conceivable. In this model, other types of funding do not withdrawal their funds, but demand higher rates, which has about the same effect.

The model assumes, that withdrawals are triggered by a perilously low leverage ratio of the banks' balance sheet. We assume run off rates, on average, of 10% per year, when the leverage ratio is below 3.5%. Run off rates differ per deposit class, see appendix.

C.0.3 Spread, dividend and tax

The interest income, denoted by $\vec{a}_t$, from assets are assumed fixed. A bank is able to, but restricted to a certain extent, pass through changes of funding costs to the clients. Fixed income is quite conservative.

The spread (S_t) at time t is:

$$S_t = \left[\left(\vec{a}_t \cdot \vec{x}_t\right) - \left(\vec{f}_t \cdot \vec{y}_t\right)\right] \qquad \text{for all } t \tag{C.18}$$

First, fixed expenses are substracted from the spread (such as staff expenses and other operating expenses, denoted with E_t). tax (δ) is paid on the spread. Which is equal to 40%, if the spread is positive, else zero.

Then, dependent on the dividend policy, divided (ψ) is paid to the banks' shareholders, which is the cost of capital (f_{10_t}) We assume a dividend policy of 40% of the residual of the spread after tax. Again, if the spread turns out to be negative, dividends are not distributed. The remainder is classified as retained earnings (RE_t) and added to the capital position. An equivalent amount is added (or subtracted if $S_t < 0$) to the cash position of the bank.

$$RE_t = \left[\left(S_t - E_t\right)\left((1-\delta)(1-\psi)\right)\right] \qquad \text{for all } t \tag{C.19}$$

C.1 Restrictions

While optimizing the total spread, which is:

$$S = \sum_{t=1}^{T} \left[\left(\vec{a}_t \cdot \vec{x}_t \right) \left(\vec{f}_t \cdot \vec{y}_t \right) \right] \qquad \text{for all } t \tag{C.20}$$

We assume a set of six restrictions. The first four are discussed in chapter 3.

- The total capital ratio $\geq$ 10.5%; we refer to Equation C.21 and figure A.1 for the regulatory composition of 10.5 percent. For the risk weights (denoted by $\vec{RW}$) we refer to table B.5. The fixed percentage of 15 percent of annual gross income shows that banks are ougt to set aside capital for operational risk.

$$\frac{y_{10,t}}{\sum \left(\vec{x}_t \cdot \vec{RW} \right) + \left((S \cdot 0.15)/3 \right)} \geq 0.105 \tag{C.21}$$

- The NSFR $\geq$ 100%; we refer to subsection A.4.2 for more information about the NSFR. For the weighting scheme of "stable" assets ($\vec{RSF}$) and liabilities ($\vec{ASF}$) we refer to table B.4 and table B.3.

$$\frac{\sum \left(\vec{RSF} \cdot \vec{x}_t \right)}{\sum \left(\vec{ASF} \cdot \vec{y}_t \right)} \geq 1 \tag{C.22}$$

- The LCR $\geq$ 100%; we refer to Equation A.5 for more information about the LCR. For the weighting scheme denoting the liquidity of assets ($\vec{HQLA}$) we refer to table B.1, and table B.2 for the weighting scheme denoting the outflow of funding classes in a 30 day stressed period ($\vec{CO}$).

$$\frac{\sum \left(\vec{HQLA} \cdot \vec{x}_t \right)}{\sum \left(\vec{CO} \cdot \vec{y}_t \right)} \geq 1 \tag{C.23}$$

- The leverage ratio $\geq$ 3%; for more information about the leverage ratio we refer to Equation A.4.

$$\frac{y_{10,t}}{\sum \vec{x}_t} \geq 0.03 \tag{C.24}$$

The latter two restrictions are the Markowitz restriction, and the maximum shifts in both asset and funding portfolios.

- The basic concept of Modern Portfolio Theory (MPT) is that given a set of m risky securities with expected return of asset i ($i = 1..m$) denoted by E_i ($E_i = \bar{r}_i$), the risk denoted by the variance of return σ_i^2 and the covariance of returns between security i and security j denoted by σ_{ij}, we can construct a frontier which describes the set of portfolios consisting of m securities, were each portfolio has the smallest variance possible for a prescribed expected return (Markowitz, 1952).

  The model maximizes the expected return of a portfolio, denoted by E_p, given an amount of risk tolerance, denoted by $\widetilde{\sigma_p^2}$

  Let w_i be the weight of the ith investment in the portfolio, $\sum_{i=1}^{m} w_i = 1$, then the set of efficient portfolios with constrained portfolio variance, satisfies:

$$\max \sum_{i=1}^{m} w_i E_i \tag{C.25}$$

$$\text{s.t.} \qquad \sum_{i=1}^{m} w_i = 1 \tag{C.26}$$

$$\sigma_p^2 = \sum_{i=1}^{m} \sum_{j=1}^{m} w_i w_j \rho_{ij} \leq \widetilde{\sigma}_p \tag{C.27}$$

  The variance per asset class is added in table B.9. The covariance is derived from our dataset.

- The starting balances are $\vec{x}_0$ and $\vec{y}_0$, which corresponds, on an aggregated level, to the four Dutch banks.

  The optimal balance sheet could deviate substantially from the current balance sheet. Banks are not able to divest large parts of their portfolio, or change their funding profile considerably. Therefore, we include a maximum allowed shift in both the asset and funding portfolio of the bank.

$$\sum_{i=1}^{n} \mid \vec{x}_0 - \vec{x}_{Optimal} \mid \leq \text{maximum allowed shift} \tag{C.28}$$

$$\sum_{j=1}^{m} \mid \vec{y}_0 - \vec{y}_{Optimal} \mid \leq \text{maximum allowed shift} \tag{C.29}$$

C.2 Improving the balance sheet

The optimization of the spread, while maintaining a prudent risk profile during the stress period of three years, is implemented with the use of the sequential quadratic programming (SQP) algorithm for non-linearly constrained gradient-based optimization (supporting both inequality and equality constraints), based on the implementation by Kraft (1994), and is a part of NLOPT package of R.

C.3 Input Data

Interest per class is shown in table B.9 and table B.10 in table form. In figure 4.3 the interest motion of the different classes is shown (extracted from Bloomberg and DNB documentation). We used the average interest rate as input, and used the standard deviation for the Markowitz restriction. The asset shocks are derived from EBA EU-wide stress test 2014 data, including the PD and LGD shocks.

In the model we included 43 assets classes ($n = 43$) and 18 funding classes ($m = 18$). With this set of classes we are able to stress a particular bank in a proper way, very stylized nevertheless.

We included the following asset classes:
- 16 Residential Mortgage Loans ($i = 1$) with different LTV, credit rating and maturity.
- 3 Other Retail Loans ($i = 2$) with different maturities.
- 6 Corporate & Commercial Loans ($i = 3$), with different maturities.
- 6 Loans and Advances to Banks ($i = 4$), with different maturities and credit ratings.
- 6 Bonds ($i = 5$), with different maturities and credit ratings.
- 5 Trading securities ($i = 6$), with different maturities.

We included the folowing funding classes:
- Customer deposits - current ($j = 1$).
- Customer deposits - savings ($j = 2$)
- Customer deposits - term ($j = 3$)
- 2 Corporate deposits ($j = 4$), with different maturities.
- 3 Bank deposits ($j = 5$), with different maturities.

- 3 Debt securities ($j = 6$), with different maturities.
- 2 Subordinated borrowings ($j = 7$), with different maturities.
- 1 Derivaties ($j = 8$).
- 3 Trading Liabilities ($j = 9$), with different maturities.

The distribution is set to the average distributions of the ING bank, Rabobank, ABN AMRO bank and the SNS bank (The structure of the portfolios is visualized in B.1 and B.2). The data is extracted from annual reports.

C.3.1 Benchmark risk parameters

The EBA provided central authorities with key risk parameters regarding credit risk. For benchmark purposes and for banks without proper satellite models in place. For this thesis, I use these risk parameters for credit risk for the sake of simplicity. Financial institution have great difficulty to properly translate risk factors into risk parameters, therefore it is prudent to use the benchmark parameters instead of designing satellite models for each exposure class myself.

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