Interest Rate Risk in the Banking Book goes ballet:

balancing between earnings and economic value volatilities

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Abstract

The phrase *'interest rate risk in the banking book'* implies that the banking book is sensitive to fluctuations in market interest rates. Interest rate risk in the banking book (IRRBB) and its complexity has remained unexplored as the spotlight on the banking industry has been mostly on liquidity, capital conduct and regulatory scrutiny. However, this situation is changing. Currently, regulators are considering standardizing the management of IRRBB to a certain extent. IRRBB can be evaluated from both earnings and economic value perspectives. These two perspectives are the focus of this research. In this research the earnings perspective is measured in terms of NII and the economic value perspective is measured in terms of EVE. These two perspectives have different assumptions, employ different methodologies and results in different outcomes. Thus, these two perspectives result in a trade-off. This research investigates this trade-off with risk management hedging techniques. The banking book of a retail bank is usually hedged from the earnings perspective which results in stable and predictable earnings and low earnings volatility. However, hedging from the earnings perspective results in a margin that is not being hedged and economic value volatility. By means of conducting a case study and implementing BPV and notional hedging techniques it is shown that the economic value volatility arises when there is no earnings volatility and earnings volatility arises when there is no economic value volatility. The optimal balance in the trade-off between earnings and economic value volatilities depends on the bank's risk appetite and balance sheet.

Keywords: *interest rate risk in the banking book, IRRBB, retail bank, NII, EVE, interest rate swaps, scenario analysis, trade-off, optimum, BPV hedging, notional hedging*

Contents

Listing of figures

List of Tables

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Utrecht, February 2018

Laura Seidel

It is not knowledge, but the act of learning, not possession but the act of getting there, which grants the greatest enjoyment.

Carl Friedrich Gauss

1 Introduction

This chapter introduces the topic of the research. Firstly, background information is provided. Secondly, an elaboration is given on the research objective. Subsequently, the main research question is presented. The main research question is accompanied by several research sub-questions. Afterwards, the methodology applied to reach the research objective is described. The final section illustrates the outline of this paper.

1.1 Background

Asset and Liability Management (ALM) is a mechanism to address the risks faced by a bank that arise as a result of a mismatch between assets and liabilities due to liquidity and changes in interest rates. One of the central issues of ALM is to manage interest rate risk associated with long-term and non tradable assets and liabilities (Adam, 2008). ALM focuses on bank's earnings and value which aim to measure the interest rate risk in the banking book (Arnold, 2000).

The phrase *'interest rate risk in the banking book'* implies that the bank's position and its financial situation are sensitive to fluctuations in market interest rates. Interest rate risk in the banking book (IRRBB from hereon) and its complexity has remained unexplored, since before the financial crisis, the spotlight on the banking industry has been mostly on liquidity, capital conduct and regulatory scrutiny. However, this situation is changing. Management of the IRRBB has started to receive much more attention, after a long period in which other regulatory and risk management issues were prevailing in the banking world. Since not much emphasizes has been put on IRRBB from the part of regulators, banks developed their own approaches to manage and hedge IRRBB. It resulted in various internal models and diverse opinions.

Currently, regulators are considering standardizing the management of IRRBB to a certain extent. An example of a step taken in this direction are the reporting standards to IRRBB proposed by Basel Committee on Banking Supervision (BCBS) which were issued in April 2016 with the title: *"Standards on Interest Rate Risk in the Banking Book"*. The new reporting standards propose two perspectives on evaluating IRRBB: earnings and economic value. The earnings perspective focuses on the impact of interest rate movements on the net interest or accrued income of a bank over a time horizon of several years. This perspective is measured in terms of Net Interest Income (NII). The economic value perspective focuses on the impact of changes in interest rate movements on the value of an institution's asset, liabilities and off-balance sheet items. This perspective is measured in terms of Economic Value of Equity (EVE) (BCBS, 2016). These two perspectives are based on different concepts, yield different results and employ different interest rate risk strategies.

The earnings perspective captures the short-term effect of interest rate changes, whereas the economic value perspective captures the long-term effect of interest rate changes. Therefore, the two perspectives are considered complementary. As such, regulators require banks to disclose both metrics, in order to enable comparability. These two perspectives however follow different procedures and lead to different outcomes. Nevertheless, these two perspectives cannot be considered separately either. A pure focus on one could lead to destabilization of the alternative resulting in a trade-off.

Banks that are unaware of this trade-off may employ risk management hedging strategies that leads to undesirable results by increasing interest rate risk unintentionally.

Therefore, it would be helpful if this trade-off is investigated in more detail.

1.2 Research objective

The objective of this research is to investigate the relationship between the earnings and economic value volatilities by implementing risk management hedging techniques. In order to conduct the analysis, a model needs to be developed. The model should generate cash flows given a portfolio of a bank and output the relevant NII and EVE metrics, which measure respectively the earnings and economic value. Moreover, the model should also generate a hedge so that the earnings and economic value volatilities can be stabilized. In this way the relationship between the volatilities can be analyzed.

The existing academic literature on the relationship between earnings and economic value volatilities studied from the perspective of hedging techniques is very scarce if not non-existing. This study is an attempt to fill this gap.

1.3 Research question

In order to reach the research objective the following main research question is established:

"***How can the earnings volatility and economic value volatility be managed with hedging techniques?***"

The main research question will be answered with the help of several research sub-questions. The research sub-questions are as follows:

1. What does it mean to measure interest rate risk from earnings and economic value perspectives?
    1.1. What is IRRBB?
    1.2. What are the regulatory developments regarding IRRBB?
    1.3. How can IRRBB be quantified?

1.4. What are the differences and similarities between earnings and economic value perspectives?

2. What are the most important characteristics of a retail banking business?
3. Which hedging techniques can be used to hedge IRRBB?
4. How can a model that hedges earnings and economic value volatilities be constructed?
   4.1. Which inputs are necessary?
   4.2. What are the characteristics of these inputs?
5. What is the effect of hedging economic value volatility on earnings and earnings volatility?
6. Can an optimal balance be found between EVE and NII?

1.4 Methodology

The main research question is answered with the help of the research sub-questions. The first three research sub-questions aim to gather information in the form of a literature review and an expert opinion about interest rate risk, banking book and hedging techniques. The fourth research sub-questions embrace the construction of the model. At this stage a cash flow generator and hedging algorithm is developed. In order to develop the algorithm the knowledge gained by answering the previous sub-questions are used. Additionally, new information is gathered from experts and from existing literature to decide on the relevant inputs and its characteristics. The algorithm can be seen as a tool composed of various modules that interact with each other correspondingly. To construct the algorithm various models in banking are assumed, e.g. models for term structure of interest rates or prepayment risk. The algorithm is developed in such a way so it is flexible and adjustable to different data input and interest rate scenarios.

The resulting model projects NII and EVE measures given a portfolio of retail products as well as automatically generate a hedge. The un-hedged and hedged portfolio can then be assessed with respect to different scenarios, allowing the analysis of the trade-off between EVE and NII. The developed model is then applied on a hypothetical portfolio.

Finally, the last step taken to achieve the goal of this study is to find out if an optimal balance between earning and economic value can be achieved. This is done by a thorough analysis of the results and its comparison, thereby answering the fifth and sixth research question.

1.5 Thesis outline

The structure of this research is portrayed in figure 1.1. The first chapter introduced the reader to the topic and indicates why the research is conducted. The second chapter is the literature review which contains existing theory regarding IRRBB. This is followed by the third chapter, in which two IRRBB measures that captures earnings and economic value volatilities, namely NII and EVE, are analyzed. The fourth chapter is centered around the banking analysis and the fifth chapter explores the hedging techniques. In the sixth chapter, the model is developed using all the information from the previous chapters. The seventh chapter presents the results and the eighth chapter includes the discussion. The last chapter concludes and presents recommendations for further research.

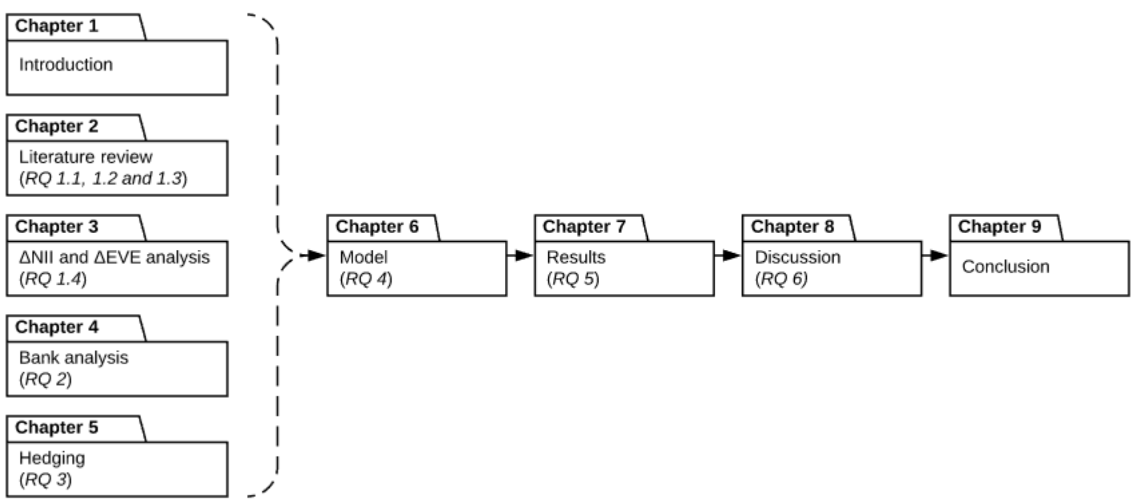

Figure 1.1: Research outline

If we knew what it was we were doing, it would not be called research, would it?

Albert Einstein

2 Literature Review

Interest rate risk in the banking book, otherwise known as IRRBB, is the central topic in this research. Therefore in this chapter, the concept is investigated in more detail. Firstly, IRRBB is defined. Secondly, the sources of its exposure are explained. Afterwards, the distinction between trading book and banking book is put forward. This is followed by an elaboration on the regulatory framework to IRRBB. Finally, IRRBB measurement techniques are explained.

2.1 IRRBB - definition

IRRBB can be defined as "*the current or prospective risk to the bank's capital and earnings arising from adverse movements in interest rates that affect the bank's banking book position*" (BCBS, 2016).

The BCBS definition of IRRBB states two important facts. The first one is that changes in interest rates affect the bank's capital. Changes in interest rates affect the present value of future cash flows. Interest rates are an important input variable for the discounting curve used to value the bank's assets, liabilities and off-balance sheet items. Consequently, the present value of future cash flows arising from the bank's assets, liabilities and off-balance sheet items are used to determine the economic value. The second fact is that changes in interest rates affect the bank's earnings. Changes in interest rates alter interest rate-sensitive income and expenses which are the input variables for calculating the net interest income of the bank.

Additionally, changes in interest rates affect the timing of future cash flows. Movements in interest rates may affect clients' behavior regarding prepayments and withdrawals. The timing of future cash flows has an impact on both bank's earnings and capital. Hence, IRRBB due to its potential impact on bank's current capital bases and future earnings ought to be managed adequately as it affect the bank's overall financial position (BCBS, 2016).

2.2 Sources of IRRBB

Three main sources of IRRBB can be distinguished. These are gap risk, basis risk and option risk. These constituents can take place concurrently and potentially impact the bank's earnings and economic value (BCBS, 2016). The sources of IRRBB are described below:

- Gap risk results "*from the term structure of banking book instruments, and describes the risk arising from the timing of instrument rate changes*" (BCBS, 2016). Gap risk in its definition compromises two other risks which are yield curve risk and repricing risk. Yield curve risk arises from shifts in the shape of the term structure of interest rates. These shifts may be parallel and non-parallel shocks and they do affect bank's earnings and value. Repricing risk is the risk that arises when assets and liabilities have different repricing tenors. For instance, a bank holding an asset that pays a fixed interest rate which is funded with a liability that reprices against 3 month Euribor. An increase in the interest rates would result in the funding becoming more expensive and shrinkage of the interest margin.
- Basis risk is defined as "*the impact of relative changes in interest rates for financial instruments that have similar tenor but are repriced using different interest rate in-*

dices" (BCBS, 2016). This risk arises from the lack of perfect correlation between reference rates used to adjust interest rates received and paid on different instruments with otherwise similar repricing characteristics. In case of similar repricing charactistics but different reference rates, changes in interest rates may lead to unexpected changes in the cash flows between assets, liabilities and off-balance sheet items (Noorali & Santos, 2005; BCBS, 2004; Bohn & Elkenbracht-Huizing, 2014). For instance, funding one-year loan that reprices monthly based on one-month US Treasury bill rate with one-year deposit that reprices monthly based on one-month LIBOR may result in unexpected changes in the spread between the two reference rates (BCBS, 2004).

- Option risk arises from embedded options included in the assets, liabilities and off-balances sheet items (BCBS, 2016). An option is a financial instrument that provides the holder the right but not the obligation to buy or sell the underlying asset (Hull, 2012). In the context of IRRBB, it refers to prepayment and withdrawal options. Prepayment option designates any early principal repayment made in excess of the regular repayment schedule (Martellini et al., 2003). Withdrawal option refers to the possibility of lowering or increasing at any time the balance on a non-maturing deposit (Frachot, 2001). Changes in interest rates triggers the exercise of such options. In this way the client can influence the magnitude and timing of the cash flows and thus influence the level of interest rate risk the bank is exposed to (BCBS, 2016; Noorali & Santos, 2005).

2.3 Distinction between trading book and banking book

The balance sheet of a bank is divided into two parts: the trading book and the banking book. The trading book consists of all the operation accounted for in marked-to-market that come from the trading business. The banking book holds positions that are recorded on accrued basis and which are meant to be held to maturity (Adam, 2008). The risks that these two books are exposed to are measured differently and treated differently by regulators. Interest rate risk in the trading book is part of the standardized Pillar I approach in the Basel framework. The interest rate risk in the banking book is captured in the enhanced Pillar II approach of Basel. The difference between these two books enables the understanding of the interest risk in the banking book and the motivation of regulators to establish standards on IRRBB reporting. The main differences between the trading book and banking book are the following.

Firstly, one of the most important differences is that banking book positions are held to maturity and are held on an accrual basis on the balance sheet. On the other hand, items on the trading book are held on an economic value basis (market value). This means that a loss in economic value for items in the banking book does not always have to be a problem, since it will not be traded.

Secondly, interest rate risk in the banking book is fundamentally different to interest rate risk in the trading book. Trading book positions, assuming liquidity, can be adjusted or closed at any time. It implies that the management of daily activities can be easily delegated. In case the senior management is not satisfied with the risk level in the trading positions it can be adjusted or reversed quickly. Contrarily, banking book positions represents what the bank does as a bank and the full closure of banking book positions is not an option if the bank wants to remain in business. Thus, more senior management involvement takes place. As a companion, banking book positions are not liquid, meaning that they cannot be easily adjusted (Newson, 2017).

Thirdly, the degree of usage of sophisticated mathematical modeling differs. In case of trading book, complex mathematical techniques are highly important as a small change in market rates may significantly impact the trading positions. This effect can however be precisely quantified since the trading positions are contractual. In contrast, mathematical models used to measure IRRBB serve to inform judgment and wider decision making process. Risk management estimates the probability of suffering from adverse changes in interest rates and the decision on whether it is worth taking the risk is made. Moreover, analyzing banking book positions through trading book models would overestimate one risk and underestimate or miss another. Even relying exclusively on models designed specifically for IRRBB has dangers unless the assumptions underlying such models are fully understood and subject to regular challenge (Newson, 2017).

Finally, there is a crucial difference between pricing the trading book products and banking book products. The pricing of banking book products is not solely based on the market interest rates, but based on judgment of senior management and assumptions made about customer and competitor behavior. The assumptions that support IRRBB control and measurement should be in line with the assumptions made to run the daily business of the bank. As already mentioned, senior management is more involved in the management of IRRBB (Newson, 2017).

2.4 Regulatory framework

This section presents two regulatory bodies involved in the attempt of standardizing the IRRBB framework. Additionally, the development in the IRRBB regulation is delineated.

2.4.1 Regulatory bodies

Basel Committee for Banking Supervision

The Basel Committee for Banking Supervision (BCBS) is a global organization that set standards for prudential regulation of banks and provides a forum for cooperation on banking supervisory matters. The aim of BCBS is to strengthen the regulation, supervision and practices of bank worldwide with the purpose of enhancing financial stability. Although, BCBS determines minimum standards and promotes best practices to improve cross-border cooperation, the decisions of the organization do not have legal force (BIS, 2017).

European Banking Authority

The European Banking Authority (EBA) is an independent EU Authority which aim to ensure effective and consistent prudential regulations and supervision within the European banking sector. EBA was created on 1 January 2011 as part of the European System of Financial Supervision (ESFS). The objectives of EBA are to maintain financial stability within EU and to safeguard the integrity, efficiency and orderly functioning of the banking sector. The main tasks of EBA are: to contribute to the formation of the European Single Rulebook with single set of harmonized prudential rules for financial institutions across the EU; to promote convergence of supervisory practices; and to assess risks and vulnerabilities in the EU banking sector (EBA, 2017).

2.4.2 Development in IRRBB regulation

The "*Principles for the Management and Supervision of Interest Rate Risk*" published in 2004 are the first regulatory guidelines on IRRBB. This publication defines the sources and effects of IRRBB and also establishes 15 principles on management of IRRBB. In 2006 Committee of European Banking Supervision (CEBS) published "*Technical aspects of the management of interest rate risk arising from non trading activities under the supervisory review process*". In this document CEBS specifies further the BCBS guidelines on IRRBB. In 2012 BCBS published consultation document titled "*Fundamental Review of the Trading Book*" in which capital charges for IRRBB are discussed and potential capital arbitrage due to inconsistent risk measurement is presented. In that same year, CEBS transit into EBA. In 2013 EBA issued a consultation paper proposing changes to the existing guidelines. This consultation paper included scenarios, stress testing, methods to measure IRRBB, governance and capital for IRRBB. In June 2015 BCBS issued another consultation document on IRRBB. In May 2015 EBA published final guidelines on management of interest rate risk for non-trading activities. The standard procedure for Europa consisted of BCBS issuing worldwide standards that are detailed by EBA for EU implementation. In 2015 a deviation of this standard procedure occurred when EBA publishes updated guidelines while BCBS was still in consultation phase.

The BCBS final standards on the IRRBB were published on April 21, 2016. These standards replaced the Principles for the Management and Supervision of Interest Rate Risk from July 2004 and build up on the consultation phase from 2015. The final reporting standards include and reflect the feedback gained during the consultation phase. The most relevant feedback was the inadequate measurement of IRRBB using a standardized approach because it does not take into account the heterogeneous and complex nature of the different institutions. Mainly in terms of business models, risks and processes used to manage them. The attempts to define Pillar 1 capital framework for IRRBB did not succeed. The final reporting standards have the purpose to develop an industry-wide benchmark. The final reporting standards are expected to be implemented by 2018.

2.5 IRRBB measurement techniques

IRRBB can be measured from the perspective of earnings and economic value. The earnings perspective focuses on the impact of changes in interest rates on the net interest income of the bank over a short time horizon, usually of one to three years. The economic value perspective focuses on the impact of changes in interest rates on the assets, liabilities and off-balance sheet instruments over a long-term time horizon. The earnings perspective has been the traditional approach used by banks to evaluate their interest rate risk positions, particularly in retail bank. Yet, this perspective does not take into account the effects that might take place beyond its short-time horizon. Therefore, banks adequately measure their interest rate risk exposure taking into consideration both perspectives (Bohn & Elkenbracht-Huizing, 2014). Several measurement techniques exist to analyze the interest rate risk exposure of a bank, both in terms of earnings and economic value perspectives. These methods are explained in the following sub sections. The BCBS final reporting standards emphasizes delta NII and delta EVE as adequate measures of IRRBB (BCBS, 2016).

2.5.1 Earnings-based risk metrics

The most commonly used techniques that fall under the umbrella of earnings perspective metrics are gap analysis and ΔNII.

Gap analysis

Gap analysis is one of the most traditional techniques which is still commonly used by financial institutions. It allocates assets, liabilities and off-balance sheet items to time buckets in accordance to their repricing characteristics (Hull, 2012). The net difference in a specific bucket is the net exposure to changes in interest rates. Gap analysis is characterized by its simplicity and as a consequence has also several disadvantages. Its first disadvantage is the fact that gap analysis is a static model which means that it does not take into account the behavioral aspects of retail products such as prepayments and withdrawals. These may vary as a result of changes in interest rates and consequently alter substantially the exposure to interest rate risk. The second disadvantage is that it does not take into account the yield curve risk and basis risk. To account for these risk additional analysis need to be performed. The third shortcoming is that this analysis is based on the assumptions that all positions reprice at the same time. This assumption is simplistic as in practice banks hold position which reprice asynchronously. The fourth main disadvantage is that this analysis does not take into consideration the changes in the bank's spreads (DNB, 2005). Finally, the result of the gap analysis is not represented in the form of a single number which disables comparison between banks.

ΔNII

ΔNII measures the impact of changes in interest rates on the net interest income. ΔNII is measured over a short-term time horizon usually up to three years. This method considers parallel as well as non-parallel shifts in the yield curve. It is a simulation method. This method is also more dynamic. It takes into account repricing risk and behavioral risk. Assumptions are made regarding retail products with embedded options. Under this method a base interest rate scenario is estimated and from this scenario net interest income is calculated. Subsequently, alternative interest rate scenarios are developed based upon assumed interest rate sensitivity. The NII from the alternative scenarios are compared with the NII of the base scenario. In this manner the ΔNII (NII at risk) is determined. The NII approach has several advantages. This approach is dynamic as it takes into account the behavioral aspects linked to prepayment risk and non-maturing deposits; and takes into account new business. Secondly, it takes into account both the parallel and non-parallel shifts in the yield curve. However, this technique also has few drawbacks. Firstly, it only considers the short-term impact on earnings resulting from changes in interest rates. Secondly, it relies heavily on assumptions, in terms of behavioral modeling and new production which may be complex and non-transparent (DNB, 2005).

2.5.2 Economic-value-based risk metrics

The most commonly used techniques that fall under the umbrella of economic value perspective are duration of equity and ΔEVE.

Duration of equity

Another traditional method to measure the interest rate risk exposure in the banking book is the duration of equity. Modified duration measures the change in price of a financial instrument or in the value of a portfolio as a consequence to parallel shifts in the interest rates. From modified duration it is possible to derive the price value of a basis point (PV01) measurement which shows the change in price resulting from a one basis point (0.01%) shift in the yield curve in terms of monetary units. In order for modified duration and PV01 to be applied to the total portfolio of a banking book, similarly as in gap analysis, all interest rate sensitive assets, liabilities and off-balance sheet items are allocated to time buckets. After that a yield curve is selected and a benchmark duration per maturity is estimated. The modified duration per time bucket is then calculated by multiplying the benchmark maturity with the given position in the time bucket assuming shift of 0.01% in the interest rates. The impact due to changes in interest rates on economic value of equity is then computed as the sum of all assets, liabilities and off-balance sheet instruments. The advantage of this method is its simplicity which consequently brings few drawbacks. The first drawback is that the duration of equity method only applies to parallel shifts in the yield curve implying that it misses to capture the basis risk and yield curve risk which arises due to non-parallel shifts. Secondly, it is a static method. It is based on the current state of the balance sheet of a bank and thus falls short to consider new business or applying mitigation strategies. Thirdly, it fails to take into account the behavioral nature of embedded options in financial retail products (DNB, 2005; BCBS, 2016).

ΔEVE

ΔEVE measures the impact of changes in the interest rates on the market value of equity. This approach considers parallel and non-parallel shifts in the interest rates. It also takes into consideration the behavioral risk that arises as consequence of embedded options in the retail products. EVE is also a simulation approach. In the EVE approach, firstly a base interest rate scenario is developed. Under the base scenario the EVE is computed which equals to the present value of assets minus liabilities. After that, alternative interest rate scenarios are developed and the EVE is recalculated under these scenarios and compared with the EVE of the base scenario. The EVE approach is substantially dependent on the assumption used to forecast the future cash flows and the discount rates used. The EVE model has the following advantages. Firstly, the interest rate risk is measured in terms of economic value. Secondly, this method takes into account basis risk and parallel as well as non-parallel shifts in interest rates. This method has also its disadvantages. The first disadvantage is that the asset and liabilities in the banking book are valued on a mark-to-model basis which implies using theoretical pricing models. This is so due to the fact that banking book items cannot be traded and thus are difficult to value at market prices. The second drawback is that EVE is a static approach meaning the analysis is based on the current state of the banking book portfolio. It does not take into account new business (DNB, 2005; BCBS, 2016).

2.6 End of chapter summary

The focus of this chapter was on IRRBB. The following research questions have been answered:

What is IRRBB?

IRRBB in this research is defined according to the definition proposed by the BCBS final reporting standards as the current or prospective risk to the bank's earnings and economic value as a consequence of adverse movements in interest rates.

What are the regulatory developments regarding IRRBB?

Recently, the management of IRRBB has started to receive much more attention from the part of regulators. Attempts have been made to standardize the management of IRRBB to a certain extent. The result of those attempts are the final reporting standards to IRRBB proposed by BCBS. The two regulatory bodies involved in setting common standards to IRRBB are BCBS, on global level, and EBA, on European level.

How can IRRBB be quantified?

IRRBB can be measured from both earnings and economic value perspectives. Several measurement techniques can be distinguished to measure IRRBB from each perspective. From the earnings perspective IRRBB can be measured in terms of gap analysis and ΔNII. From the economic value perspective IRRBB can be measured in terms of duration and ΔEVE. In this research IRRBB is measured in terms of ΔNII and ΔEVE as prescribed by the BCBS final reporting standards. Both measurements will be investigated more thoroughly in the next chapter.

Details create the big picture.

Sanford I. Weill

3

ΔNII and ΔEVE Analysis

The purpose of this chapter is to analyze the aspects that need to be taken into consideration in the calculation of ΔNII and ΔEVE. The chapter starts with an elaboration on the required input parameters for the computation of NII and EVE. To compute the deltas of these measurements, scenarios are required. These scenarios will be described in the third section. Finally, a numerical example of computing ΔNII and ΔEVE is given.

3.1 Input variables

This section describes the input variables and their differences used in the computation of NII and EVE.

3.1.1 Cash flows

NII is defined as the difference between the interest rate revenues and interest rate expenses. For the purpose of computing NII, the bank should include expected cash flows from all interest rate sensitive assets, liabilities and off-balance sheet items (BCBS, 2016). In connection with this, coupon cash flows are used to calculate NII. Repayment cash flows and prepayments cash flows are excluded. Contrary to EVE, the cash flows used to calculate NII are not discounted. NII can be illustrated with the following equation:

$$NII = \left(\sum_{t=1}^{T} \sum_{i=1}^{A} CouponCF_{t,assets(i)} - \sum_{t=1}^{T} \sum_{j=1}^{L} CouponCF_{t,liabilities(j)} \right) \tag{3.1}$$

Where T in months is either *12*, *24* and *36* for the first year, second year and third year respectively. Moreover, i is the index of an asset till the maximum of A and j is the index of a liability till the maximum of L

EVE can be seen as the present value of liabilities subtracted from the present value of assets. For the purpose of calculating EVE, a bank should include all cash flows from all interest rate sensitive assets, liabilities and off-balance sheet items (BCBS, 2016). Therefore, the input variables taken into account to calculate EVE are the principal cash flows which include repayment cash flows, prepayment cash flows and coupon cash flows. Interest rate cash flows and coupon cash flows are used interchangeably in this research, similarly as principal cash flows and notional cash flows. In mathematical terms, EVE can be represented as follows:

$$EVE = \left(\sum_{t=1}^{T} \sum_{i=1}^{A} DCF_{t,assets(i)} - \sum_{t=1}^{T} \sum_{j=1}^{L} DCF_{t,liabilities(j)} \right) \tag{3.2}$$

Where t is the time in months. Moreover, i is the index of an asset till the maximum of A and j is the index of a liability till the maximum of L. Notice that the corresponding total cash flows are discounted with an appropriate discount curve. This curve is discussed in the next section.

3.1.2 Discount curve

For the purpose of calculating EVE the corresponding cash flows are to be discounted. The final reporting standards on IRRBB (BCBS, 2016) indicate that cash flows are to be discounted with either the risk free curve or risk adjusted curve. The risk adjusted curve is the risk free rate including commercial margins and other spread components. In this research the choice is made to discount with the risk adjusted curve. Mathematically, the discount factor (d_t) at time t in months can be represented as follows:

$$d_t = \frac{1}{(1 + r_t + s_t)^{t/12}} \tag{3.3}$$

Where:

- r_t stands for risk free rate at time t
- s_t stands for spread of a given retail product at time t

The choice is made to discount with the risk adjusted curve, because the aim is to include the full value. EVE represents the value, the price of the whole portfolio or the price of a given product that one is willing to pay for. Therefore, it should include all components of the cash flows. By using risk free rate as discount rate, the cash flows are being stripped from the components that carry value. Furthermore, another reason for this choice is that the commercial margin component is also exposed to interest rate risk.

3.1.3 Time horizon

NII is a short to medium term measure. BCBS (2016) prescribes to disclose NII for a 12-months period. In this research a time period of 3 years is used on a monthly time scale. The reason is twofold. Firstly, a horizon of 3 years is deemed appropriate for internal purposes and is the one most used in practice. Secondly, a longer time horizon gives a better picture on changes to NII. The calculation of NII consists of three outcomes: NII for the first year, the accumulated NII for the first and second year and the accumulated NII for the first, second and third year. Thus, T is 12, 24 and 36 respectively in equation 3.1.

EVE, on the other hand, is a long term measure. It is calculated over the remaining life of the bank's assets liabilities and off- balance sheet items. In this research a period of 30 years is assumed. Therefore, T is 360 months in equation 3.2.

3.1.4 Time buckets

All the projected cash flows arising from interest rate sensitive assets, liabilities and off-balance items are allocated linearly to 19 time buckets based on their contractual maturities. The different time buckets are represented in Figure 3.1.

Short-term rates	Overnight (0.0028Y)	O/N< t^{CF} ≦1M (0.0417Y)	1M< t^{CF} ≦3M (0.1667Y)	3M< t^{CF} ≦6M (0.375Y)	6M< t^{CF} ≦9M (0.625Y)	9M< t^{CF} ≦1Y (0.875Y)	1Y< t^{CF} ≦1.5Y (1.25Y)	1.5Y< t^{CF} ≦2Y (1.75Y)
Medium-term rates	2Y< t^{CF} ≦3Y (2.5Y)	3Y< t^{CF} ≦4Y (3.5Y)	4Y < t^{CF} ≦ 5Y (4.5Y)	5Y< t^{CF} ≦6Y (5.5Y)	6Y< t^{CF} ≦7Y (6.5Y)			
Long-term rates	7Y< t^{CF} ≦8Y (7.5Y)	8Y < t^{CF} ≦ 9Y (8.5Y)	9Y < t^{CF} ≦ 10Y (9.5Y)	10Y< t^{CF} ≦ 15Y (12.5Y)	15Y< t^{CF} ≦ 20Y (17.5Y)	t^{CF} > 20Y (25Y)		

Figure 3.1: Time bucket intervals.
Source: BCBS (2016)

The time buckets are not required for the computation of EVE and NII but are relevant if one wishes to assess the interest rate risk exposure through a bucket analysis and for hedging purposes.

3.1.5 Balance sheet assumption

The balance sheet of a bank is important for the computation of EVE and NII, since asset and liability products are required in order to estimate cash flows. In the next chapter, a more thorough discussion is given regarding the balance sheet. For now, it is important to understand that both NII and EVE have different assumptions concerning the balance sheet.

NII assumes a constant balance sheet which takes into account new business. Existing banking book positions when matured are replaced by products with similar characteristics in terms of principal amount, coupon rates, repricing periods and spread components. EVE, on the contrary, assumes a run-off balance sheet where existing banking book positions amortize, mature and are not replaced by new business.

3.2 ΔNII and ΔEVE

The exposure to IRRBB in terms of the measures EVE and NII is determined with scenario analysis. Firstly, a base case scenario is determined. A base scenario should reflect the assumptions regarding business development and customer behavior incorporated into the institution's business plans (EBA, 2015). Secondly, alternative scenarios are developed in which the interest rates are shocked. The exposure is then determined by subtracting the base case scenario from the alternative scenario. The difference leads to ΔNII and ΔEVE, where s is a shocked scenario:

$$\Delta NII_s = NII_s - NII_0 \tag{3.4}$$

$$\Delta EVE_s = EVE_s - EVE_0 \tag{3.5}$$

Reporting standards from 2016 advice banks to use six prescribed interest rate shock scenarios to capture parallel and non-parallel gap risk for EVE and two prescribed interest rate scenarios for NII (BCBS, 2016). These shock scenarios will be examined in the next section.

3.3 Interest rate scenarios

The prescribed interest rate scenarios for EVE are the following: parallel shock up, parallel shock down, steepener, flattener, short rates shock up and short rates shock down. The prescribed interest rate scenarios for NII are: parallel up and parallel down. In this research all scenarios are applied to both EVE and NII. All scenarios and their assumptions are described in the following sub-sections. The interest rate scenarios have an effect on the behavioral risk: prepayment risk and redemption risk. This research investigates prepayment risk but omits redemption risk.

3.3.1 Parallel shock up

Description: Parallel shock up refers to constant parallel increase across all time points meaning that each point on the yield curve increases with the same amount. In this scenario a 200 bps shift is applied.

Assumptions: Assumptions are made regarding prepayments. Prepayment speed vary according to the interest rate shock scenarios. Prepayments are expected to be lower during periods of raising interest rates. The expectation is based on the fact that during periods of raising interest rates no advantage can be taken from refinancing with lower interest rates. This assumption is reflected in the prepayment model for this scenario. The reporting standards prescribe that the conditional prepayment rate for fixed loans should decrease with 20%. The metric for the prepayment rate is only applied to mortgages and bullet loans with fixed interest rate as floating interest rates move in line with the term structure of interest rates. This assumption is reflected in the prepayment formula as follows:

$$p_t = \begin{cases} 0.8 \times SMM + \varepsilon, & \text{if C = fixed.} \\ SMM + \varepsilon, & \text{if C = float.} \end{cases} \tag{3.6}$$

where *SMM* stands for single monthly mortality which is the monthly equivalent of *CPR* (conditional prepayment rate).

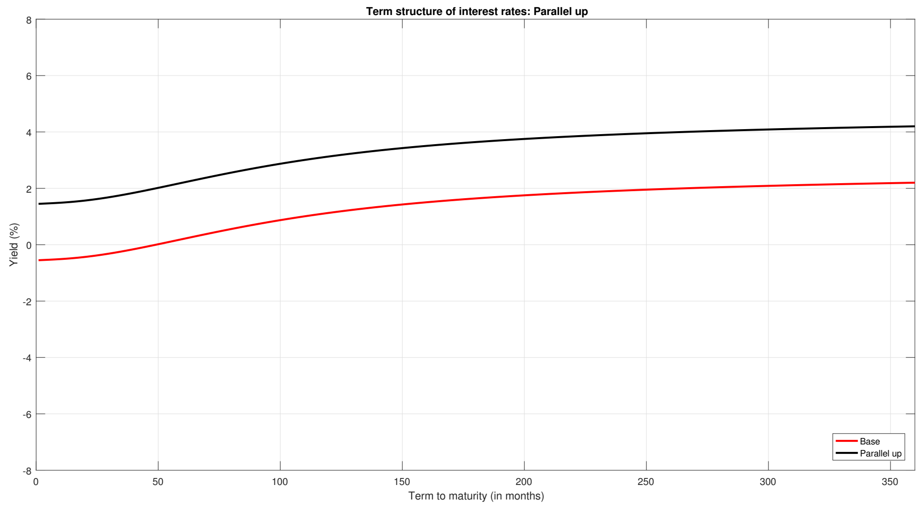

Figure 3.2: Parallel shock up

3.3.2 Parallel shock down

Description: Parallel shock down refers to a constant parallel shock down across all time buckets meaning that each point on the yield curve decrease with the same amount. In this scenario a 200 bps shift down is applied.

Assumptions: Prepayments are expected to be higher during periods of falling interest rates. This expectation is the result of advantageous situation to refinance with lower interest rates for the product holder. The reporting standards propose to account for this expectation by increasing the conditional prepayment rate with 20%. This increase only applies to fixed interest rate assets as floating interest rate assets move in line with the changes in the yield curve. This assumption is reflected in the prepayment formula as follows:

$$p_t = \begin{cases} 1.2 \times SMM + \varepsilon, & \text{if C = fixed.} \\ SMM + \varepsilon, & \text{if C = float.} \end{cases} \tag{3.7}$$

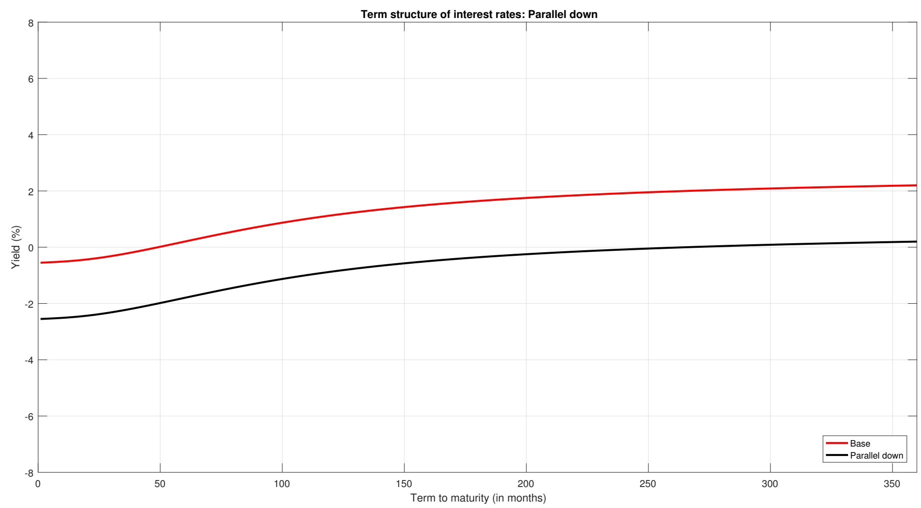

Figure 3.3: Parallel shock down

3.3.3 Steepener

Description: In this scenario interest rates for shorter maturities move down and interest rates for longer maturities move up.

Assumptions: It is assumed that the conditional prepayment rate decreases. The interest rates are rising therefore, there is no opportunity for refinancing with lower interest rates in the long term. This expectation is reflected by decreasing the rates by 20% as prescribed by the reporting standards. It can be seen in the formula below:

$$p_t = \begin{cases} 0.8 \times SMM + \varepsilon, & \text{if C} = \text{fixed.} \\ SMM + \varepsilon, & \text{if C} = \text{float.} \end{cases} \tag{3.8}$$

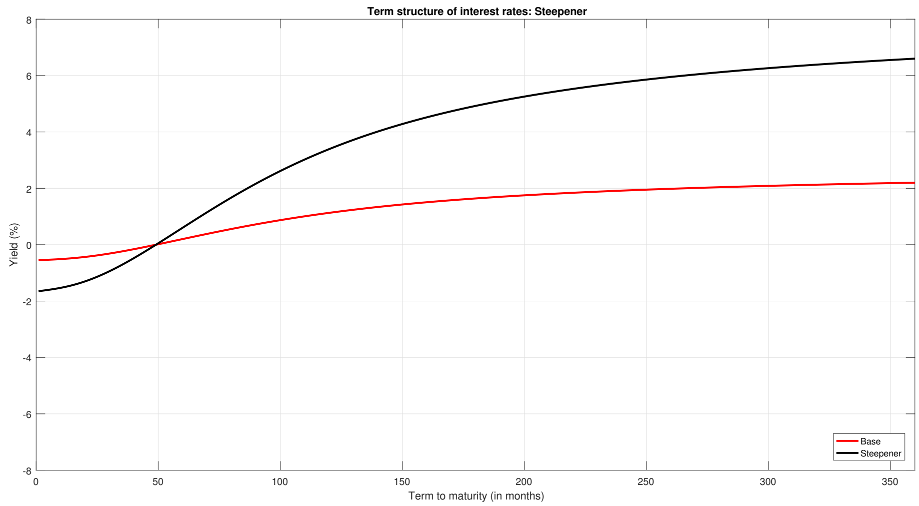

Figure 3.4: Steepener

3.3.4 Flattener

Description: In this interest rate scenario rates for shorter maturities move up and rates for longer rates move down.

Assumptions: In this scenario the prepayments are expected to increase. This is reflected by adjusting accordingly the conditional prepayment rates:

$$p_t = \begin{cases} 1.2 \times SMM + \varepsilon, & \text{if C} = \text{fixed.} \\ SMM + \varepsilon, & \text{if C} = \text{float.} \end{cases} \tag{3.9}$$

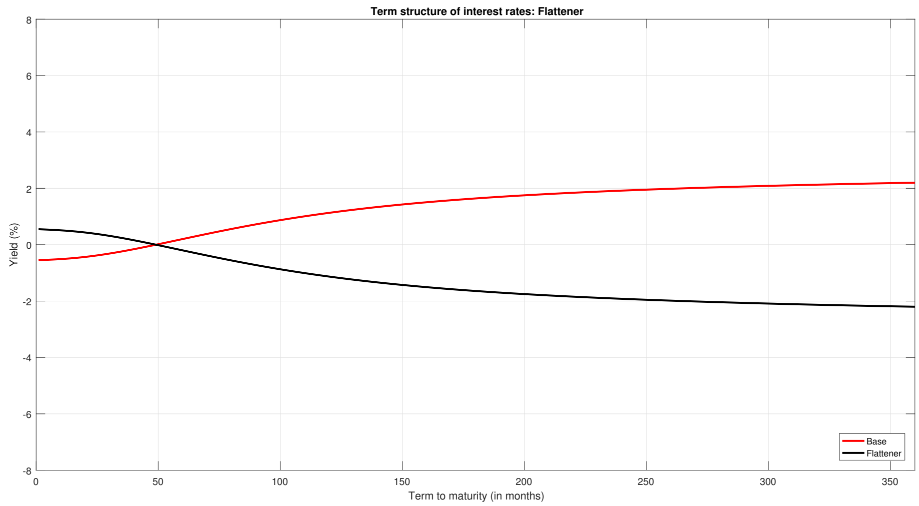

Figure 3.5: Flattener

3.3.5 Short rates shock up

Description: This scenario only affects the short term interest rates by increasing them whereas the long term interest rates remain the same. The prepayment rate changes however.

Assumptions: In this case the conditional prepayment rate decreases.

$$p_t = \begin{cases} 0.8 \times SMM + \varepsilon, & \text{if C = fixed.} \\ SMM + \varepsilon, & \text{if C = float.} \end{cases} \tag{3.10}$$

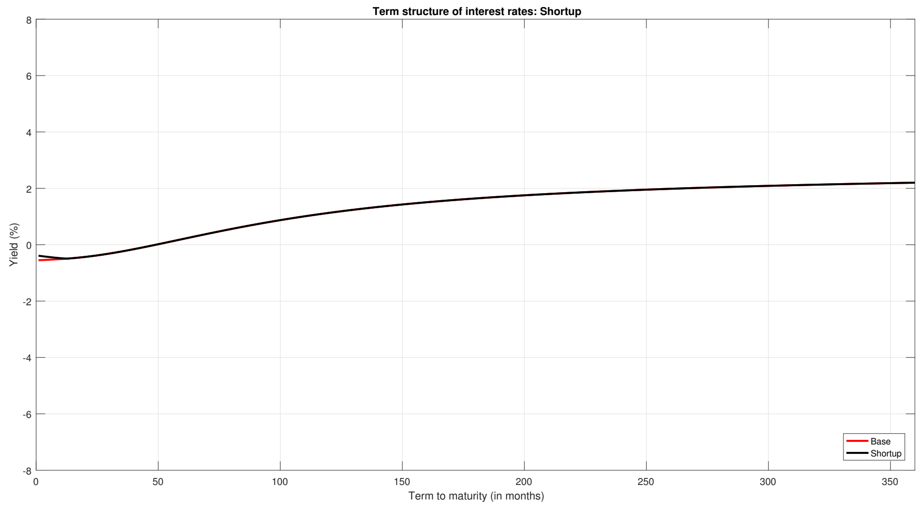

Figure 3.6: Short rates shock up

3.3.6 Short rates shock down

Description: Short rate shock down this scenario only affects the short term interest rates by decreasing them whereas the long term interest rates remain the same. The prepayment rate changes however.

Assumptions: In this case the conditional prepayment rate increases.

$$p_t = \begin{cases} 1.2 \times SMM + \varepsilon, & \text{if C = fixed.} \\ SMM + \varepsilon, & \text{if C = float.} \end{cases} \tag{3.11}$$

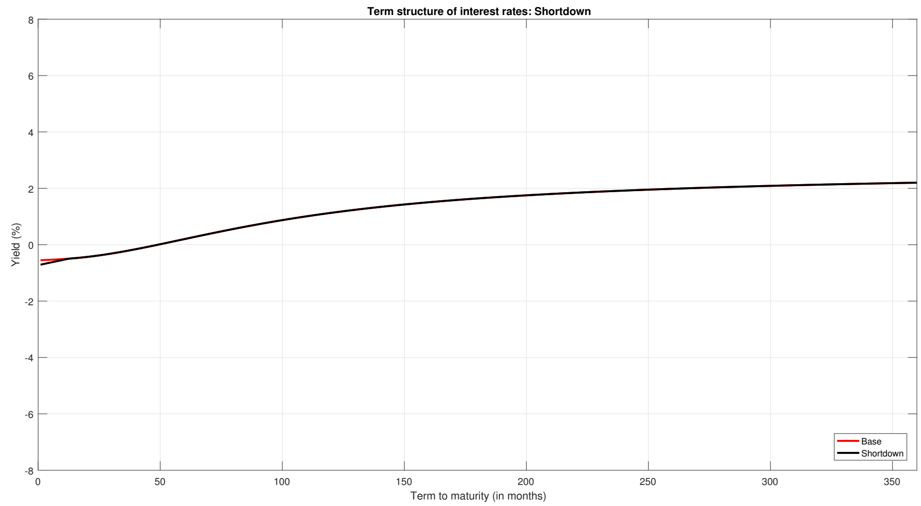

Figure 3.7: Short rates shock down

The corresponding conditional prepayment rate (CPR) multipliers for each interest rate shock scenario prescribed by the final reporting standards are illustrated in Table 3.1.

Scenario	CPR multiplier
Parallel-up	0.8
Parallel-down	1.2
Steepener	0.8
Flattener	1.2
Short rate up	0.8
Short rate down	1.2

Table 3.1: Interest rate scenarios and multipliers

3.4 Numerical examples

This section will present two numerical examples for respectively the computation of ΔNII and ΔEVE. Both examples uses a simple balance sheet as presented in Table 3.2.

Asset		**Liability**	
Bullet loan		**Non-maturing deposit**	
- *Notional*	100	- *Notional*	100
- *Maturity*	5 years	- *Maturity*	5 years
- *Coupon (fixed)*	5%	- *Coupon (floating)*	
Risk free rate	(2%)	*Reprices annually*	(2%)
Interest margin	(3%)	*Interest margin*	(0.75%)[*]

Table 3.2: Simple balance sheet

On the asset side there is a bullet loan with notional of 100, contractual maturity of 5 years and fixed coupon rate of 5%. The coupon is structured with 2% risk-free rate and 3% interest margin. For simplicity, it assumed that the loan is not exposed to prepayment risk. This loan is funded with a non-maturing deposit with floating interest rate that reprices annually. Due to historical observation such a non-maturing deposit can be treated as a long-term deposit thus the volume of its notional is to be assumed 100 for the next 5 years. [†] The risk-free rate for the next period is known to be 2%. It is also assumed that each year the rate reprices to 2% consistently. The interest margin for the non-maturing deposit is 0.75%.

3.4.1 Example: Calculation ΔNII

The coupon cash flows are required for the computation of NII. For the bullet loan asset, the coupon cash flows are derived by multiplying the coupon rate 5% (2% + 3%) with the notional 100. For the deposit, the notional 100 is multiplied with the repricing

[*] It is common for the interest margin to be lower than the market rate (risk free rate). Currently, however, in the negative interest rate environment it is not the case as banks take a margin on savings and loans. However, for simplicity in this example positive market rates are assumed.

[†] A common approach adopted by banks to model the evolution of the balance of non-maturing deposits is the replicating portfolio.

coupon rate, which is 2.75% (2% + 0.75%) each year. The results are shown in Table 3.3.

T (in years)	**1**	**2**	**3**	**4**	**5**
Coupon CF asset (in EURO)	5	5	5	5	5
Coupon CF liability (in EURO)	2.75	2.75	2.75	2.75	2.75
Asset - liability (in EURO)	**2.25**	**2.25**	**2.25**	**2.25**	**2.25**

Table 3.3: Coupon cash flows

The NII under the base scenario is as follows: $NII_{0_I} = 2.25$, $NII_{0_{II}} = 2.25 + 2.25 = 4.50$, $NII_{0_{III}} = 2.25 + 2.25 + 2.25 = 6.75$. The bank has an asset that pays fixed interest rates and a liability with a floating interest rate that reprices annually. Therefore, the bank is exposed to an increase in the interest rates.

Lets assume a parallel shocked scenario in which the interest rate increases by 200bps. Since the bullet loan asset reprices at maturity in five years, the coupon rate for the bullet loan remains unchanged. For the demand deposit however, the coupon rate reprices annually, meaning that the coupon rate will change to $2.75\% + 2\% = 4.75\%$. The new coupon cash flows are shown in Table 3.4.

T (in years)	**1**	**2**	**3**	**4**	**5**
Coupon CF asset (in EURO)	5	5	5	5	5
Coupon CF liability (in EURO)	4.75	4.75	4.75	4.75	4.75
Asset - liability (in EURO)	**0.25**	**0.25**	**0.25**	**0.25**	**0.25**

Table 3.4: Coupon cash flows in a shocked scenario

The NII under this scenario is as follows: $NII_{s_I} = 0.25$, $NII_{s_{II}} = 0.25 + 0.25 = 0.50$, $NII_{s_{III}} = 0.25 + 0.25 + 0.25 = 0.75$. Consequently, ΔNII can be computed using equation 3.4 which result in the following: $\Delta NII_{s_I} = 0.25 - 2.25 = -2$, $\Delta NII_{s_{II}} = 0.50 - 4.50 = -4$, $\Delta NII_{s_{III}} = 0.75 - 6.75 = -6$. The interest rate received on the loan remained the same but the interest rate on the deposit increased by 2% which resulted in lower interest margin and economic loss.

3.4.2 Example: Calculation ΔEVE

For the purpose of calculating EVE, all cash flows are included. In this case the coupon cash flows as well as the notional amount. Furthermore, discounting is necessary. As indicated in section 3.1.2 to account for all the components that carry value the discounting for EVE is performed with the risk-adjusted curve. The total discounted cash flows are presented in Table 3.5.

T (in years)	**1**	**2**	**3**	**4**	**5**
Total CF asset (in EURO)	5	5	5	5	105
Discount factor (with 5%)	0.95	0.91	0.86	0.82	0.78
Total DCF asset (in EURO)	**4.76**	**4.54**	**4.32**	**4.11**	**82.27**
Total CF liability (in EURO)	2.75	2.75	2.75	2.75	102.75
Discount factor (with 2.75%)	0.97	0.95	0.92	0.90	0.87
Total DCF liability (in EURO)	**2.68**	**2.60**	**2.54**	**2.47**	**89.72**
Asset - liability (in EURO)	**2.09**	**1.93**	**1.78**	**1.65**	**-7.45**

Table 3.5: Total cash flows

Under the base scenario the EVE is as follows: $EVE_0 = (2.09+1.93+1.78+1.65-7.45) = 0$.

Now lets assume a shocked scenario in which the interest rate increases by 200bps. Both discounting factors for the bullet loan and demand deposit are influenced. Also, the cash flow for the liabilities changes because of the repricing. This is shown in Table 3.6.

T (in years)	**1**	**2**	**3**	**4**	**5**
Total CF asset (in EURO)	5	5	5	5	105
Discount factor (with 7%)	0.93	0.87	0.82	0.76	0.71
Total DCF asset (in EURO)	**4.67**	**4.37**	**4.08**	**3.81**	**74.86**
Total CF liability (in EURO)	4.75	4.75	4.75	4.75	104.75
Discount factor (with 4.75%)	0.95	0.91	0.87	0.83	0.79
Total DCF liability (in EURO)	**4.53**	**4.33**	**4.13**	**3.95**	**83.06**
Asset - liability (in EURO)	**0.14**	**0.04**	**-0.05**	**-0.13**	**-8.19**

Table 3.6: Total cash flows in a shocked scenario

The EVE under the shocked scenario is as follows: $EVE_s = (0.14+0.04-0.05-0.13-8.19) = -8.20$. The ΔEVE is the following: $\Delta EVE_s = -8.20 - 0 = -8.20$. An increase in the interest rate of 2% led to a decrease in the economic value from 0 to -8.20.

3.5 End of chapter summary

This chapter covered in detail the aspects needed to be taken into account while computing NII and EVE. This chapter had the objective to answer the following research sub-question:

What are the differences and similarities between earnings and economic value perspectives?

The main similarity between earnings and economic value perspective is that they measure the same thing, which is IRRBB. However, the methodologies these two perspectives employ to measure IRRBB are different. They are based on different concepts, use different inputs, are based on different methodologies and lead to different results. The objective of the earnings perspective is to preserve the earnings level. The earnings perspective is measured in terms of NII. The inputs used are the coupon cash flows which are not discounted. The earnings perspective assumes short-time horizon and constant balance sheet. The objective of the economic value perspective is to maintain the value of the bank. The inputs used are all cash flows which consequently are discounted. The economic value perspective assumes long-term horizon and run-off balance sheet.

The main differences between the two perspectives are highlighted in Table 3.7.

	NII	**EVE**
Objective	Maintaining earnings level	Maintaining value of a bank
Cash flows	Coupon cash flows	All cash flows: *Coupon cash flows* *Repayment cash flows* *Prepayment cash flows*
Discount curve	Not discounted	Discounted with risk free or risk free + spread
Time horizon	Short-term	Long-term including all exposures
Balance Sheet assumption	Constant: going concern perspective	Run-off: gone concern perspective

Table 3.7: Comparison of NII and EVE

A small leak will sink a great ship.

Benjamin Franklin

4

Bank Analysis

This chapter provides a context of a retail bank. Firstly, the business model of a retail bank is defined. Secondly, the composition of a typical balance sheet of a retail bank is explained. Thirdly, the main retail products are identified. Subsequently, an elaboration is given on the concept of funds transfer pricing. Furthermore, the structure and components of customer rates are put forward. Finally, the importance of behavioral aspects is underlined. The information acquired in this chapter is used for building a cash flow generating algorithm for the analysis of the trade-off between EVE and NII.

4.1 Business model of a retail bank

The term *bank* can be defined as an organization that undertakes certain specific financial activities and functions. The fundamental function of the bank is to act as an intermediary between those who wish to borrow and those who wish to lend (Newson, 2017).

Banks have three important roles in the functioning of the economy. The first role is to provide current accounts and payment services (Newson, 2017). Banks provide payments services to households and companies by enabling them to settle transactions. The second role is lending (Newson, 2017). Banks provide credit to the real economy by providing mortgage to households and loans to companies (Bohn & Elkenbracht-Huizing, 2014). The third role is to enable savings (Newson, 2017). Banks help households and businesses to manage various risks they face such as offering depositors access to their current account *on demand* as well as providing derivative transactions of other financial insurance services for their broader customer base (Bohn & Elkenbracht-Huizing, 2014). Borrowers need sizable long-term credit to fund their investments. Parties with surplus funds usually have them in smaller amount and wish to have swifter access to some or all of their funds (Bohn & Elkenbracht-Huizing, 2014). Banks by accepting deposits from many customers are able to pass the surplus funds to customers who wish to borrow. In fact, what banks do is to transform many small size and short-term deposits into fewer large size long-term loans. This so called *maturity transformation* is an inherent part of the bank's business model (Bohn & Elkenbracht-Huizing, 2014). During this process, banks charge interest rates on the loans and mortgages that they issue and pay interest rates to depositors and other sources of funding. The price that is charged is higher than the price paid and the difference results in the profit of the bank and this is commonly known as net interest margin (NIM).

There are different types of banks, namely commercial banks and investment banks. The former consist of retail and wholesale banks. Retail banks provide services to private clients and small businesses, where wholesale banks tend to lend to financial institutions and larger corporate clients (Hull, 2015). Investment banks on the other hand, are involved in trading of securities and corporate finance decisions such as mergers and acquisitions (Hull, 2015). In this research, the focus will be on retail banks.

4.2 Balance sheet of a retail bank

A balance sheet represents the financial situation of the bank at a given point in time. It shows the bank's uses of funds in terms of assets on one side and the sources of funds which are liabilities and capital on the other side. According to accounting rule total assets equal total liabilities plus capital. Banks, in order to funds their business activities seek funding in the form of a mixture of borrowed funds which constitute liabilities and their own capital. Liabilities of a bank include retail deposits from households and firms such as current and savings account. Banks may also seek wholesale funding which consists of funds from institutional investors such as pension funds and other banks. Bank's capital includes its own funds which is composed of common equity and retained earnings (Bohn & Elkenbracht-Huizing, 2014).

The assets of the bank include all financial, tangible and intangible assets that the bank currently holds or are to be paid at some agreed point in time. The financial assets of the bank include personal loans and mortgage to households and loans to businesses as well as wholesale lending to other banks. Bank also holds liquid assets such as cash and central bank or government reserves. The tangible assets of the bank include physical infrastructure. Intangible assets of the bank refer to goodwill, image and brand. Additionally, bank has exposures which are considered *off-balance sheet* which include commitments to lend or derivative contracts such as swaps (Bohn & Elkenbracht-Huizing, 2014). Table 4.1 shows an example of a balance sheet of a retail bank. The composition of the retail bank balance sheet and its inherent characteristic of maturity transformation results in many risks, inter alia, interest rate risk in the banking book which is the main topic of this research.

4.3 Retail products

The balance sheet of a bank is important for the computation of EVE and NII, since the products on the balance sheet are required in order to estimate cash flows. This research focuses on the cash flows of the retail products. Therefore, these retail products need to be investigated more thoroughly. In this section more detail is given on the retail products.

4.3.1 Mortgage

Mortgage is a debt instrument, secured by a collateral of specified real estate property, that the borrower is obliged to pay back with predetermined set of payments. Mortgages are used by individuals and businesses to make large real estate purchases without pay-

Assets	**Liabilities & Equity**
Retail	**Retail**
- *Mortgages*	- *Demand deposits*
- *Loans*	- *Term deposits*
Wholesale	**Wholesale funding**
- *Mortgages*	
- *Loans*	
Trading securities	**Trading liabilities**
Other	**Equity**
- *Goodwill*	
- *Premises and equipment*	
Off-balance sheet instruments	
- *Interest rate swaps*	

Table 4.1: Balance sheet of retail bank.

ing an entire value of the purchase up front. Over a period of many years, the borrower repays the loan plus interest, until he/she eventually repays the whole mortgage.

4.3.2 Commercial loan

Commercial loan is a loan where a payment of the entire principal of the loan and sometimes the principal and interest is due at the end of the loan term. The payment that is due at the end of the loan is referred to as the bullet payment or balloon payment. Commercial loans should be contrasted with amortizing loan or bullet loan, where the amount of principal is paid down over the life of the loan. A bullet loan can be seen as a plain vanilla bond which pays period coupons over the life of the loan and repays the principal at maturity. Bullet loan and commercial loan are used interchangeably in this research.

4.3.3 Term deposit

The main feature of a term deposit is that it has a fixed term during which the amount deposited cannot be withdrawn. Term deposits usually have short-term maturities ranging from a month to a few years. In exchange of not being able to withdraw from the account at any time the bank offers the client higher interest rates. Usually fixed interest rates are offered.

4.3.4 Demand deposit

Demand deposit falls under the umbrella of non-maturing deposits. Non-maturing deposits are deposits with non-predetermined, unknown maturity. The holder of non-maturing deposit can increase, lower or withdraw all deposited amount at any time. The variable rate on these demand deposit can be changed at any time. This is in contrast with a floating rate, which can only be changed every 1,3,6, or 12 months.

4.4 Funds transfer pricing

This section introduces the concept of Funds Transfer Pricing. Funds Transfer Pricing is relevant for this research as it helps to identify the structure of the coupon and the commercial margin that is charged to customers. Moreover, it is a mechanism established to price the risks the banks is exposed to.

The net interest income is the bank's main source of income and indicator of its profitability. Net interest income can be decomposed into interest income and interest expense. This straightforward decomposition would imply that all loans and mortgages generate profit and all deposits incur costs. Considering that all deposits incur costs is however incorrect as the funds held in the form of deposits are being used to issue loans and mortgages. This link between bank's assets and liabilities is not always clear and direct. The separation theorem in banking suggests pricing loans, mortgages and deposits independently. Two implications emerge from the separation theorem. Firstly, it states to identify the relevant interest rates to price assets and liabilities. Secondly, it enables to divide the bank into a set of profit centers (Fuster, 2008). The separation theorem gave birth to the concept of *Funds Transfer Pricing* (FTP).

FTP can be defined as the process of setting interest rates and a mechanism designed to account for funding costs, liquidity risk, interest rate risk and currency risk linked to lending funds and taking deposits (Cadamagnani et al., 2015). FTP is an internal process which consists of creating a fictitious balance sheet of a bank and borrowing the funds from deposit taking units and lending them to loan originating units. FTP is carried out by the *Treasury Department* within a bank which acts as a central risk management hub. Performing this function it can be stated that Treasury operates as a "*bank within a bank*" (Cadamagnani et al., 2015).

The Treasury of the bank aggregates funds centrally and then redistributes them to corresponding business units balancing excesses and shortages of funding. In case there is still deficit of funding, Treasury borrows money from the capital market. In case of surplus of funds Treasury invest them or lends in the wholesale market (Tumasyan, 2012).

Next to transfer of funds FTP has other roles. By aggregating the interest rate risk, FTP achieves to make the balance sheet of a bank resistant to shifts in interest rates. Subsequently, by charging transfer rates FTP allows to determine profitability of business units, separate elements on the balance sheet and customers. Moreover, FTP is responsible for charging costs for funding and managing liquidity risk of the bank (Tumasyan, 2012).

Each funds transfer pricing system relies on transfer prices. A transfer price is an internal rate of interest used to calculate transfer income or transfer cost. For every loan there is a transfer cost and for every deposit there is a transfer income. The difference between the interest rate and a transfer price is the interest margin which is internal interest profit on a transaction. Each product has different interest rate characteristics and maturity characteristics and these are the basis for assigning transfer prices (Dermine, 2012). FTP allows for decomposition of net interest margin (NIM) into lending business NIM and deposit taking NIM, which results in a commercial margin of the bank and into a transformation result (Tumasyan, 2012). The methods of assigning FTP to a retail product depends on the choice of FTP methodology.

Various FTP methodologies exist with different level of accurateness and complexity and they differ by their approach to transfer price calculation and by the level of asset and liabilities decomposition that they allow. There are two main approaches that

Treasuries employ to determine the FTP rates. These are pool approach which can be categorized into single and multiple pool approaches and matched maturity approach (Tumasyan, 2012).

4.4.1 Single pool approach

Single pool method treats all transactions uniformly and allocates them in one pool of funds. This implies that one single price is assigned to all products. The providers of the funds contribute to the pool and the users of the funds withdraw from the pool. No difference is made between transactions with different maturity and repricing characteristics (Smullen, 2001). The advantage of the single pool method is that it is very simple (Smullen, 2001). However, its simplicity results in many drawbacks. By pooling all providers and users of funds together imply that some products, customers and business units will be unfairly advantaged while other disadvantaged (Fuster, 2008).

4.4.2 Multiple pool approach

Under multiple pool approach all assets and liabilities are classified into different pools using different criteria. Such criteria may include factors such as maturity, repricing, product type or behavioral patterns. Under this approach each pool is assigned specific FTP rate based on product specific characteristics. The advantage of the multiple pool approach is that is enables accurate calculation of profitability of pools of rate products. The disadvantage of this approach is that it is relatively simple and depends on pool averages and assumptions made about acceptable granularity and number of pools (Tumasyan, 2012). It is subject to change in market interest rates. It does not make a distinction between interest rate risk and credit risk.

4.4.3 Matched maturity approach

The matched maturity approach is considered as the most adequate one for achieving the objective of FTP (Tumasyan, 2012). Under this approach prices are allocated to loans and deposit separately and equal corresponding market rate or yield to maturity (Lindblom & Elliot, 2014). This method is able to capture the contributing interest margin of every single transaction. The advantage is that this approach enables the centralization of interest risk and its transfer to responsible business units. The disadvantage is that it is complex to implement.

4.5 Structure and components of customer rates

FTP helps to identify the costs of production and enables to charge for those costs, such that the final price offered to the customer includes all the costs of production. If fees and interests do not match the costs, losses arise. In banking business, dealing with customers implies not only costs but also transfer of risks and these risks have prices as well. Issuing retail products involves costs such as administrative costs, employee wages, premises, or regulatory expenses but also includes the following risks: interest rate risk, liquidity risk, credit risk, basis risk and prepayment risk (Barbican Consulting, 2017). As continuation the risks and costs are described.

- **Interest rate risk**. Interest rate risk refers to the reference rate or in other words, market rate that the retail products are priced against. Assets are priced above the reference rate and the liabilities are priced below the reference rate. Business units within a bank may price its products against different reference rates which consequently, may results in basis risk. A price needs to be charged for this risk as well as for the cost hedging this risk.

- **Liquidity risk**. Liquidity risk can be seen as contingent liquidity cost or buffer cost. Bank hold buffers assets which in case of stressed situations can be converted into cash. Holding such assets is expensive and the cost needs to be charged to the products that create the need to hold the buffer. In addition, every product creates its own requirements and the buffer needs to be product specific. For instance, demand deposit creates higher buffer than term deposit. Liquidity risk is an additional spread on top of the reference rate reflecting the funding costs of the bank.

- **Credit risk**. Credit risk it the credit spread that reflects the probability of adjusted loss in default. The expected loss represents the average expectation of loss associated with a loan. It can be thought of as a combination of the likelihood that a borrower will default and the loss suffered by a bank if the default were to occur. The potential loss from default includes lost principal and interest and increased collection costs (Bessis, 2011). Estimates for expected losses are affected by the outlook for the creditworthiness of borrowers and general economic conditions (Cadamagnani et al., 2015).

- **Option risk**. Option risk is the option spread that is charged for embedded options included in retail products. In case of a loan or mortgage the clients has the right to prepay its mortgage or loan. If this occurs the bank loses potential interest which otherwise would have earned. Such an option thus carries a price which is included in the coupon of the product. The option spread charged depends on the characteristics of the option. For instance, in case of non-maturing deposit the client has the right to withdraw all his or her deposited money at any time. This option is included in the pricing that the bank pays the client for holding and managing his or her money. The interest rate paid on non-maturing deposit is thus much lower compared with term deposit. Term deposit is a deposit where the client cannot withdraw the deposited amount or it may withdraw the deposited amount provided that a penalty is paid. Consequently, the interest rate on term deposit is thus much higher.

- **Other costs**. Other costs include indirect costs that accompany the origination of a retail product such as administrative costs, employee wages, premises or expenses related to regulatory requirements.

- **Mark-up or mark-down**. Mark-up or mark-down is the interest margin. It represents the amount bank charges to ensure that each retail products generates an expected rate of return. It is an additional spread, positive or negative, on top of the reference rate. Mark-up is the interest margin charged for an asset and mark-down is the interest margin charged for a liability (Cadamagnani et al., 2015).

Figure 4.1 represents a stylized example of loan pricing. A bank business line pays 2.5% transfer price to the treasury function and charges the customer 3.5% for the loan. In this example the transfer price includes reference rate, liquidity risk, credit risk, option spread and other costs. It may be the case that the transfer price includes reference rate and option spread which are managed centrally by the treasury function and the other costs are managed by the business function. In this example it is assumed that all costs are included in the transfer price. Every retail product has its own internal transfer pricing curve (Adam, 2008). In this example the loan originating business line generates 0.5% return on the loan which is the difference between the customer rate and the costs.

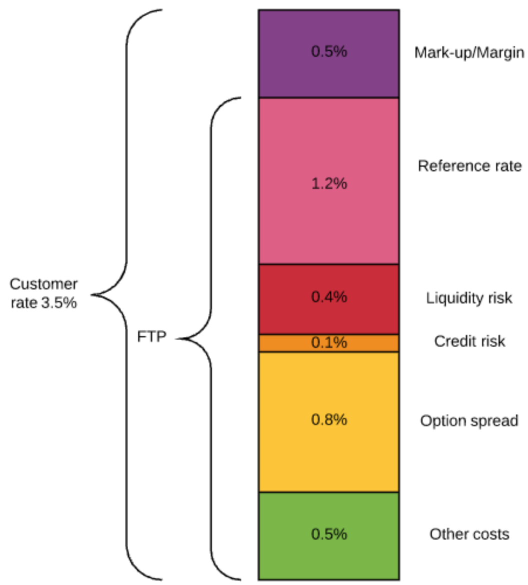

Figure 4.1: Stylized example of loan pricing

Figure 4.2 represents example of deposits pricing. Pricing a deposit differs from pricing of a loan. Deposit is the source of funds for a bank. In this case the deposit taking business lines receives from the treasury an internal rebate for acquiring deposit funding (Cadamagnani et al., 2015). In the example in figure 4.2 the business lines receives 1.4% transfer price from the treasury and pays the customer 1%. The spread between the the transfer price and customer rate reflects the return on the deposit which in this case is 0.4%.

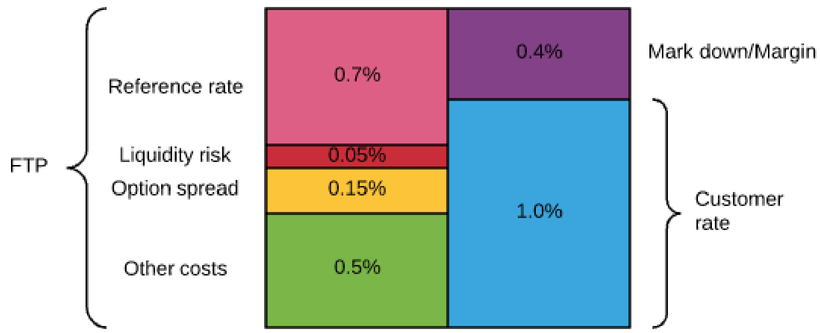

Figure 4.2: Stylized example of deposit pricing

4.6 Behavioral aspects

This section elaborates more on the behavioral risks inherent in retail products. This subsection also shows the importance of behavioral risk modelling. Without adequate expected future cash flows, treasury and risk management steer on incorrect measures.

4.6.1 Prepayment risk

Prepayment risk refers to the uncertainty in the amount and timing of the principal repayments of loans and mortgages. Loans and mortgages hold an embedded option to prepay (Lyuu, 2002).

A typical loan and mortgage makes a commitment to pay the mortgagor in monthly payments for the term of the product. Loan or mortgage contract includes the right of the mortgagee to exercise his/her right to prepay the loan or mortgage at any point in time. This option may be exercised without financial penalty to be paid to the mortgagor (Goodarzi et al., 1998). In the Netherlands however, prepayment without penalty is not always the case.

The exercise of options on most securities is considered and expected to be *rational*. *Rationality* in this case means that the option is exercised when it is profitable to do so. In case of retail products the notion of *rationality* is relaxed (Lyuu, 2002). The option of prepaying may be exercised due to various reasons such as changes in interest rates, refinancing into another loan with a lower interest rate and payment requirements, the sale of underlying property or personal issues of the individual such as employment status, family status, income, relocation, retirement or health related impacts (Goodarzi et al., 1998).

On the other hand, the mortgagor also holds an option to terminate the contract in case the mortgagee default on the required payments. Issuers of loans and mortgages are exposed to significant interest rate risk when these products are prepaid and to credit risk when terminated due to default (Goodarzi et al., 1998).

Prepayments will halt the stream of cash flows that the issuers expect to receive. For instance, in the scenario of declining interest rates there will be an increase in prepayment activity. Lower interest rates will cause the product holders to reinvest at the new lower interest rate level. On the contrary, in case of an increase in interest rates a decrease in prepayment will follow. Higher interest rates will result that product holders wait longer before they reinvest at the new higher interest rate level. Therefore, the ability to accurately predict the likelihood to prepay is vital to the estimation of future cash flows (Goodarzi et al., 1998).

Modeling of prepayment is an important aspect of hedging and risk assessment. Studies indicate that different prepayment estimations and forecast methodologies may result in 20% - 30% difference in the cash flow of a portfolio (Goodarzi et al., 1998).

For illustration, Figure 4.3 represents the contractual repayment cash flows scheme of a linear mortgage with principal of 10.000, fixed interest rate of 3% and 10 years to maturity. Contractual cash flows are the scheduled cash flows outlined in the mortgage contract.

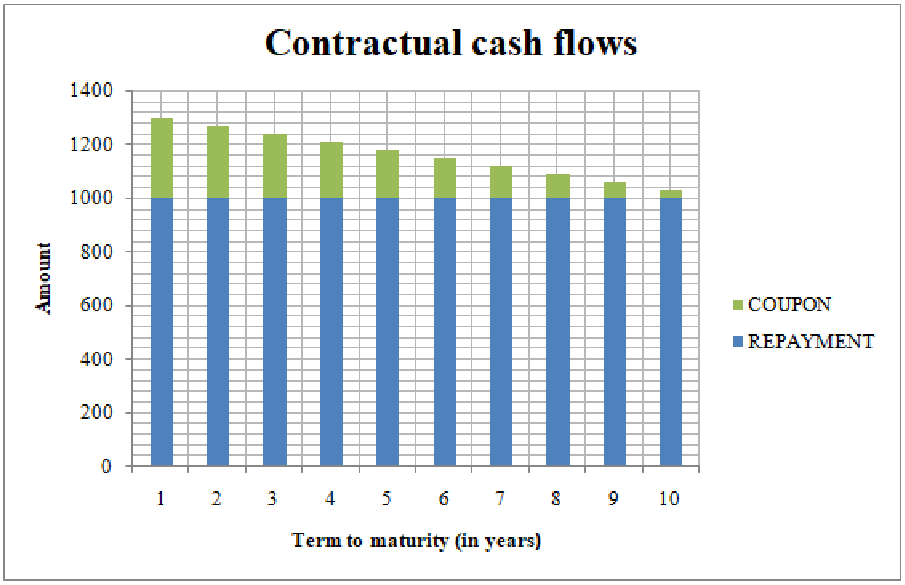

Figure 4.3: Mortgage contractual cash flows with CPR of 0%.

Figure 4.4 illustrates the expected cash flows assuming a conditional prepayment rate (CPR) of 1%. Expected cash flows take into account behavioral factors. It can be seen that the prepayment option has shorten the mortgage's cash flow profile. The non-contractual repayment has decreased the level of cash flows received in terms of interest rates. Thus, the bank has incurred an economic loss. Additionally, the prepayment option has altered the interest rate risk exposure of the bank. In practice, in case prepayments take place the repayment schedule is altered as well. In this research, however, the assumption is that in case of prepayments the repayment schedule remains the same, only the final repayment amount decreases.

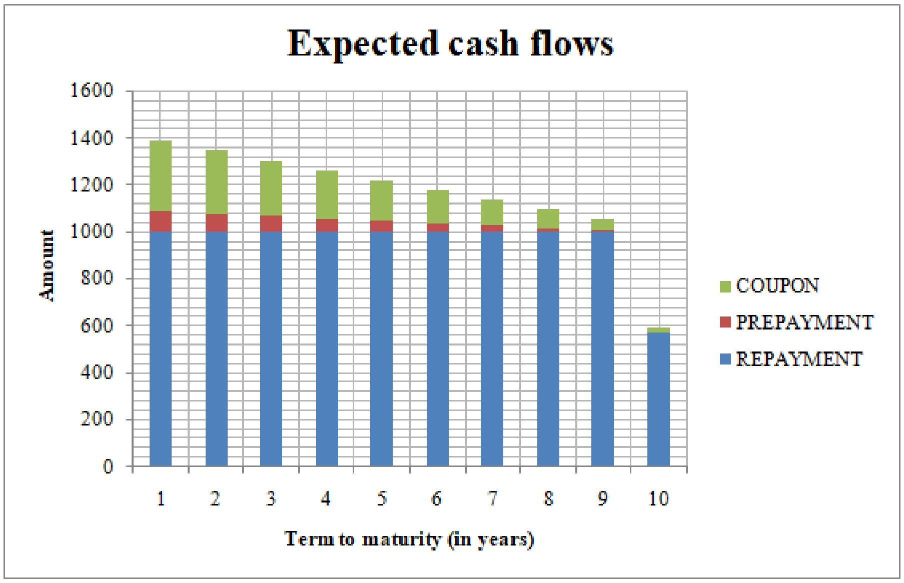

Figure 4.4: Mortgage expected cash flows with CPR of 1%.

4.6.2 Withdrawal risk

Withdrawal risk or redemption risk refers to the optionality in non-maturing deposits. The feature of unknown maturity implies that the holder of the products can withdraw the whole notional at any time. Non-maturing deposits constitute the main source of funding for retail banking. Additionally, deposits also have the lowest funding costs amongst the different funding sources. As a consequence, the modeling of non-maturing liabilities is crucial for valuation, hedging and liquidity risk (Castagna & Manenti, 2013).

4.7 End of chapter summary

This chapter made an analysis of the retail bank. The business model, balance sheet and risks on the balance sheet of a retail bank have been explained. Also, the second research question has been answered:

What are the most important characteristics of a retail banking business?

The business model of a retail bank is characterized by acting as an intermediary between those who wish to borrow and those who wish to lend. During this process banks charge interest rates on the mortgages and assets that they issue and pay interest rates to depositors and other sources of funding. The price that is charged is higher than the price paid. The difference results in the profit of the bank.

Bank set customer rates through an internal system called Funds Transfer Pricing which enables to allocate costs and profits to various business units, products and customers. FTP can be seen as *"bank within a bank"*.

A bank issuing a retail product incurs several costs and risks. These costs and risks need to be included in the final price to the customer else the bank risks to make losses. The components of customer rates identified in this chapter are interest rate risk, liquidity risk, credit risk, option spread, administrative costs and interest margin.

Risk comes from not knowing what you are doing.

Warren Buffett

5 Hedging

The aim of this research is to investigate the trade-off between NII and EVE by hedging the volatility. Therefore, this chapter is dedicated to hedging IRRBB. In the first section the purpose of hedging is defined. Subsequently, two possible hedging techniques are presented: notional and basis point value (BPV) hedging.

5.1 Purpose of hedging

A hedge is a position that intends to offset potential losses or gains that may be incurred by another position. A hedge reduces risk exposures or even eliminates them provided that the cash flows of the hedge position are equal in magnitude but opposite in directions to those of the existing exposure (Lyuu, 2002). In practice, IRRBB is usually hedged with IRSs. Therefore, in this research the scope of hedging IRRBB is limited to IRSs.

A *"plain vanilla"* interest rate swap (IRS) is a contract between two parties to exchange a stream of cash flows in accordance to pre-agreed terms. One party periodically pays a cash flow determined by a fixed interest rate so called the fixed leg and receives a cash flow determined by a floating interest rate so called the floating leg. The other party does the opposite. No principal is exchanged. A swap has four major components which are: notional principal amount, interest rates for the parties, frequency of cash exchanges and duration of the swap (Lyuu, 2002).

5.2 Hedging techniques

While hedging with IRSs two hedging techniques can be distinguished: notional hedging and BPV hedging. BPV stands for basis point value and is a hedging technique for measuring interest rate risk. BPV determines the magnitude of gain or loss on a position due to a change of 1bps in the yield curve.

Notional hedging implies assigning a notional amount to the swap transaction based on the notional amount of the original transaction. Whereas, BPV hedging implies assigning a notional amount to the swap transaction such that the BPV profile of the swap transaction matches the BPV profile of the original transaction. In such a way the BPV profile of the product or portfolio in question would sum approximately to 0 or within limits of the risk appetite.

5.3 Hedging from earnings perspective

Hedging from earnings perspectives implies to stabilize the NII of the product or portfolio in question and thus mitigate its volatility. For the purpose of stabilizing the NII and reducing its volatility notional hedging could be used. For instance, let consider a simple balance sheet of a retail bank which consists of a bullet loan with notional of 100, fixed coupon rate of 5% annually and 5 years to maturity. It is assumed that the coupon of the bullet loan consists of 3% risk free rate (in this example assumed to be EURIBOR) and 2% interest margin. The bullet loan is funded with a deposit with the same notional amount but floating coupon rate linked to 1 year EURIBOR. This portfolio is exposed to earnings volatility as the level of the floating interest rate is unknown. In order to stabilize earnings the bank could enter into a swap in which it pays fixed interest rate of 3% each year and receives floating interest rate equal to 12 months EURIBOR. In this way the bank manages to lock the net interest margin. Regardless, in which direction interest rates fluctuate the margin remains fixed. The swap transaction is illustrated in Figure 5.1. Bank 1 receives margin (2%) and floating EURIBOR, but is funded by floating EURIBOR, meaning only the margin remains.

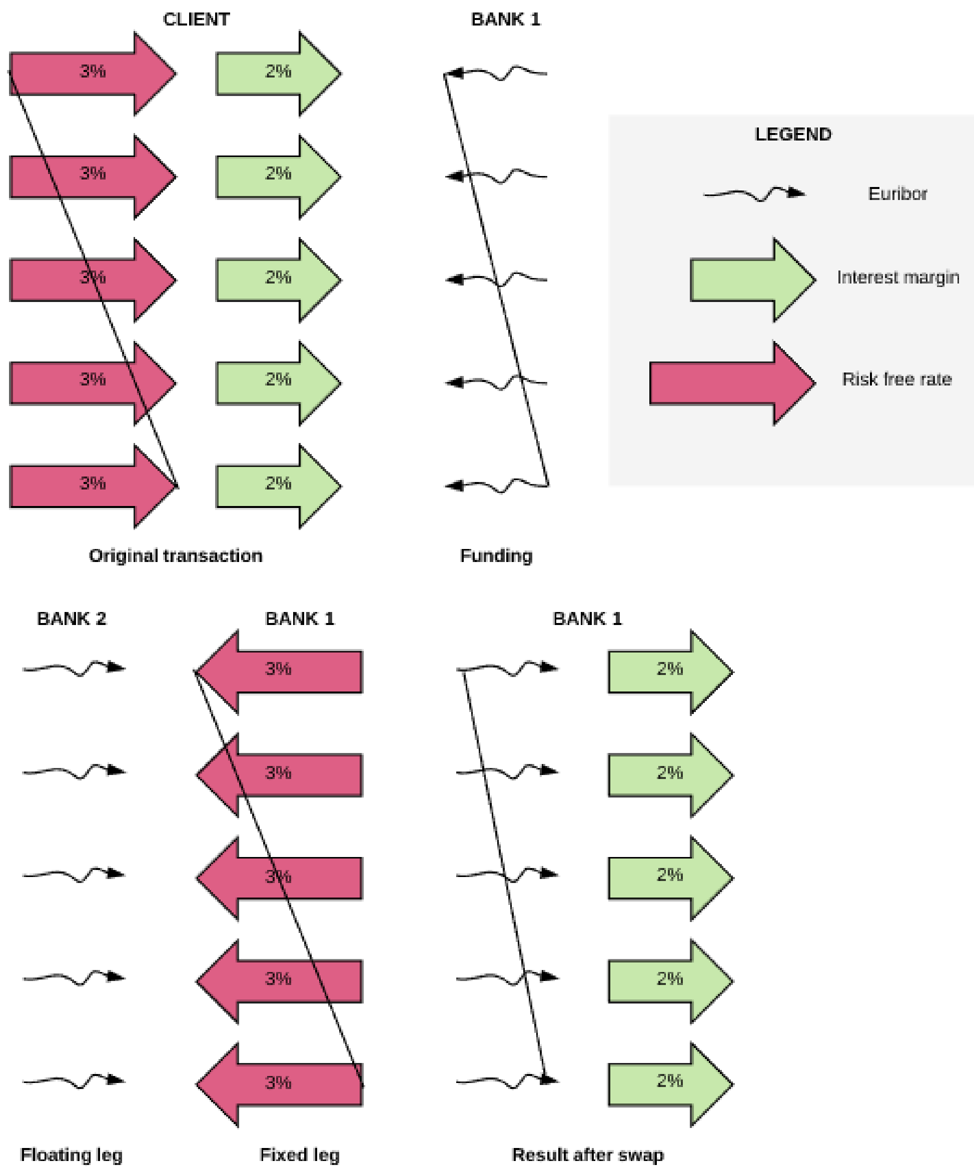

Figure 5.1: Hedging from earnings perspective: Notional hedge

Hedging from economic value perspective implies stabilization of the net present value (NPV) of the product or portfolio in question and thus mitigating its volatility. As interest rate change the net stream of cash flows must diverge from the stream initially planned in terms of its total amount, its timing, or both, if the net present value of the portfolio is to remain unchanged. It is necessary to calculate the change in the present value of the portfolio for a small change in interest rates. This change in net present value must be offset by an opposite change in the net present value of the hedging instrument.

For the purpose of stabilizing the NPV and reducing its volatility BPV hedging could be applied. For illustration, lets consider the same bullet loan with a notional of 100, fixed coupon rate of 5% with 5 years to maturity. The coupon of the bullet loan consists of 3% risk free and 2% commercial margin. The NPV of the bullet loan is exposed to value volatility in case the interest rate change. The BPV is calculated as 1bps change in the NPV of the product or portfolio in question. This can be shown in Table 5.1. The BPV of the bullet loan is $(4.76+4.53+4.32+4.11+82.23)-(4.76+4.54+4.32+4.11+82.27) = -0.043$. This means that the loan loses -0.043 EURO in value whenever the interest rate moves up with 1 bps. This negative BPV is intuitive, because a higher discount rate result in a lower present value of the asset.

T (in years)	**1**	**2**	**3**	**4**	**5**
Total CF bullet loan (in EURO)	5	5	5	5	105
Discount factor (with 5%)	0.952	0.907	0.864	0.823	0.784
Total DCF (in EURO)	**4.76**	**4.54**	**4.32**	**4.11**	**82.27**
Total CF bullet loan (in EURO)	5	5	5	5	105
Discount factor (with 5% + 1bps)	0.952	0.907	0.864	0.822	0.783
Total DCF (in EURO)	**4.76**	**4.53**	**4.32**	**4.11**	**82.23**

Table 5.1: Computing the BPV for the bullet loan

The NPV of the bullet loan could be hedged with a swap that offsets the BPV profile of the bullet loan. The BPV of the swap transaction is the sum of the BPV of its fixed and floating legs. The characteristics of the fixed leg would be 100 notional, fixed coupon of 3% and 5 years to maturity. The characteristics of the floating leg would be notional of 100 and floating coupon that reprices annually. The floating leg of the swap from the economic value perspective is seen as depositing money on a bank account for a period of 1 year and receiving interest rate and then unwinding the position. At $t = 0$ the interest rate to be received at $t = 1$ for depositing money for one year is known. At $t = 0$ the interest risk free interest rate at $t = i + 1$, where $i = \{1..n\}$ is not known. However, regardless what the value of the rate is the NPV of the deposited amount will equal the notional amount (notice that this view changed after the introduction of Overnight Index Swap discounting, but this will not be taken into account in this research). Therefore, given the characteristics of the fixed leg and assuming 3% for the floating leg at $t = 1$ the BPV of the fixed leg is -0.0458 and the BPV of the floating leg is -0.0094. The total BPV is then -0.0094 - -0.0458 (BPV asset leg - BPV liability leg) = 0.036 (with a notional value of 100). In order to match the required BPV profile of the original transaction the notional amounts of the swap legs need to be adjusted. The needed notional amounts are obtained with the following computation: 100 $\times \frac{-0.043}{0.036}$. The required notional amounts for these two legs would be 120. The notional of 120 for both swap legs would result in a BPV of 0.043 (with a notional value of 120 the BPV fixed leg is -0.054 and BPV floating leg is -0.011). In case of changes in interest rates the change in NPV of the original transaction would be offset by the change in the NPV of the swap transaction. If the interest rates increase by 1% the change in NPV of the original transaction of -4.3 will be offset by change in the NPV of 4.3 in the swap transaction. Such a hedge would enable to stabilize the value to certain extent. The illustrative representation of the swap transaction is depicted in Figure 5.2.

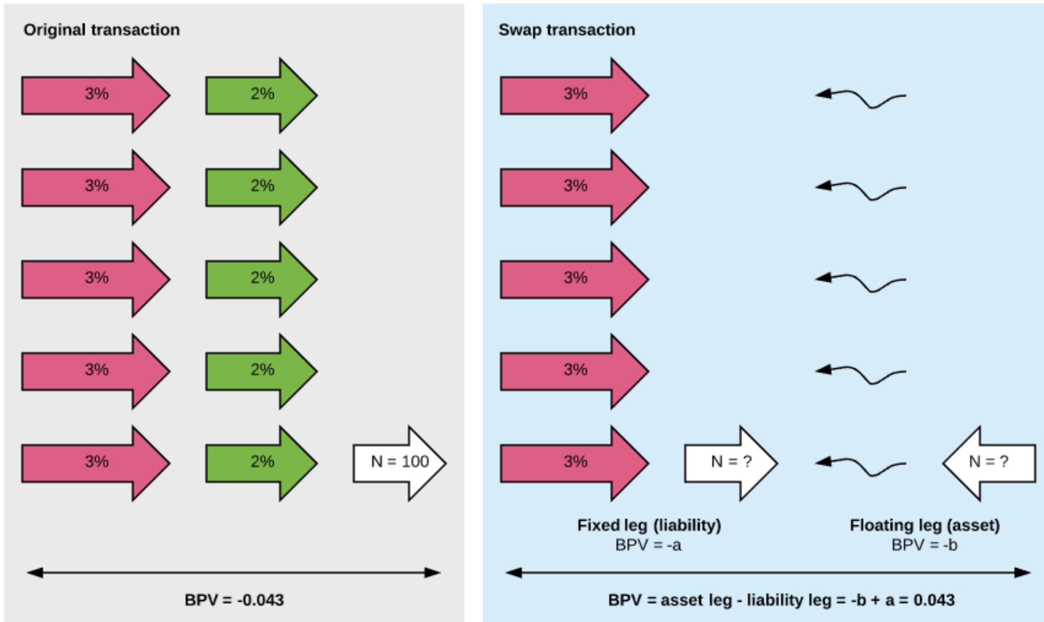

Figure 5.2: Hedging from economic value perspective: BPV hedge

5.5 End of chapter summary

In this chapter the following research questions have been answered:

Which hedging techniques can be used to hedge IRRBB?

Two main hedging techniques are used in practice to hedge IRRBB: notional and BPV hedging. Notional hedging consists of assigning a notional to the swap transaction such that it equals the notional of the original transaction. BPV hedging consists of assigning a notional to the swap transaction such that the BPV profile of the swap transaction matches the BPV profile of the original transaction. The drawback of economic value hedging is that it does not take into second order effects such as that earnings may change as well.

Notional hedging seem more adequate to hedge IRRBB from earnings perspective thus stabilizing the NII. BPV hedging seem more applicable to hedge IRRBB from the economic value perspective thus stabilizing the EVE. As a consequence, the economic value volatility can be hedged by applying BPV hedging. The drawback of earnings hedging is that it does not take into account economic value. Another drawback is that when interest rates do not go against the bank, the hedge is unnecessary. For instance, when interest rates go up, the bank should receive more coupon, but because of the hedge this coupon is not received.

An algorithm must be seen to be believed.

Donald Knuth

6 Model

The goal of this research is to investigate the relationship between EVE and NII with and without hedging. For this purpose a model is constructed in the MATLAB environment using *Object Oriented Programming*. The model is able to output EVE and NII metrics given a portfolio of a bank as well as automatically generate a BPV and notional hedge. The un-hedged and hedged portfolio can then be assessed with respect to the six scenarios mentioned in chapter 3, while taking into account the possibility of prepayments. As mentioned in chapter 3 all assumptions made for EVE and NII are based on BCBS (2016).

In this chapter, all components of the model will be outlined. The chapter starts with a delineation of the term structure, discount curve, prepayment, outflow and repricing models. Afterwards, the cash flow generating algorithm will be elaborated. Finally, the BPV and notional hedging models will be explained. A stylized illustration of the conceptual model is given in figure 6.1.

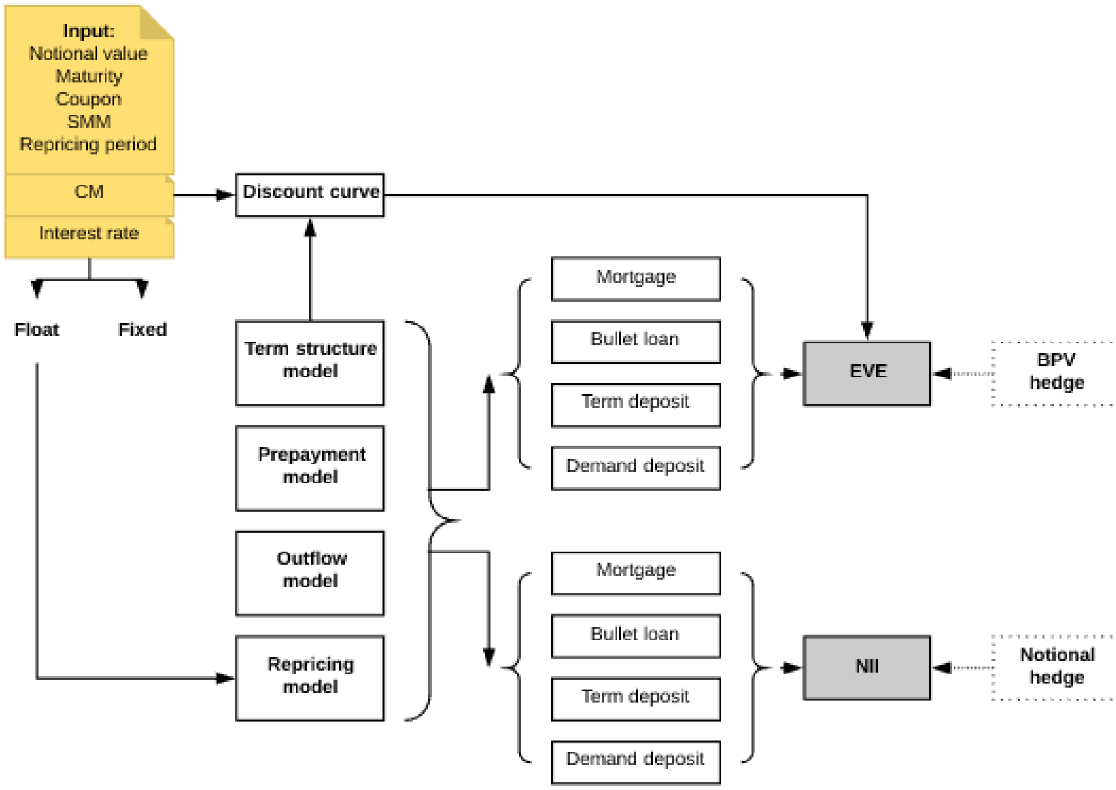

Figure 6.1: Stylized representation of the conceptual model

Before going into more depth on the modeling of the retail products, some supporting models are required. These models include the term structure model, prepayment model, the outflow model and the repricing model. These models support the modeling of the cash flows of the retail products elaborated later on.

6.1 Term structure model

The term structure of interest rates, also known as the yield curve represents the relationship between the market interest rates and the term to maturity. The information incorporated in the term structure reflects the asset pricing process on financial markets and is fundamental to the valuation of fixed-income securities. The yield curve can be derived from zero coupon rates. A zero coupon bond is a bond that pays no coupon and is sold at a discount from its face value. The zero coupon curve represents the yield to maturity of hypothetical zero coupon bonds. The zero coupon bonds are not directly observable in the market and thus needs to be estimated from existing zero coupon bonds and fixed coupon bonds prices or yield.

The interest rates data to construct the yield curve for this research has been retrieved from the European Central Bank (ECB). The data set contains AAA-rates and other euro area central government bonds. The missing points on the term structure have been calibrated with the Nelson-Siegel-Svensson (NSS) model. The NSS model is a parametric model that specifies a functional form for the spot rate and can be expressed with the following formula:

$$y(T) = \beta_0 + \beta_1 \left[\frac{1 - e^{\left(\frac{-T}{\tau_1}\right)}}{\frac{-T}{\tau_1}} \right] + \beta_2 \left[\frac{1 - e^{\left(\frac{-T}{\tau_1}\right)}}{\frac{-T}{\tau_1}} - e^{\left(\frac{-T}{\tau_1}\right)} \right] + \beta_3 \left[\frac{1 - e^{\left(\frac{-T}{\tau_2}\right)}}{\frac{-T}{\tau_2}} - e^{\left(\frac{-T}{\tau_2}\right)} \right] \tag{6.1}$$

where T denotes the *term to maturity* and β_i and τ_i are parameters to be estimated. The term to maturity ranges from 1 month up to and including 30 years of residual maturity. The estimated parameters are shown in Table 6.1. The current yield curve is illustrated in Figure 6.2.

Parameter	β_0	β_1	β_2	β_3	τ_1	τ_2
Value	2.762834	-3.316999	37.887917	-42.725487	1.702520	1.772731

Table 6.1: NSS parameters
Source: European Central Bank

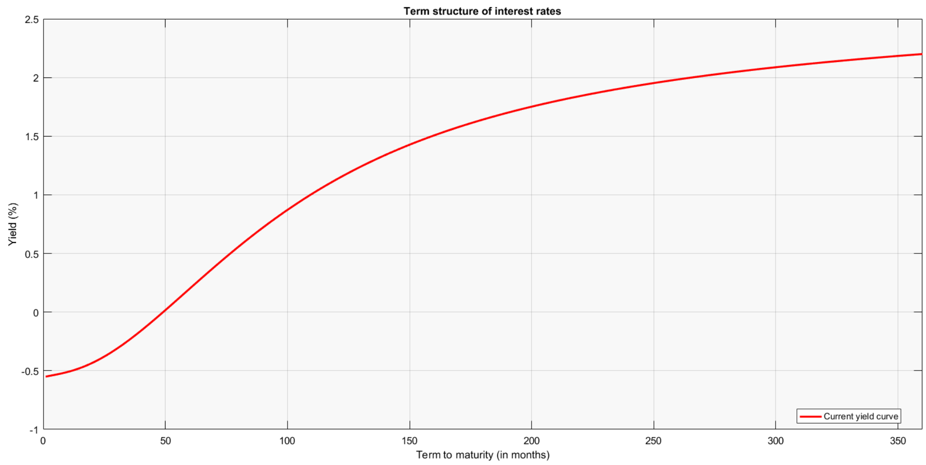

Figure 6.2: Term structure of interest rates

6.2 Discount curve

From the term structure model, the discount curve for each retail product can be derived. Mathematically, the discount factor at time t for a product p can be represented as follows:

$$d_{t,p} = \frac{1}{(1 + r_t + s_{t,p})^{t/12}} \tag{6.2}$$

Where:

- r_t stands for risk free rate at time t (month)
- $s_{t,p}$ stands for spread (commercial margin) of a given retail product p at time t

The cash flows used to calculate NII are not discounted, whereas the cash flows used to calculate EVE need to be discounted.

6.3 Prepayment model

Prepayment risk is characterized by its unpredictability. Prepayment represents the principal payment made in excess of the scheduled principal amortization. In order to determine if prepayments have occurred it is necessary to compare the scheduled remaining principal with the reported balance. The amount by which the reported factor exceeds the amortization factor is the prepayment amount (Lyuu, 2002).

Conditional prepayment rate (CPR) refers to annualized percentage of the remaining principal balance that is expected to be prepaid in a year. CPR is an annual rate. Loan and mortgage prepayments happen on a monthly basis. Therefore, a single monthly mortality (SMM) rate is defined. A SMM of w means that $w\%$ of the schedule remaining principal at the end of the month will prepay (Lyuu, 2002).

The CPR is the annualized equivalent of the SMM:

$$CPR = 1 - \left(1 - SMM\right)^{12} \tag{6.3}$$

Correspondingly, SMM is the monthly equivalent of CPR:

$$SMM = 1 - \left(1 - CPR\right)^{1/12} \tag{6.4}$$

If a single CPR is assumed as true prepayment speed the resulting number can be seen as a constant prepayment rate. To reflect the unpredictability and randomness of prepayments an extra volatility is added to the prepayment model represented by ε. ε is a random number from the normal distribution with mean parameter μ and standard deviation parameter σ. This leads to the following prepayment model:

$$P_{t,p} = \max(SMM_p + \varepsilon_t, 0) \tag{6.5}$$

where $P_{t,p}$ stands for prepayment rate at time t on monthly basis for a retail product p, and $\varepsilon \sim \mathcal{N}(\mu, \sigma^2)$. Notice that there is a floor at 0, meaning that negative prepayments are non-existent. Negative prepayment would imply an increase in the mortgage and loan balance.

6.4 Outflow model

The purpose of the outflow model is to model the demand deposit which is a non maturing deposit. One of the most common methodologies adopted by banks to model the evolution of the balance of non-maturing deposits is the replicating portfolio approach.

Replicating portfolio approach split the deposited amount into two parts: the core part and the volatile part. The core part is assumed to be immune to changes in the market rates. The core part is assumed to decline gradually over the life period of the product and amortize completely at the end of it. The volatile part is assumed to be exposed to withdrawal risk. This part is invested in overnight deposits and serves as liquidity buffer to cope with the daily withdrawals (Castagna & Manenti, 2013).

In this research the outflow model serves to determine the volatile part V of the non-maturing deposit. The assumption is made that the outflow from a non-maturing deposit at time t is a random number from the normal distribution with mean parameter μ and standard deviation parameter σ. Thus, the volatile part V is normally distributed: $V \sim \mathcal{N}(\mu, \sigma^2)$. Notice that for the outflow model, no floor is specified. This is intuitive, since a negative withdrawal means adding in more deposits.

6.5 Repricing model

The coupon of a retail product can be fixed or floating. In case the coupon is fixed it remains fixed for the entire maturity of the product in question. If however the product has a floating coupon a repricing model is needed. In case of floating coupon, the coupon of the product will reprice every x of time against a given reference curve (the term structure model). Thus the interest rate of the coupon will change over the product's maturity. The repricing model is expressed in the form of pseudo-code in Algorithm 1.

Algorithm 1 Repricing model

```
input: X[1..n],reprice;
real: A[ ], B[ ];
integer: i;

A = zeros(1, length(X));
B = zeros(1, length(X));
A(1:reprice:length(X)) = 1;
Index array = find(A);

for  j = 1 to length(index array)  do
    if j = length(index array) then
        B(index array(j):index array (j+1) =X(1+reprice*(j-1));
    elseB(index array(length(index array)):length(X)) = X(1+reprice*(j-1));

return: B[ ];
```

6.6 Cash flow generator

In the previous section the supporting models were explained. In this section the cash flow generator will be outlined. The cash flow generating algorithm is scoped to four retail products: mortgage, bullet loan, demand deposit and term deposit. The properties for these products are the characteristics such as notional amount; maturity; coupon; type of interest rate: fixed or floating (in case of floating repricing specification is needed); commercial margin and single monthly mortality rate which is the monthly conditional prepayment rate. In this research an Excel file will be created that will form the basis of a portfolio of a bank. This file will be read in by MATLAB, and the cash flow generating algorithm will assign the properties to each product as well as generating the respective cash flows for each product.

The cash flows of the retail products are modeled accordingly to EVE and NII perspectives, implying that differences between these two metrics are taken into consideration. The next subsections includes the cash flow modeling of the retail products used in this research. The assumption made are presented and the distinction between NII and EVE underlined.

6.6.1 Mortgage

In order to model cash flows of one mortgage product the following assumptions are made:

- Mortgage amortized linearly over its maturity. This research considers solely linear mortgages.
- Mortgage is exposed to prepayment risk. Thus, the prepayment model has to be applied.
- Distinction is made between fixed and floating interest rate. In case of floating interest rate the repricing model is used.
- Distinction is made between EVE and NII. For the purpose of EVE the total discounted cash flows of the current mortgage is considered. For the purpose of NII, only the coupon cash flows are examined. Furthermore, for the purpose of NII, when the mortgage expires, repays or prepays it is replaced with a new business, new mortgage with similar characteristics so that the constant balance sheet assumptions holds.

The mortgage cash flow model creates the following cash flows, starting with the beginning balance, where P_t is a parameter from the prepayment model:

$$BeginBalance_t = \begin{cases} N_t & \text{if t} = 1 \\ N_{t-1} - Amortization_{t-1} - (N_{t-1} - Amortization_{t-1}) * P_{t-1} & \text{if t} = 2 \ldots \text{T} \end{cases} \tag{6.6}$$

The amortization cash flows, where N is the notional are calculated using the following expression:

$$Amortization_t = \begin{cases} N/T & \text{if } Amortization_t \leq BeginBalance_t \\ \\ BeginBalance_t & \text{if } Amortization_t > BeginBalance_t \end{cases} \tag{6.7}$$

Prepayment cashflows are as follows, where P_t comes from the prepayment model.

$$PrepaymentCF_t = (BeginBalance_t - Amortization_t) * P_t \tag{6.8}$$

Coupon cash flows required for NII are, where C_t is the coupon rate:

$$CouponCF_t = BeginBalance_t * C_t \tag{6.9}$$

where C_t can be either fixed or float. In case C_t is float then the repricing function is used. This is expressed as follows, where r_t, $s_{t,p}$ and $repricing_{t,x}$ denotes respectively the risk free rate at time t, the commercial margin of a given retail product p at time t and the repricing rate at time t with repricing frequency x:

$$C_t = \begin{cases} r_t + s_{t,p} & \text{if } C_t = \text{fixed} \\ repricing_{t,x} + s_{t,p} & \text{if } C_t = \text{float} \end{cases} \tag{6.10}$$

Finally, the discounted total cash flows for EVE can be computed, where d_t comes from the yield curve model:

$$DCF_t = (Amortization_t + PrepaymentCF_t + CouponCF_t) * d_t \tag{6.11}$$

6.6.2 Bullet loan

In order to model cash flows of one bullet loan product the following assumptions are made:

- Bullet loan is exposed to prepayment risk and thus the prepayment model is used.
- Distinction is made between fixed and floating interest rate. In case of floating interest rate the repricing model is used.
- Distinction is made between EVE and NII. For the purpose of EVE the total discounted cash flows of the bullet loan is considered. For the purpose of NII, only the coupon cash flows are examined. To assume the constant balance sheet,

the current bullet loan in case it matures or prepays it is replaces with a new bullet loan with similar characteristics.

The bullet loan cash flow model returns the following beginning balance cash flows, where P_t parameter comes from the prepayment model:

$$BeginBalance_t = \begin{cases} N_t & \text{if t = 1} \\ N_{t-1} * (1 - P_{t-1}) & \text{if t = 2 ... T} \end{cases} \tag{6.12}$$

The prepayment cash flows are as follows:

$$PrepaymentCF_t = BeginBalance_t * P_t \tag{6.13}$$

The coupon cash flows for NII are:

$$CouponCF_t = BeginBalance_t * C_t \tag{6.14}$$

where C_t can be either fixed or float. In case C_t is float then the repricing function is used. This is expressed as follows, where r_t, $s_{t,p}$ and $repricing_{t,x}$ denotes respectively the risk free rate at time t, the commercial margin of a given retail product p at time t and the repricing rate at time t with repricing frequency x:

$$C_t = \begin{cases} r_t + s_{t,p} & \text{if } C_t = \text{fixed} \\ repricing_{t,x} + s_{t,p} & \text{if } C_t = \text{float} \end{cases} \tag{6.15}$$

The discounted total cash flows for EVE can be computed, where d_t comes from the yield curve model:

$$DCF_t = \begin{cases} (PrepaymentCF_t + CouponCF_t) * d_t & \text{if t} \neq \text{T} \\ (CouponCF_t + BeginBalance_1) * d_t & \text{if t = T} \end{cases} \tag{6.16}$$

6.6.3 Demand deposit

In order to model cash flows of one demand deposit product the following assumptions are made:

- The amount held on demand deposit can be adjusted at any time. Therefore, the deposited amount is divided into core and volatile parts.
- $x\%$ of the deposited amount is assumed to be the core part and 1-$x\%$ is assumed to be volatile. The latter also contains a parameter V_t which is normal distributed as specified in the outflow model.
- Distinction is made between fixed and floating interest rate. In case of floating interest rate the repricing model is used.
- Distinction is made between EVE and NII. For the purpose of EVE the current total discounted cash flows are required. For the purpose of NII, the coupon cash flows are considered. In case of a withdrawal and expiration, the gap is replaced with new business with similar characteristics.

The core part of the demand deposit is computed as follows, where N is the notional of the demand deposit:

$$Core_t = \begin{cases} x * N & \text{if t = 1} \\ Core_{t-1} - ((x * N)/T) & \text{if t = 2 ... T} \end{cases} \tag{6.17}$$

The volatile part is calculated as:

$$Volatile_t = (1 - x) * N + V_t \tag{6.18}$$

The coupon cash flows for NII are then:

$$CouponCF_t = (Core_t + Volatile_t) * C_t \tag{6.19}$$

where C_t can be either fixed or float. In case C_t is float then the repricing function is used. This is expressed as follows, where r_t, $s_{t,p}$ and $repricing_{t,x}$ denotes respectively the risk free rate at time t, the commercial margin of a given retail product p at time t and the repricing rate at time t with repricing frequency x:

$$C_t = \begin{cases} r_t + s_{t,p} & \text{if } C_t = \text{fixed} \\ repricing_{t,x} + s_{t,p} & \text{if } C_t = \text{float} \end{cases} \tag{6.20}$$

And the discounted total cash flows are computed as:

$$DCF_t = (Core_t + Volatile_t + CouponCF_t) * d_t \tag{6.21}$$

6.6.4 Term deposit

In order to model cash flows of one term deposit the following assumptions are made:

- The amount held on term deposit cannot be withdrawn.
- Distinction is made between fixed and floating interest rate. In case of floating interest rate the repricing model is used.
- Distinction is made between EVE and NII. For the purpose of EVE the current term deposit is considered. For the purpose of NII, only the coupon cash flows are considered. In case the current term deposit matures it is replaces with new business with similar characteristics.

The NII coupon cash flows are as follows, where N is the notional of the term deposit:

$$CouponCF_t = C_t * N \tag{6.22}$$

where C_t can be either fixed or float. In case C_t is float then the repricing function is used. This is expressed as follows, where r_t, $s_{t,p}$ and $repricing_{t,x}$ denotes respectively the risk free rate at time t, the commercial margin of a given retail product p at time t and the repricing rate at time t with repricing frequency x:

$$C_t = \begin{cases} r_t + s_{t,p} & \text{if } C_t = \text{fixed} \\ repricing_{t,x} + s_{t,p} & \text{if } C_t = \text{float} \end{cases} \tag{6.23}$$

The total discounted cash flows are computed as, where d_t comes from the yield curve model:

$$DCF_t = \begin{cases} C_t * N * d_t & \text{if t} \neq \text{T} \\ (C_t * N + N) * d_t & \text{if t} = \text{T} \end{cases} \tag{6.24}$$

6.6.5 Interest rate measures: ΔEVE and ΔNII

From the generated cash flows of the retail products, two interest rate measures can be computed: ΔEVE and ΔNII. As mentioned in chapter 3, the calculation of EVE takes into account *all* cash flows: notional cash flows which are repayments cash flows and prepayments cash flows and coupon cash flows. The total cash flows of each retail products are then discounted by the yield curve plus the commercial margin of the respective retail product. For the purpose of calculating EVE the total discounted cash flows from liabilities which are demand deposits and term deposits are subtracted from the total discounted cash flows of assets which are mortgages and bullet loans. The equation to calculated EVE is outlined below:

$$\begin{aligned} EVE = \Bigg(\sum_{t=1}^{T} \sum_{i=1}^{K} DCF_{t,mortgage(i)} + \sum_{t=1}^{T} \sum_{i=1}^{L} DCF_{t,bl(i)} \Bigg) \\ - \Bigg(\sum_{t=1}^{T} \sum_{i=1}^{M} DCF_{t,dd(i)} + \sum_{t=1}^{T} \sum_{i=1}^{N} DCF_{t,td(i)} \Bigg) \end{aligned} \tag{6.25}$$

Where i is the index of product till the maximum of K, L, M, N. K is the total amount of mortgages, L total amount of bullet loans, M total amount of term deposits and N total amount of demand deposits. Subsequently, the ΔEVE can be computed as the difference between the EVE in a shocked and unshocked scenario, where the shocked scenario could be any scenario or the six scenarios specified by the BCBS.

$$\Delta EVE = EVE_{shocked} - EVE_{unshocked} \tag{6.26}$$

The short term interest rate risk measure ΔNII takes into account only coupon cash flows. NII is being calculated for three years, where each subsequent year is a cumulative sum of the previous and current year. For the purpose of calculating NII the coupon cash flows of the liabilities which are demand deposits and term deposits are subtracted from the coupon cash flows of the assets which are mortgages and bullets loans. The equation to calculate NII is expressed below:

$$\begin{aligned} NII = &\left(\sum_{t=1}^{T}\sum_{i=1}^{K} CouponCF_{t,mortgage(i)} + \sum_{t=1}^{T}\sum_{i=1}^{L} CouponCF_{t,bl(i)}\right) \\ &- \left(\sum_{t=1}^{T}\sum_{i=1}^{M} CouponCF_{t,td(i)} + \sum_{t=1}^{T}\sum_{i=1}^{N} CouponCF_{t,dd(i)}\right) \end{aligned} \tag{6.27}$$

where T is *12*, *24* and *36* for the first year, second year and third year respectively. Furthermore, i denotes the index of product till the maximum of K, L, M, N. K is the total amount of mortgages, L total amount of bullet loans, M total amount of term deposits and N total amount of demand deposits. The ΔNII is then computed as the difference between the NII in a shocked and unshocked scenario, as expressed in the following equation:

$$\Delta NII = NII_{shocked} - NII_{unshocked} \tag{6.28}$$

From the Δ measures, it is possible to examine whether there is interest rate risk in the portfolio in question. More specifically, when $\Delta\text{EVE} \neq 0$ or $\Delta\text{NII} \neq 0$, the portfolio is sensitive to interest rate risk. This may be positive or negative. For example, when the EVE measure is positive, an interest rate shock has a positive influence on the value of the portfolio. On the other hand, if the measure is negative, the portfolio loses value when a interest rate shock is applied. It may be for the banks best interest to hedge against these possible adverse volatilities. Thus, two hedging algorithms are constructed.

6.7 Hedging

In this section two hedging algorithms are delineated: BPV and notional hedging.

6.7.1 BPV hedging

This hedging algorithm can be used to hedge against ΔEVE. The BPV hedging algorithm starts with a bucket analysis. After the retail product cash flows are generated, the discounted cash flows are allocated into buckets to determine the interest rate exposure of the portfolio. For the allocation, the repricing moment is crucial. Furthermore, a distinction is made between retail products with fixed and floating interest rate. The repricing for the former is determined by its maturity, whereas for the latter, the repricing is the moment of change in the coupon rate.

As mentioned in chapter 3, there are 19 buckets in total with each bucket having a distinct time interval. However, for the purpose of this research the O/N bucket is represented by the second bucket. The main reason is to simplify MATLAB computations. In MATLAB, time t is represented by an 1*360 array, with each t corresponding to a month (total of 30 years). Thus, $t = 1$ is represents both buckets 1 (O/N) and 2 ($t \leq 1$) outlined in the BCBS reporting standards. Just like the retail products, the buckets are modeled as a *class* within MATLAB. Each instantiated *object* of the *bucket* class corresponds to a bucket b. This is shown mathematically by the following expression:

$$b = \begin{cases} 1 & \text{if t} \leq 1 \\ 2 & \text{if } 2 \leq \text{t} \leq 3 \\ 3 & \text{if } 4 \leq \text{t} \leq 6 \\ 4 & \text{if } 7 \leq \text{t} \leq 9 \\ 5 & \text{if } 10 \leq \text{t} \leq 12 \\ 6 & \text{if } 13 \leq \text{t} \leq 18 \\ 7 & \text{if } 19 \leq \text{t} \leq 24 \\ 8 & \text{if } 25 \leq \text{t} \leq 36 \\ 9 & \text{if } 37 \leq \text{t} \leq 48 \\ 10 & \text{if } 49 \leq \text{t} \leq 60 \\ 11 & \text{if } 61 \leq \text{t} \leq 72 \\ 12 & \text{if } 73 \leq \text{t} \leq 84 \\ 13 & \text{if } 85 \leq \text{t} \leq 96 \\ 14 & \text{if } 97 \leq \text{t} \leq 108 \\ 15 & \text{if } 109 \leq \text{t} \leq 120 \\ 16 & \text{if } 121 \leq \text{t} \leq 180 \\ 17 & \text{if } 181 \leq \text{t} \leq 240 \\ 18 & \text{if } 241 \leq \text{t} \leq 360 \end{cases} \tag{6.29}$$

After positioning all the relevant discounted cash flows in each bucket, the BPV can be determined. This measurement forms the basis of the BPV hedging algorithm. The BPV of a bucket b can be computed by equation 6.30, where B is the total discounted cash flows in a bucket b, which can be both positive or negative depending whether the assets or the liabilities are higher:

$$BPV_b = B_{b,+1bps} - B_{b,0bps} \tag{6.30}$$

A negative BPV implies that $B_{b,0bps}$ is higher than $B_{b,+1bps}$, meaning that the bucket will lose economic value if the interest rates goes up with 1bps. A positive BPV means that the economic value will go up if the interest rates goes up with 1bps. The total BPV of the portfolio can then be computed by:

$$BPV_{portfolio} = \sum_{b=1}^{18} BPV_b \tag{6.31}$$

If $BPV_{portfolio} \neq 0$, then the portfolio is sensitive to interest rates. To hedge against this, swaps are required. More specifically, the following equation for a hedge (where i is the number of swaps = 1,2 .... S) needs to be satisfied:

$$BPV_{portfolio} - \sum_{i=1}^{S} BPV_{swap(i)} \approx 0 \tag{6.32}$$

To determine the required swaps for the hedge, the *gap* has to be determined for each bucket b. There exist a *positive* gap in bucket b if the discounted cash flows from the assets within a bucket b is larger than the the discounted cash flows from the liabilities within a bucket b. For a *negative* gap it is the other way round. In mathematical terms:

$$DCF_{assets,b} - DCF_{liabilities,b} > 0 \text{ (positive gap)} \tag{6.33}$$

$$DCF_{assets,b} - DCF_{liabilities,b} < 0 \text{ (negative gap)} \tag{6.34}$$

This distinction matters, since each gap requires a different kind of swap for hedging. A positive gap requires a payer swap, in which you pay fixed (liability) and receive floating (asset). Whereas for a negative gap, one requires a receiver swap, where you receive fixed (asset) and pay floating (liability). In order to determine the BPV of the swaps, the present value of the swaps (and thus the discounted cash flows) needs to be computed.

The swaps are modeled in MATLAB. Each swap s consist of two legs: a floating and a fixed leg. The swap has the following properties: notional, tenor and coupon rate. The notional is the same for both legs. However, both tenor and coupon rate differ.

The coupon rate of a floating leg depends on the swap curve (or in this research the term structure model). The coupon rate of the fixed leg can be computed by setting the present value of the fixed leg equal to the present value of the floating leg. This is possible at time $t = 0$, because at swap initiation, market participants should be indifferent between paying (or receiving) the fixed rate over time or paying (or receiving) a rate that can fluctuate over time. Setting the present value equal to each other results in the following formula for the fixed leg rate:

$$c_{s,fixed} = \frac{(1 - d_{s,T})}{\sum_{t=1}^{T} d_{s,t}} \tag{6.35}$$

Both the payer and receiver swap generates different cash flows, because the floating and fixed leg are different. Now let swap s be either a payer or receiver swap (the notation s in a formula denotes a payer swap if s = 1 and denotes a receiver swap if s = 0):

$$s = \begin{cases} 1 & \text{if payer swap} \\ 0 & \text{if receiver swap} \end{cases} \tag{6.36}$$

The discounted cash flows ($DCF_{s,t}$) for a payer swap s can be computed by equation 6.37 (floating leg) and 6.38 (fixed leg), where $d_{t,s}$ is the discount rate for the payer swap s:

$$DCF_{1,t,floating} = (N_1 + N_1 * c_{1,float,t}) * d_{t,1} \text{ Receive floating leg if t = floating leg tenor T} \tag{6.37}$$

$$DCF_{1,t,fixed} = \begin{cases} N_1 * c_{1,fixed} * d_{t,1} & \text{Pay fixed leg if t = 1 ... T-1} \\ (N_1 + N_1 * c_{1,fixed}) * d_{t,1} & \text{Pay fixed leg if t = T} \end{cases} \tag{6.38}$$

The present value of the payer swap can then be computed by subtracting the fixed leg (liability) from the floating leg (asset):

$$PV_1 = \sum_{t=1}^{T} DCF_{1,t,floating} - \sum_{t=1}^{T} DCF_{1,t,fixed} \tag{6.39}$$

For a receiver swap $s = 0$ the discounted cash flows $DCF_{s,t}$ can be computed by:

$$DCF_{0,t,fixed} = \begin{cases} N_0 * c_{0,fixed} * d_{t,0} & \text{Receive fixed leg if t = 1 ... T-1} \\ (N_0 + N_0 * c_{0,fixed}) * d_{t,0} & \text{Receive fixed leg if t = T} \end{cases} \tag{6.40}$$

$$DCF_{0,t,floating} = (N_0 + N_0 * c_{0,float,t}) * d_{t,0} \text{ Pay floating leg if t = floating leg tenor T} \tag{6.41}$$

The present value of the receiver swap can be computed by subtracting the floating leg (liability) from the fixed leg (asset):

$$PV_0 = \sum_{t=1}^{T} DCF_{0,t,fixed} - \sum_{t=1}^{T} DCF_{0,t,floating} \tag{6.42}$$

To compute the BPV of the swap, the interest rate can be shocked with 1bps and the difference between the present value is the BPV of swap s:

$$BPV_s = PV_{s,+1bps} - PV_{s,0bps} \tag{6.43}$$

As mentioned earlier, the goal of the hedge is to match the BPV of the portfolio with the BPV of the swap. To do this, the BPV of each bucket is going to be matched with a swap, except for the first bucket. This is because every mismatch of a bucket b will be offset by creating a mismatch in bucket 1. If the assumption is made that the hedge is created and then immediately shocked (near t=0), it means that at initialization the created mismatch will not have any effect on delta EVE (because the discount factor with and without a 1bps shock is approximately equal $d_0 = \frac{1}{(1+r_t)}^0 = \frac{1}{(1+r_t+0.0001)}^0$). Thus, 17 swaps are required for 18 buckets each bought at $t = 0$. Each swap has a contractual maturity of the bucket. The floating leg rate can be observed through the swap curve (or the yield curve model) and the fixed leg can be computed by equation 6.35. To compute the PV and therefore the BPV, the only variable left is the notional of the swap.

The goal of the hedging algorithm is to alter the notional of the swap so that the BPV of the swap and bucket will match. In order to do so, the method employed in chapter 5 is used. The method requires the notional of a bucket b (total undiscounted cash flows in a bucket), multiply this with the BPV of the same bucket b and divide with the initial BPV of swap s computed with the notional of swap s set equal to the notional of bucket b. This is expressed mathematically as follows, where a_s and b_s are the asset (floating leg in case of payer swap, fixed leg in case of receiver swap) and liability leg (fixed leg in case of payer swap, floating leg in case of receiver swap) BPV for a swap s respectively:

$$N_s = \frac{N_b * BPV_b}{a_s - b_s} \tag{6.44}$$

By doing this, the notional for the swap can be computed. This notional creates a BPV that matches the BPV of the bucket. Notice that each swap will create cash flows. Thus, it is important to start setting a swap to the bucket with the largest maturity and then work backwards, as otherwise a new swap will influence the swap of an earlier bucket.

6.7.2 Notional hedging

The notional hedging algorithm is used to hedge against ΔNII. The algorithm starts with identifying the retail products that are exposed to earnings volatility. A product p is exposed to earnings volatility when the coupon rate is floating and funded by a fixed rate coupon or vice versa. When interest rate changes, the coupon of the floating will change but the fixed will not, resulting in earnings risk. To offset this, a single swap with the same notional and maturity as the original transaction can be used. This will be done for every floating rate coupon product. A payer swap is required for a floating rate liability, whereas a receiver swap is used for floating rate assets.

6.8 End of chapter summary

In this chapter the following research question is answered:

How can a model that hedges earnings and economic value volatilities be constructed?

This research question has been answered with the help of the following research sub-questions:

Which inputs are necessary?

Before the hedging algorithm can be implemented, first a cash flow generating model was constructed. The input variables of this model are the following: yield curve, discount rate and various retail products on the balance sheet of a retail bank. Decision has been made to include the following retail products: mortgage, bullet loan, demand deposit and term deposit.

What are the characteristics of these inputs?

The retail products used in the model have the following characteristics: notional amount, maturity, coupon which can be fixed or floating, SMM, repricing time and commercial margin.

Moreover, the cash flows of the retail products have to be modeled accordingly. Different models are implemented to take into account the different characteristics of the retail products such as prepayment model, outflow model and repricing model. The assets which are mortgage and bullet loans are exposed to prepayment risk. Demand deposits are non-maturing deposits. To estimate the core and volatile volume the outflow model is used. In case a retail product has a floating interest rate the repricing model. The input variables and its characteristics together with the relevant models enable to output the NII and EVE measures.

After creating the cash flow generating algorithm, the hedging was implemented. The first hedging technique is the BPV hedging. Firstly, a bucket analysis is performed by placing the generated cash flows of the portfolio in the relevant BCBS buckets. Secondly, the BPV per bucket is computed. Finally, swaps were chosen in such a way that the BPV of the swap and bucket matches.

For the notional hedging, an individual swap can be used for each floating rate coupon product with the same notional and maturity as the original transaction.

In mathematics you don't understand things. You just get used to them.

Johann von Neumann

7

Results

This chapter presents two case studies for the analysis of ΔEVE and ΔNII. The first section introduces case study I. This study aims to show the hedging techniques discussed in the previous chapter on a simple example. By using a simple example with one bullet loan, the analysis and results are more intuitive compared with a bigger portfolio. The latter is examined in the second section. Study case II considers a stylized portfolio of a retail bank, which is generated using the model in the previous chapter.

7.1 Study case I

To start off, the first study case considers a single bullet loan. The notional amount of the bullet loan is 100 and the contractual maturity is 5 years. Moreover, the loan has a floating coupon rate, which reprices every single year. The risk-free rate for the next period (and for the next few years) is known to be 3% and the interest margin is 2%. It is assumed that the prepayment rate is zero. This assumption is relaxed later on.

7.1.1 Bullet loan with BPV hedging

The first hedging technique used is BPV hedging. Since only one single bullet loan is investigated, no bucket analysis is required. The NII of the bullet loan is 5, 10 and 15 EURO for the first, second and third year respectively. To see the effect of fluctuations in interest rates on earnings, the term structure is shocked by 1bps. After a 1bps shock, the NII becomes 5.01, 10.02 and 15.03, making the ΔNIIs 0.01, 0.02 and 0.03 EURO for the first, second and third year. This means that higher interest rates are beneficial for the earnings of the bullet loan, since it results in a higher coupon rate and therefore more coupon cash flows.

The EVE of the bullet loan is 100 EURO. After a 1bps shock, the EVE becomes 99.567 EURO, meaning that the BPV of the loan is 99.567 - 100 = -0.0433 EURO. This means that the loan loses -0.0433 EURO in value whenever the interest rate moves up with 1 bps. This negative BPV is intuitive, because a higher discount rate results in a lower present value of the asset.

To hedge this bullet loan, one single payer swap is used with the same risk-free coupon rate and maturity as the loan. The notional amount required for the swap can be computed by using equation 6.44 in the previous chapter, which result in a notional value of approximately 120. This swap has a BPV of 0.0043, which is the exact opposite of the bullet loan resulting in a net BPV of zero. This is also shown in Figure 7.1.

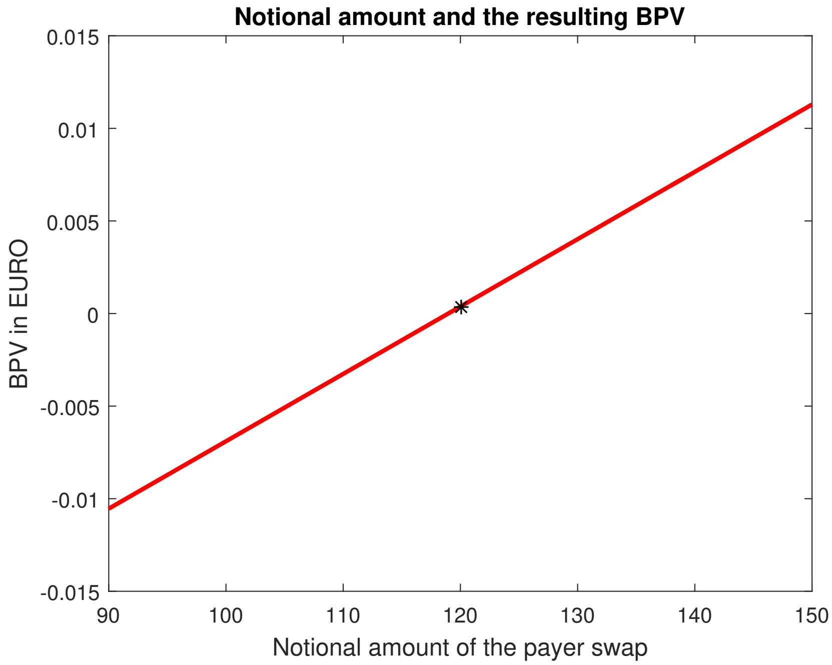

Figure 7.1: The BPV of the bullet loan plus payer swap for different notional values

The red line corresponds to the bullet loan + payer swap BPV for different notional values. The black cross shows that for a notional amount of 120, the BPV of the bullet loan and payer swap equals 0. In other words, the BPV hedge is reached with a payer swap with notional 120. Figure 7.2 shows the result of the BPV hedge in terms of ΔEVE and ΔNII for the bullet loan with -200bps till 200bps shocks to the risk-free rate.

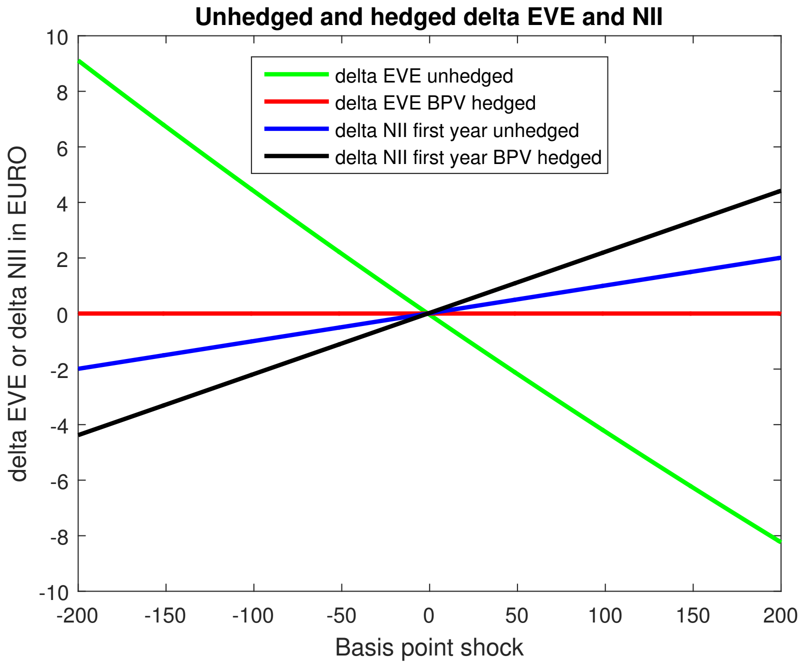

Figure 7.2: Interest rate exposure of the bullet loan for different basis point shocks after the BPV hedge

The figure shows that initially the bullet loan is exposed to economic value volatility (green line). The higher the shock, the more negative ΔEVE becomes due to a higher discount rate. On the other hand, a negative shock is positive for the bullet loan since ΔEVE increases. The straight red line near zero shows the BPV hedge. The ΔEVE is completely hedged, meaning that the bullet loan is not exposed to economic value volatility. A shock of 200bps has the same effect on the ΔEVE as a shock of 0bps, which represent the no shock base case. However, ΔNII becomes more volatile after the BPV hedge. This is shown by the slope. The slope of the black line is steeper than the blue line. Notice that only the ΔNII for the first year is plotted, otherwise there are too many lines.

7.1.2 Bullet loan with notional hedging

For the notional hedge a different kind of swap is required, namely a receiver swap. The floating rate of the bullet loan is offset by the floating leg of the receiver swap resulting in stable earnings. The notional required for the receiver swap is just the notional of the original transaction (100). This is shown in Figure 7.3. The figure shows the result of the hedge with different notional values for the receiver swap when interest rates move up with 1bps. Indeed, the notional is 100 for a complete earnings hedge.

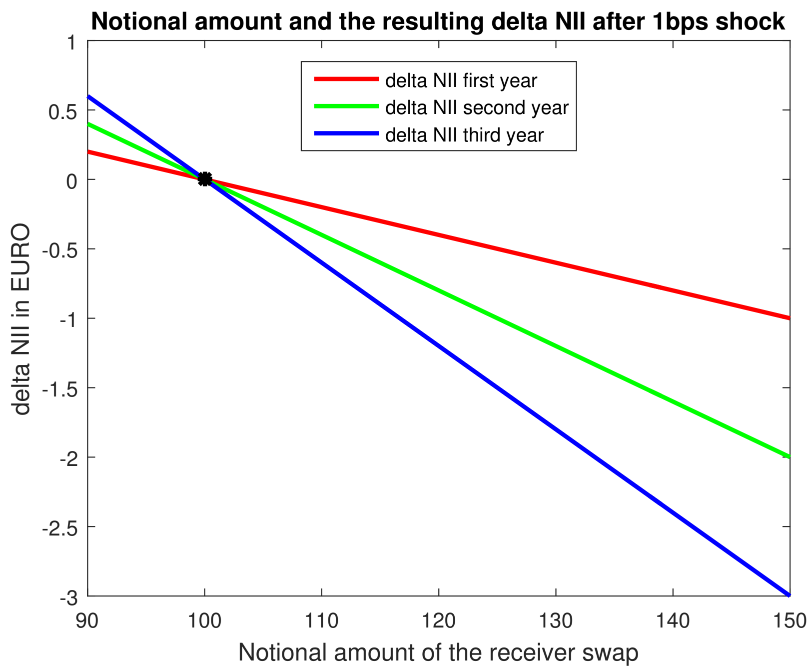

Figure 7.3: The delta NII of the first, second and third year of the bullet loan after 1bps shock for different notional values

Figure 7.4 shows the result of the notional hedge for the bullet loan with different shocks to the risk-free rate. The black line represents the ΔNII notional hedged for the first, second and third year (the ΔNII for the first, second and third year are actually not the same, but it results graphically in almost the exact line).

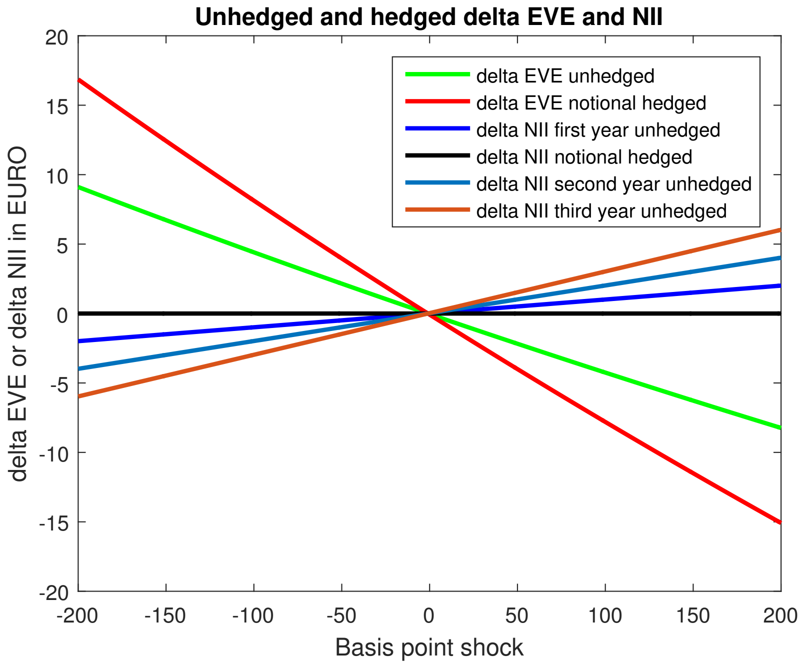

Figure 7.4: The delta NII of the first, second and third year of the bullet loan after 1bps shock for different notional

The earnings volatility is stabilized, since the black line is straight near zero for every bps shock. However, the economic value volatility has increased. This is shown by the slope of the red line. The slope of the red line is steeper than the green line.

From this simple case study, it can be concluded that there is a trade-off between ΔNII and ΔEVE. Whenever a BPV hedge is used, economic value is stabilized, but earnings volatility arises. On the other hand, whenever a notional hedge is used, earnings are stabilized but economic value volatility arises. Both volatilities cannot be hedged at the same time. This is intuitive since both hedges require different swaps with different notional values. A payer swap with a notional value of 120 does not have the same BPV as the receiver swap with a notional value of 100.

7.1.3 Effect of prepayments on hedging

The effect of prepayments on the previous hedges are considered in this section. It is assumed that the yearly prepayment rate for the bullet loan is 10%. The following graph presents the original BPV hedge with a payer swap with notional value of 120 with prepayments.

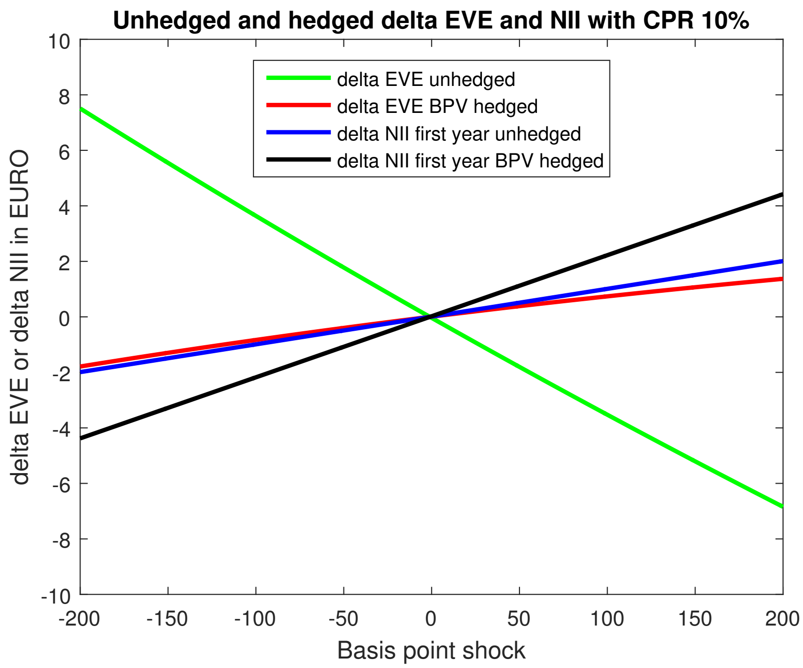

Figure 7.5: The effect of prepayments on the original BPV hedge

Figure 7.5 shows that the original BPV hedge does not work anymore. Unlike before the prepayments, the red line is not a straight line through zero, indicating an imperfect hedge. This outcome is logical as the prepayments changed the total cash flows of the bullet loan and therefore the BPV. The EVE after 1bps shock becomes 99.964 EURO making the new BPV after prepayments 99.964 - 100 = -0.036 EURO. The original BPV of the swap (0.0043) cannot offset the bullet loan.

The ΔNII of the first year, however, looks almost the same as before the hedge (see Figure 7.2). That is quite logical since the prepayment in the first year is low, resulting in minor changes in the cash flows.

The effect of prepayments on the original notional hedge, a receiver swap with notional value of 120, is shown in Figure 7.6.

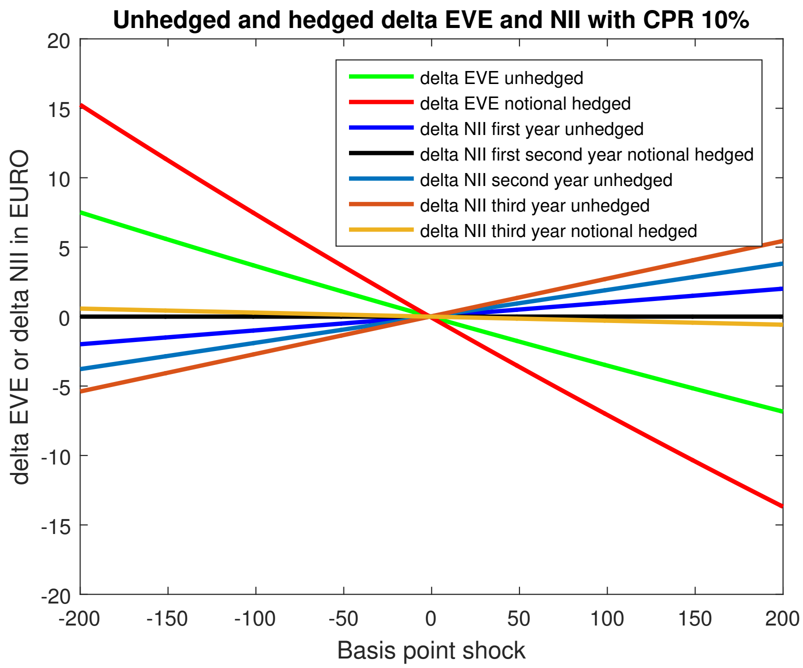

Figure 7.6: The effect of prepayments on the original notional hedge

The prepayment rate changes the cash flows of the bullet loan. However, the prepayment happens yearly, so the coupons cash flows changes are minor. The new NII for the bullet loan is 5, 9.5 and 13.55 EURO respectively (was 5, 10 and 15). As a result, the ΔNIIs do not change much. The notional hedge remains stable for the first and second year (black line). However, ΔNII for the third year has become less stable (yellow line), since it is not an entirely straight line anymore through ΔNII 0.

From Figures 7.5 and 7.6, it can be seen that the effect of prepayments on ΔEVE is more accentuated than the effect on ΔNII. This is explained by the fact that ΔNII only takes into consideration the first, second and third year, whereas ΔEVE takes into account the whole maturity of the bullet loan asset.

In practice, it is also possible to prepay a large amount of the loan. To show the effect of a higher prepayment rate on the original BPV hedge, the prepayment rate is raised to 50% annually. It is important to note that prepayment of a large proportion of a loan would not be possible without a penalty. Such a penalty is omitted in this research. The result is presented in Figure 7.7. The prepayment rate has made the original BPV hedge ineffective, as shown by the red line.

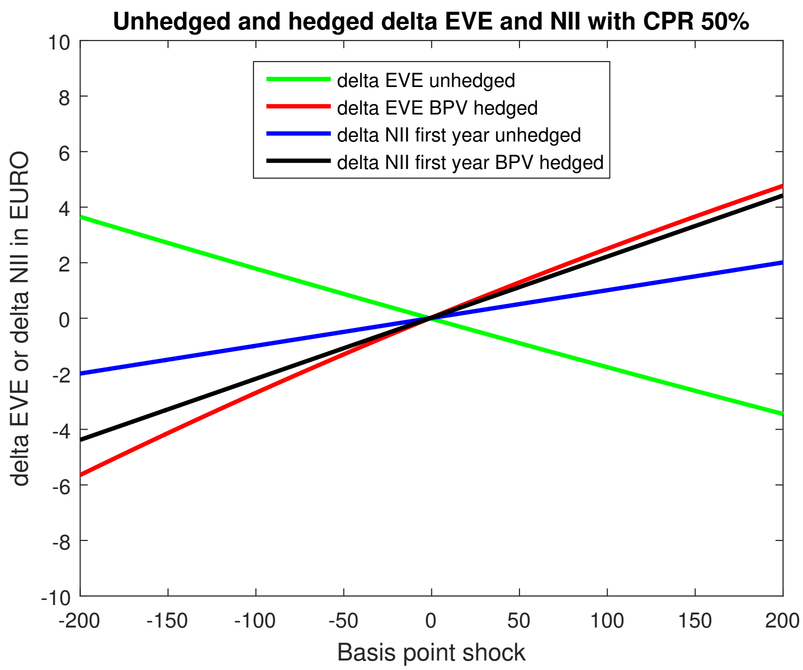

Figure 7.7: The red line becomes even more steep after a 50% prepayment rate indicating an imperfect hedge

To conclude, prepayments have effect on the original BPV and notional hedge. How large the effect is, depends on the prepayment rate and even the frequency of prepayment. Intuitively, a higher prepayment rate and a higher frequency of prepayment result in more change in the cash flows. This in turn changes the BPV of the bullet loan making the original BPV hedge ineffective. Since, the coupon cash flows changes as well due to prepayments, the notional hedge becomes imperfect as well. Thus, it is important to take prepayments into account before the hedge is made. However, prepayment may still make the hedge less effective if the true prepayment rate deviates from the expected prepayment rate used in the model.

7.2 Study case II

The previous example considered a very simple example. This section presents the results using a study case that considers a simple stylized portfolio of a retail bank X. The first sub-section introduces the specifics of the portfolio. Afterwards, the portfolio is analyzed with respect to six BCBS scenarios. Subsequently, the same portfolio is hedged both through BPV and notional hedging and analyzed using the scenarios again. The last part of the section introduces prepayment risk to the portfolio. All calculations in this chapter are done using the model developed in the previous chapter.

7.2.1 Portfolio background

The stylized portfolio of a retail bank X consist of N assets $A_t = (A_1, ..., A_N)$ and M liabilities $L_t = (L_1, ..., L_M)$ at a given time t. Each retail product has a given size, maturity, coupon type, interest rate, commercial margin, repayment schedule and repricing time. On the asset side, 30 bullet loans and 20 mortgages were generated using the cash flow generating algorithm. For all bullet loans, the notional amount is 100, with a fixed coupon of 3.45%, commercial margin of 2% and the contractual maturity follows a normal distribution with μ = 10 years and σ = 4 years. The mortgages also have 100 notional, with a fixed coupon of 4%, commercial margin of 2% however the contractual maturity is somewhat longer, following a normal distribution with μ = 20 years and σ = 4 years. The constant prepayment rate is assumed to be 0 for every asset product. This assumption will be relaxed later on.

On the liability side, the portfolio consists of 20 term deposits and 20 demand deposits. Again all the notional of the products are 100. However, the coupon and contractual maturity differs. The term deposits have a 2% coupon rate and a maturity that follows a normal distribution with μ = 10 years and σ = 3 years. The demand deposits are non-maturing deposits, however for research purposes a modeled maturity is assumed. The maturity of the demand deposits follows a normal distribution with μ = 20 years with σ = 3 years. The coupons of the demand deposit have a floating coupon rate that reprices every 3 months. The commercial margin for both product categories is assumed to be 1%.

7.2.2 Portfolio without hedging

The cash flows of the portfolio were generated and positioned in 18 buckets as determined by the BCBS (the overnight bucket was included to bucket 2, making bucket 2 the new bucket 1). The total market value (present value) of the balance sheet of bank X consists of 22649.37 EURO assets and 10602.56 EURO liabilities. The bank's exposure to interest rates is visualized in Figure 7.8.

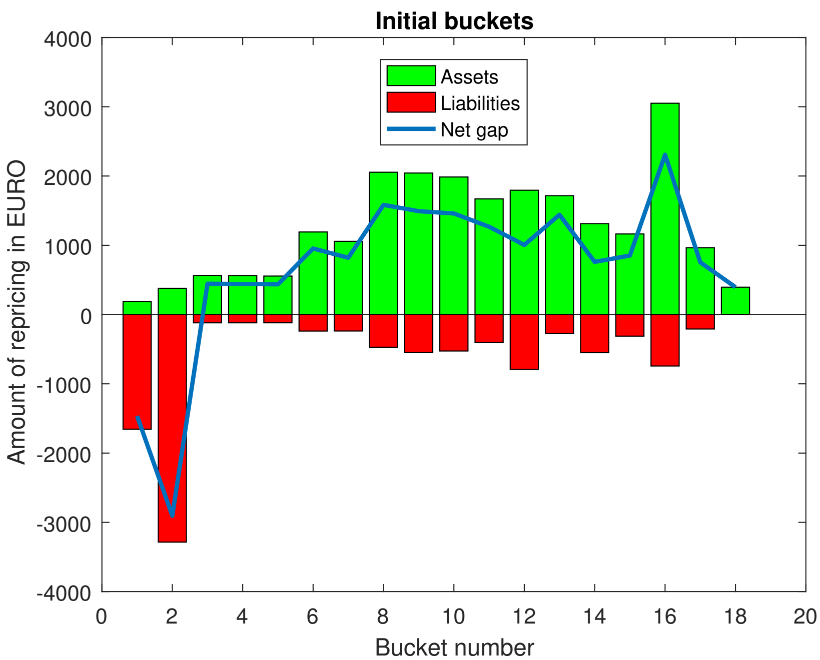

Figure 7.8: Initial bucket analysis, showing the interest rate exposures of each bucket

As shown in figure 7.8, bank X is exposed to interest rate risk, since there are mismatches in each bucket. More specifically, there is a positive mismatch (or gap) in buckets 3 till 18, and a negative mismatch in the first and second bucket. The EVE of the portfolio in the base case is: assets - liabilities = 22649.37 - 10602.56 = 12046.81 EURO. After a 1bps shock, the EVE becomes 12036.39 EURO. The BPV of the portfolio is therefore 12036.39 - 12046.81 = -10.41 EURO. This means that if the interest rate goes up with 1bps, the bank will lose 10.41 EURO in value.

The NII for the first, second and third year are respectively 1521,73, 2999.00 and 4423.72

EURO. When applying a 1bps shock, the NII becomes 1519.86, 2995.37 and 4418.44, making ΔNII -1.87, -3.63 and -5.28 respectively for the first, second and third year. This means that an interest rate shock of 1bps will be negative towards the earnings of the bank.

To show the effect of other interest rates scenarios on the portfolio, the term structure is shocked. The interest rate scenarios used are described in chapter 3. The effect that different interest rate scenarios have on the bank's X portfolio are depicted in table 7.1.

	Parallel Up	**Parallel Down**	**Short Up**	**Short Down**	**Flattener**	**Steepener**
EVE shocked	10176.33	14380.84	12047.38	12046.61	14679.89	10409.04
ΔEVE	-1870.48	2334.03	0.57	-0.20	2633.08	-1637.32
NII 1 shocked	1147.78	1895.68	1503.90	1527.89	1323.08	1720.38
ΔNII 1	-373.95	373.95	-17.83	6.16	-198.65	198.65
NII 2 shocked	2273.15	3724.85	2981.17	3005.16	2640.15	3357.85
ΔNII 2	-725.85	725.85	-17.83	6.16	-358.85	358.85
NII 3 shocked	3368.01	5479.43	4405.89	4429.88	3959.34	4888.10
ΔNII 3	-1055.71	1055.71	-17.83	6.16	-464.38	464.38

Table 7.1: Interest rate risk exposure with respect to EVE and NII without hedging

As can be seen the bank is exposed to both earnings and economic value volatilities. The economic value volatility is especially large for the parallel up, parallel down, flattener and steepener scenarios. In order to protect itself from the fluctuations in interest rates, bank X could enter into a swap position with another bank Y.

7.2.3 Portfolio with BPV hedging

In order to mitigate the economic value volatility, bank X could enter into several swap positions. The swap portfolio, in other words the hedge portfolio, is determined by the BPV hedging algorithm. The goal of this algorithm is to match the BPV in each bucket with a swap with the same BPV but in the opposite direction. The new buckets after the hedge is performed can be seen in Figure 7.9.

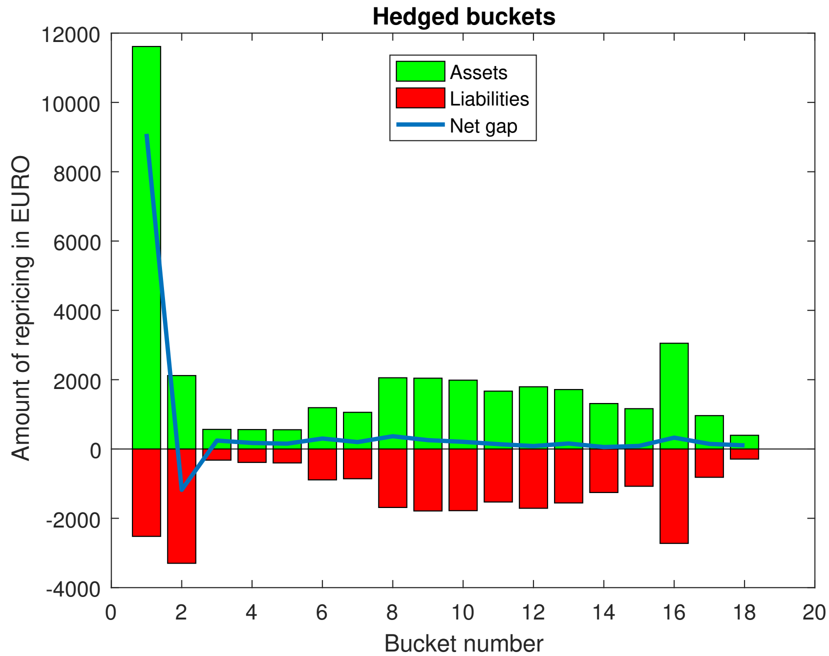

Figure 7.9: Bucket analysis after hedging

After the BPV hedge, the mismatches in the portfolio are almost gone, except for bucket 1, which increased. This is because a mismatch in bucket b will be closed by creating a mismatch in bucket 1. However, the interest rate exposure in bucket 1 is not substantial due to the time factor meaning that the shock in bucket 1 will have very minor effect on ΔEVE. Thus, the large amount of cash flow in the first bucket does not matter much for ΔEVE.

The new EVE of the portfolio is 15793.21. After a 1bps shock, the EVE becomes 15792.58 making the new BPV of the portfolio -0.63 EURO. This has decreased enormously compared with the BPV without hedge (-10.41 EURO). However, the NII also changed. The NII is 615.91, 1329.72 and 2224.22 before a shock and 629.57, 1356.53 and 2263.26 after a 1bps shock, making ΔNII for the first, second and third year respectively 13.66, 26.82 and 39.04 EURO respectively after a 1bps shock.

Figure 7.10 shows the implications of the hedge towards ΔEVE for ten basis point shocks. As shown in the figure, the value volatility decreased substantially.

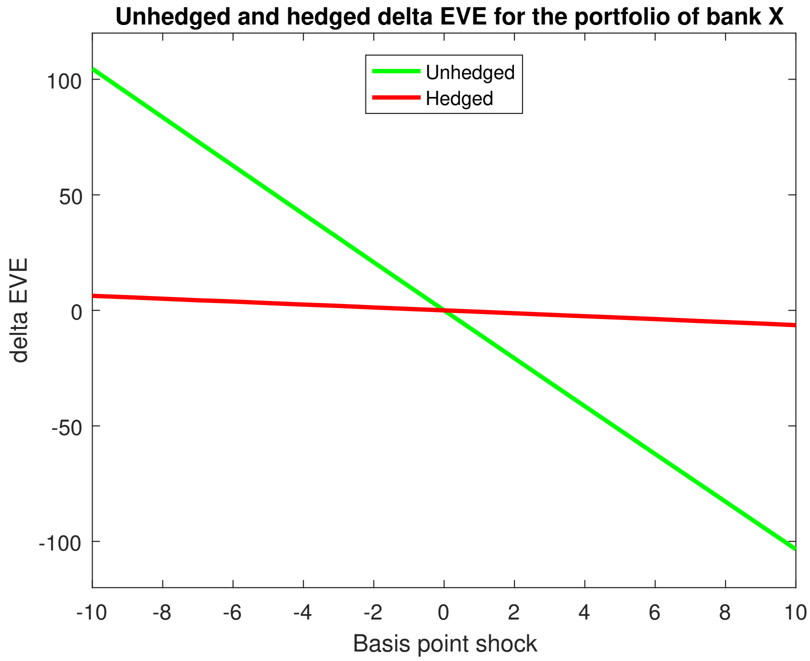

Figure 7.10: Delta EVE for different basis point shocks

The ΔEVE is also computed for the six BCBS scenarios. The results of the hedge can be seen in Table 7.2. The swaps stabilized the economic value enormously. However as can be seen there is enormous volatility in the earnings value.

	Parallel Up	**Parallel Down**	**Short Up**	**Short Down**	**Flattener**	**Steepener**
EVE shocked	15665.57	15916.75	15793.59	15792.44	15741.61	15772.71
ΔEVE	-127.64	123.54	0.38	-0.14	-51.60	-20.50
NII 1 shocked	3336.66	-987.99	743.93	571.89	2063.57	-831.08
ΔNII 1	2720.75	-1603.90	128.02	-44.02	1447.66	-1446.99
NII 2 shocked	6682.48	-1862.40	1457.74	1285.70	3976.95	-1315.84
ΔNII 2	5352.76	-3192.12	128.02	-44.02	2647.23	-2645.56
NII 3 shocked	7908.37	-5582.61	2352.24	2180.2	3055.98	-1200.82
ΔNII 3	7796.63	-7806.83	128.02	-44.02	5650.93	-3425.04

Table 7.2: Interest rate risk exposure with respect to EVE and NII with BPV hedging

7.2.4 Portfolio with Notional hedging

Instead of opting for a BPV hedge, the bank can also consider notional hedging. The aim is to stabilize earnings. Therefore, the NII metrics. Essential is to note that the earnings perspective assumes a constant balance sheet. For the portfolio in question the demand deposit portfolio is swapped with a payer swap. The new NII of the portfolio is 1328.19, 2656.37 and 3984.56 EURO respectively for the first, second and third year. The EVE of the portfolio becomes 13863.57 and the BPV becomes 24.43 EURO with the notional hedging.

This hedge stabilizes the earnings to the point where ΔNII is approximately 0. No matter how the interest rates moves, the earnings volatility is stabilized. However, value volatility still remains.

	Parallel Up	**Parallel Down**	**Short Up**	**Short Down**	**Flattener**	**Steepener**
EVE shocked	17991.19	8002.39	13885.93	13855.85	11117.88	14785.49
ΔEVE	4127.62	-5861.18	22.36	-7.72	-2745.69	921.92
NII 1 shocked	1328.19	1328.19	1328.19	1328.19	1328.19	1328.19
ΔNII 1	0	0	0	0	0	0
NII 2 shocked	2656.37	2656.37	2656.37	2656.37	2656.37	2656.37
ΔNII 2	0	0	0	0	0	0
NII 3 shocked	3984.56	3984.56	3984.56	3984.56	3984.56	3984.56
ΔNII 3	0	0	0	0	0	0

Table 7.3: Interest rate risk exposure with respect to EVE and NII with notional hedging

7.2.5 Effect of prepayments on hedging

In the previous sections the analysis was done without taking into account prepayments. In this section prepayment risk is incorporated in the portfolio, namely a monthly prepayment of 1% for every mortgage and bullet loan. In practice, this prepayment rate is very high. However, this prepayment rate is chosen intentionally to emphasize the effect of prepayment.

To analyze the effect of prepayments on hedging, the same swaps used in the original portfolio will be used for the hedge for the new portfolio with prepayments. Subsequently, this new portfolio will be analyzed with respect to the six BCBS scenarios. However, this time the scenarios will also incorporate prepayment shocks, since some scenarios will create an interest rate environment that stimulates prepayments (see chapter 3). The analysis of the scenarios on the EVE metric is given in table 7.4. Due to the prepayments, the original BPV hedge does not seem to work anymore and becomes ineffective.

	Parallel Up	**Parallel Down**	**Short Up**	**Short Down**	**Flattener**	**Steepener**
ΔEVE no P	-127.64	123.54	0.38	-0.14	-51.60	-20.50
ΔEVE with P	-1267	1454	9.37	8.33	1761	-1234

Table 7.4: Effect of prepayments on EVE with the original BPV hedge

The effect of prepayments on the notional hedge is given in Table 7.5. The notional hedging strategy with a payer swap for the demand deposit portfolio does not seem to work anymore.

	Parallel Up	**Parallel Down**	**Short Up**	**Short Down**	**Flattener**	**Steepener**
ΔNII 1 no P	0	0	0	0	0	0
ΔNII 2 no P	0	0	0	0	0	0
ΔNII 3 no P	0	0	0	0	0	0
ΔNII 1 with P	-477.60	482.40	-20.30	10.23	257.29	-252.47
ΔNII 2 with P	-995.20	964.00	-17.90	12.63	477.94	-468.34
ΔNII 3 with P	-1433	1447	-15.50	15.03	633.49	-619.09

Table 7.5: Effect of prepayments on NII with the original notional hedge

When purely looking at earnings (no delta), prepayments are the enemy of interest margin even though the prepayment percentage is low at 1%. For example, the earnings in year 1, 2 and 3 are respectively 1521,73, 2999.00 and 4423.72 EURO without prepayments in an unshocked scenario and 723.65, 1505.20 and 2418.23 with prepayments. This has a large contrast with study case I in the previous section. The ΔNII had minor changes with a 10% prepayment rate. The difference lies in the prepayment frequency and the time span. In study case II a monthly prepayment rate is used, whereas in study case I a yearly rate is used. The time span of the portfolio in case II is 30 years and the maturity of the product in case I is 5 years.

To conclude, study case II presented a more detailed portfolio which was generated using the cash flow generating algorithm developed in the previous chapter. Moreover, the portfolio was successfully hedged using BPV and notional hedging. The portfolio became largely insensitive to interest rate shocks. As expected, the original hedges became ineffective after prepayments. The deviation of the expected prepayments also effect the hedge. This means that the hedging should always be done after prepayments. Notice, that the hedging without prepayment is intentionally done so that the effect of prepayments on the hedge can be studied.

Also, essential is to note that the results are dependent on the assumption used to forecast the future cash flows and the discount rates used.

7.3 End of chapter summary

In this chapter the following research question is answered:

What is the effect of hedging economic value volatility on earnings and earnings volatility?

The BPV hedging method yields good results for the economic value as the ΔEVE was reduced enormously. However, the stability in the economic value came at the cost of increasing the volatility in the earnings and NII metrics. The notional hedging method reduces earnings volatility and stabilizes the earnings however, at the same time it increases the volatility in economic value.

This chapter also analyzed the effect of prepayments on the BPV and notional hedge. After prepayments the original BPV and notional hedge seems ineffective. That is because prepayments have effect on the cash flows. This in turn changes the BPV making the original BPV hedge ineffective. Since, the coupon cash flows changes as well due to prepayments, the notional hedge becomes ineffective as well.

Learn from yesterday, live for today, hope for tomorrow. The important thing is not to stop questioning.

Albert Einstein

8 Discussion

In this chapter the results and main findings of this research are discussed. Section 8.1 is dedicated to earnings at risk and section 8.2 examines value at risk. Afterwards, an elaboration is given on the trade-off between earnings and economic value perspectives. Finally, the effect of behavioral risk is emphasized.

8.1 Earnings at risk

Net interest income, or in other words, net interest margin is the difference between interest income and interest expenses. The net interest margin is a major indicator of the profitability of a bank. When a bank's portfolio is analyzed from an earnings perspective the focus is on NII. Earnings are sensitive to fluctuations in interest rates. The effects of such fluctuations can be enormous if interest rate risk is not managed adequately. Whether a bank's net interest margin is sensitive to movements in market rates depends on the bank's balance sheet composition. If assets and liabilities on the balance sheet of a bank have the same maturities and amounts there is no risk from interest rate fluctuations. The margin is fixed. For instance, when the banks portfolio is composed of a bullet loan with fixed interest rate of 5% and maturity of 5 years and a deposit with fixed interest rate of 3% and maturity of 5 years, the fluctuations in interest rates do not affect the bank's portfolio as the net interest margin of 2% is fixed for the next 5 years. Similarly, if the bank's portfolio is composed of floating assets and liabilities that reprice at the same intervals and have the same amounts there is no risk due to fluctuations in market interest rates. The margin is predetermined. Therefore, it can be stated that interest margin, or in other words, NII is at risk when interest income and interest expense in the bank's portfolio differ by the interest type (fixed or floating) which results in an asset and liability mismatch.

In case there is a mismatch in the bank's portfolio the objective is to reduce the risk to earnings that fluctuations in market rates pose and to lock the interest margin by securing the interest rate level for current and future transactions. This can be done by using interest rate swaps which enable to bridge the variations in assets and liabilities. The outcome is the desired fixed margin (EBF, 2006).

8.2 Economic value at risk

EVE is the difference between PV of assets minus PV of liabilities. When a bank's portfolio is analyzed from a value perspective the focus is on EVE. EVE is exposed to fluctuations in market interest rates due to the discounting factor. Market interest rates are the input for computing EVE. Therefore, even though there is no risk from the earnings perspective as the interest margin is fixed the value is exposed to fluctuations in the market interest rates.

In order to stabilize value the bank could enter into hedging positions such that the changes in EVE of the original portfolio is offset by changes in the hedging position in the opposite direction. Such a hedge portfolio can be constructed by entering a swap position such that the BPV of the original portfolio is offset by BPV of the hedging transaction. The change in net PV of the original portfolio would then be offset by the change in the hedging portfolio. Applying value hedging implies that the notional of the swap differs from the notional of the original transaction. The notional of the swap should be determined in such a way so that the desired BPV profile is achieved. The previous chapter showed that the developed BPV hedging method helps achieve with the hedge. Other methods that can be used is the rollercoaster swap. A rollercoaster swap which enables to set the notional of the swap transaction as desired over its maturity. Such a swap would enable to reach the desired BPV profile. However such a swap also presents a trade-off. The option to set the notional as desirable would turn out to be costly.

8.3 Trade-off between earnings and economic value perspectives

The trade-off between earnings and economic value perspectives, in other words in ΔNII and ΔEVE is attributable to the different characteristics inherent in these two measures and is the result of the interest risk strategies that are used to hedge them.

8.3.1 Aspects inherent to ΔNII and ΔEVE

The earnings perspective, in this research measured in terms of NII, and economic value perspective, measured in terms of EVE, are in itself a trade-off. Both metrics measure the same thing, which is IRRBB however, they have different assumptions, different inputs, are based on different formulas and lead to different outcomes and as a consequence results in different hedging strategies. The earnings perspective is a short term measure that considers coupon cash flows and thus aims to stabilize net interest margin. Economic value perspective is a long term measure of the present value of assets, liabilities and off-balance sheet items and thus aims to offset the changes in the value in the bank's banking book portfolio. The earnings perspective can be more related to market and changes in the market interest rates. The economic value uses input cash flows in its computations which are not included in calculating NII. Furthermore, many coupon rates offered by the retail bank are not perfectly linked to market interest rates. For instance, coupon rates on demand deposits are often modeled rates based on historical data or variable rates set by the bank itself.

8.3.2 Hedging

Earnings and economic value perspectives lead to contradictory risk reduction strategies. Hedges exist that could eliminate the associated interest rate risk. However, the hedges have the chance to eliminate the risk from earnings perspective or from economic value perspectives but not both as shown in the previous chapter. A combination of zeros and swaps would not reduce risk from both perspectives. In case earnings swaps were reduced, earnings risk would increase and in case value swaps were reduced economic value risk would increase. Meaning that reduced risk from one perspective would have to increase risk from other, thus creating a trade-off between these two risk measures. In connection with this, the following can be stated: Economic value volatility arises when there is no earnings volatility and earning volatility increases when there is no economic value volatility.

Figure 8.1 represents graphically a simplified illustration of the trade-off between earnings and economic value measures. It can be seen that earnings and economic value perspectives have an inverse relationship.

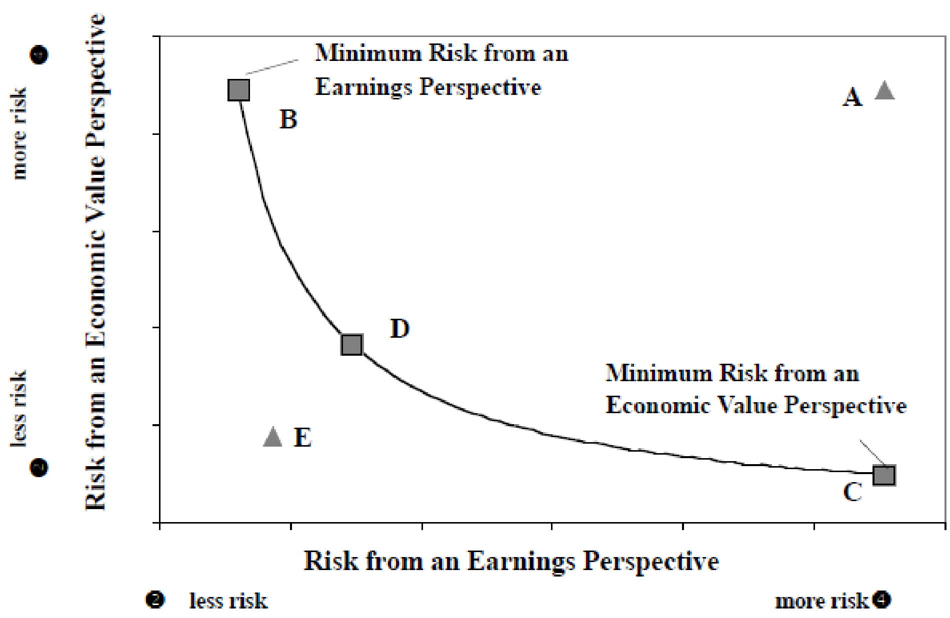

Figure 8.1: Trade-off between hedging earnings and economic value risks.
Source: Arnold (2000).

Point A represents an unhedged position. This situation is not desirable. Point B represents a situation with minimum feasible risk solely from the earnings perspective. This hedge significantly reduces the risk from the earnings perspective but results in full exposure to risk from economic value perspective. Point C represents a situation with minimum feasible risk solely from the economic value perspective. This hedge reduces significantly the risk from economic value perspective but does not reduce the risk from earnings perspective. Point D represents a hedge that simultaneously reduces risk from earnings as well as economic value perspective. Point E represents a situation that in this context does not exist. It is outside the feasible solutions. Studying closer the figure it can be seen that point D is at higher risk level than points B and C. The hedge that side by side reduces economic value and earnings perspectives implies larger exposure from both risk perspectives. Banks that are not aware of this trade-off may take actions that unintentionally increase interest rate risk (Arnold, 2000).

The results of this research can be related to the simple graphical representation of trade-off between earnings and economic value perspectives shown in figure 8.1. The results of this research are consistent with points A, B, C and E. Point A is the unhedged position, where earnings and economic value are both volatile. This is shown by the deltas in study case I if a 1bps shock is applied where ΔEVE: -0.043; ΔNII 1: 0.01; ΔNII 2: 0.02; ΔNII 3: 0.03; and study case II where ΔEVE: -10.41; ΔNII 1: -1.87; ΔNII 2: -3.63; ΔNII 3: -5.28. The deltas $\neq 0$, so there is interest rate risk exposure.

Point B stabilizes earnings but at the cost of economic value volatility. It has been shown in both study cases. This is shown by study case I where ΔEVE: -0.0696, ΔNII 1: 0; ΔNII 2: 0; ΔNII 3: 0; and study case II where ΔEVE: 24.43; ΔNII 1: 0; ΔNII 2: 0; ΔNII 3: 0.

Point C stabilized economic value volatility at the expense of earnings volatility. Study case 1 and 2 lead to the same outcome. This is shown by study case I where ΔEVE: 0; ΔNII 1: 0.022; ΔNII 2: 0.044; ΔNII 3: 0.066; and study case II where ΔEVE: -0.63; ΔNII 1: 13.66; ΔNII 2: 26.82; ΔNII 3: 39.04.

Point E does not exists as a trade-off between earnings and economic value perspectives has been identified. Either earnings volatility or economic value volatility can be reduced but not both.

To identify point D a scatter plot was made. The aim was to plot both ΔEVE and ΔNII for different hedges in study case I. Each hedge consist of 1 payer and 1 receiver swap with different notional values. The notional values are chosen in such a way that it is a X% of the notional value that result in the perfect hedge. So, for the payer swap it is 120 * X% and for the receiver swap 100 * Y%. Both hedges are used simultaneously. The goal is to see if there is a hedge that minimizes both EVE and NII to a certain extent. The scatter plot is shown in Figure 8.2. The applied weighting of immunization strategies leads to a linear inverse relationship between ΔEVE and ΔNII. Several points are highlighted for illustration purposes. For example, the green dot shows a '50% payer swap and 50% receiver swap' mix. In other words a payer swap with 120*0.50=60 notional value and a receiver swap with 100*0.50 = 50 notional value.

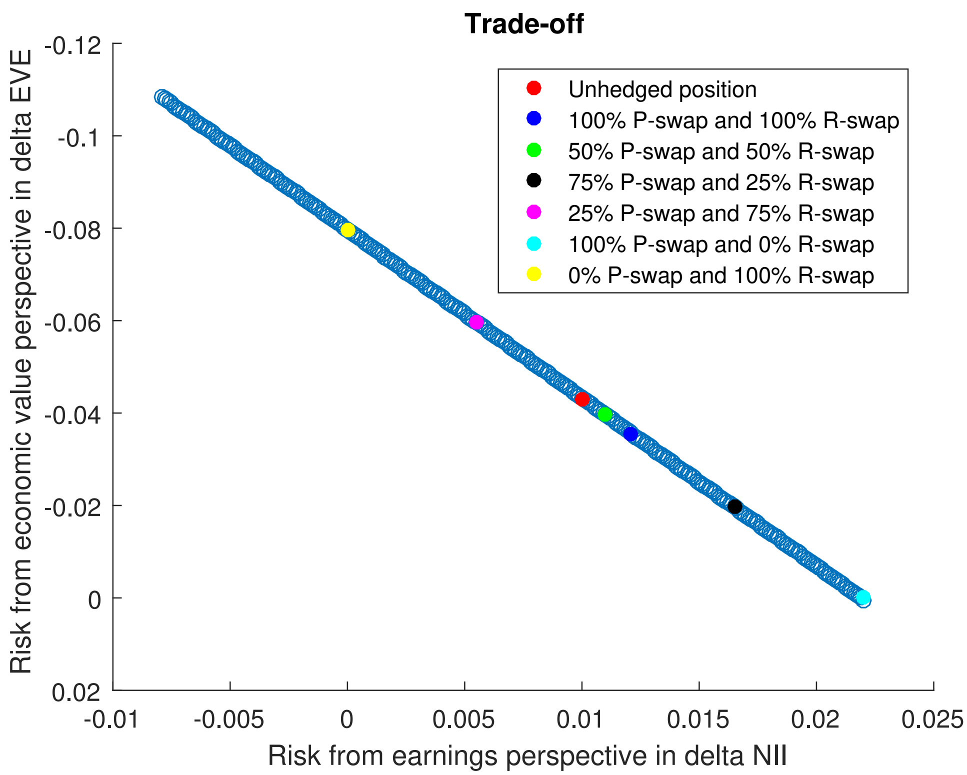

Figure 8.2: Scatter plot of delta EVE and delta NII for different hedges

The scatter plot in figure 8.2 represents a trade-off between earnings and economic value perspectives. A point D that represents a hedge that simultaneously could reduce risk from earnings as well as economic value perspective does not exist. Risk from earnings perspective can be achieved at the expense of increasing the risk from economic value perspective. Similarly, risk from economic value perspective can be reduced at the expense of increasing the risk from earnings perspective. This is shown by the linear inverse relationship in figure 8.2. Therefore, given the assumptions made, developed model and obtained results an optimal hedge that reduces the risk from both perspectives has not been found. This is emphasized by the fact that the unhedged position is on the same line with the other mixed hedges.

8.4 Optimal balance between earnings and economic value perspectives

Given the result in figure 8.2 a bank has many possible hedges to choose from. The *optimal hedge* is based on the bank's risk appetite. The risk appetite of a bank is stated in a Risk Appetite Statement (RAS). RAS defines the type and level of risk the bank is willing to accept in order to achieve its strategic objectives. Therefore, risk appetite can be seen as the bank's preference to increase risk from one perspective in order to reduce risk from the other perspective. In practice banks show preference towards reducing risk from the earnings perspective thus moving toward point B in Figure 8.1 and the yellow dot in Figure 8.2 (BCBS, 2016; Payne et al., 1999; Arnold, 2000). It can be argued that the optimum balance depends on the banks characteristics and balance sheet composition. For example, if a bank is concerned about their liquidity coverage ratio (LCR), which is an important measure of liquidity in Basel II regulations, an earnings hedge is preferred.

Economic value however, cannot be completely neglected. Although there is no recommended benchmark for earnings at risk, (BCBS, 2016) specifies an *outlier test* * based on economic value. Supervisors consider a decline in EVE of 20%, resulting from a prescribed interest rate shock scenario enough, to require the bank to take actions to reduce its exposure to interest rate risk. Thus, even if a bank decides that earnings

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*

$$\text{outlier test} = \frac{\text{Max(Change in EVE as result of +200bps shift, change in EVE as result of -200bps shift)}}{\text{Tier 1 + Tier 2 capital}} \tag{8.1}$$

hedge is the most important, it should do so in such a way that the EVE does not decline more than 20%.

8.5 The effect of behavioral risk

Behavioral risk can be seen as an enemy of the margin and value. Behavioral risk refers to prepayment risk and redemption risk.

Forecasting the prepayment of an individual product may be quite complex but for a larger portfolio of mortgages and loans the law of large numbers enables to better forecast prepayments. Loans and mortgages are exposed to prepayment risk. It implies that their expected maturity is different from the contractual maturity. Prepayments alter the net interest margin and may results in hedge ineffectiveness and over-hedging (EBF, 2006). In case a product or portfolio is hedged based on the contractual terms of the original transaction and prepayment occurs it may result in over-hedging. Over-hedging implies that the bank's offsetting position exceeds the bank's actual risk exposure. It locks more than required to protect the position. When the bank is over-hedged its ability to profit from the original position is affected. Therefore, it is more advisable to base hedging decision on the expected volume of future cash flows. A remedy that takes into account the prepayment risk provided that prepayment risk is modeled with the CPR would be an amortizing swap. So that the notional of the swap transaction decreases gradually as the notional of the original transaction. The principle is always to hedge the original transaction with a swap transaction that has the same characteristics as the original transaction. Another option to take the prepayment risk in the hedging strategy would be to reduce the duration of the swap so that it matches the duration of the original transaction accounted for prepayments.

Non-maturing deposits are characterized by the fact that they do not have a contractual maturity and thus they can be withdrawn at any time. Non-maturing deposits have low interest rates and constitute a large part of retail bank's liabilities. In practice, not all funds are being withdrawn instantaneously. A large portion of notional amount of non-maturing deposits is available as stable source of funding. Individual non-maturing deposits tend to vary however on a portfolio level, so they can be considered as a stable source of funding. Therefore, they can be regarded as long term deposits for risk management purposes. Banks use their historical experience to estimate the expected maturity of non-maturing deposits. Therefore, banks include core volume of the non-maturing deposits into the hedged portfolio based on their expected maturity. Yet the assignment of this core volume must be based on realistic and prudent assumptions (EBF, 2006).

The behavioral risk is evident and inherent in the banking book and underlines the importance of financial modeling.

8.6 Why it matters to stabilize economic value and earnings

Banks play a central role in the modern financial system and therefore they must be perceived as safe. When looking at the bank's safety, solvency and liquidity are considered.

For a bank to be solvent the economic value of the bank's assets must be worth substantially more than the economic value of its liabilities. The difference represents the capital buffer available to cover potential losses. A bank with stable economic value can be perceived as solvent. An insolvent bank cannot pay its liabilities, meaning it cannot repay its depositors, with the assets it owns even after selling all its assets because its liabilities are larger than its assets. Meaning that a bank can be liquid but insolvent.

Liquidity refers to the ability to meet cash demand as they arise. The liquidity levels of banks are crucial as the financial system becomes very fragile if banks do not have enough safety margins. Capital is the most important safety buffer as it provides resources to recover from potential losses and gives the stakeholder the confidence in the bank.

It is possible that the economic value of a bank's assets are sufficient to cover all of its liability claims but to have liquidity problems because the assets are illiquid and its liabilities have short-term maturities. Such situation may arise due to the inherent characteristic of a bank's business model which is maturity transformation mentioned in chapter 4. The main source of funding are non-maturing deposits that can be withdrawn at any time. Yet the average volumes show stability in normal times. However, if depositors start losing confidence in the bank they start to withdraw simultaneously. Therefore, even thought the bank's assets are larger than liabilities resulting in positive economic value and indicating solvency the bank might have liquidity problems (Elliott, 2014).

Furthermore, it is not uncommon for a bank to experience higher earnings but lower economic value. In particular when comparing environments with increasing and decreasing interest rates. Rise in interest rates would result in higher earnings but the economic value would decrease.

Concluding, it can be said that despite the identified trade-off both perspectives are important and require monitoring. Economic value perspective gives wider and long-term perspective of the balance sheet of a bank and as indicated by regulator the equity of a bank cannot be negative. Earnings perspective is a short term measure but indicated the liquidity level of the bank. For a bank, in order to remain in the business and not to get bankrupt the liquidity position is crucial. Therefore, a given bank that aims to stabilize value (earnings) still need to monitor its earnings (value) risk. The extent of how much risk can be incurred depends on the risk appetite and risk limits of the given bank. For instance, relating to the stylized portfolio in this research, let's assume that the bank does not want to lose more than 3 EURO in economic value per bps. In this case the bank can hedge its position in such a way that allows for some exposure in economic value risk such that the ΔEVE does not exceed 3 EURO. By allowing some risk in the economic value the bank can reduce some risk in the earnings.

The discussion in this section has shown the interrelation between earnings and economic value and the importance on why to stabilize them.

8.7 End of chapter summary

In this chapter the main findings of this research and its implications were discussed. Additionally, the final research sub-question has been answered:

Can an optimal balance be found between EVE and NII?

There is a trade-off between earnings and economic value perspectives. The earnings perspective in this research in measured in terms of NII and the economic value perspective is measured by the EVE. The trade-off between these two perspectives is attributable to the different inherent characteristics of these two metrics and to the different hedging techniques used to mitigate the volatility in these two perspectives. It can be stated that the economic value volatility arises when there is no earnings volatility and that the earnings volatility arises when there is no economic value volatility. Therefore, the optimal balance between earnings and economic value volatilities depends on the characteristics on the bank. The characteristics of the bank refers to its risk appetite and balance sheet composition. A bank that focuses on earnings would choose risk management techniques which aim to stabilize earnings volatility at the expense of economic value volatility. On the other hand, a bank that has the objective to maximize value would choose such risk management techniques to reduce value volatility at the expense of earnings volatility.

More questions may be easier to answer than just one question.

Imre Lakatos (1922–1974), Proofs and Refutations

9 Conclusion

This chapter concludes the research project. The first part of this chapter is dedicated to drawing the conclusion. Subsequently, the limitations of this research are pointed out. Finally, recommendations for further research are proposed.

9.1 Research conclusion

The purpose of this research was to investigate and gain insights into the trade-off between earnings and economic value perspectives by hedging the earnings and economic value volatilities. In order to reach the research objective a main research question was defined:

"***How can the earnings volatility and economic value volatility be managed with hedging techniques?***"

The main research questions was answered with the help of several research sub-questions:

1. What does it mean to measure interest rate risk from earnings and economic value perspectives?
    1.1. What is IRRBB?
    1.2. What are the regulatory developments regarding IRRBB?
    1.3. How can IRRBB be quantified?
    1.4. What are the differences and similarities between earnings and economic value perspectives?
2. What are the most important characteristics of a retail banking business?
3. Which hedging techniques can be used to hedge IRRBB?
4. How can a model that hedges earnings and economic value volatilities be constructed?
    4.1. Which inputs are necessary?
    4.2. What are the characteristics of these inputs?
5. What is the effect of hedging economic value volatility on earnings and earnings volatility?
6. Can an optimal balance be found between EVE and NII?

Research sub-questions **1.1 - 1.3** were answered in the *Literature Review* chapter and research sub-question **1.4** was answered in Δ*NII and* Δ*EVE Analysis* chapter. Research question **2** was answered in *Bank analysis* chapter, while research question **3** was answered in *Hedging* chapter. Research question **4** was answered in *Model* chapter. Research question **5** was answered in *Results* chapter. Finally, research question **6** was answered in *Discussion* chapter.

The research process can be depicted as follows. Firstly, a literature review was conducted to answer research question **1**. By answering this research question, a good understanding was gained regarding IRRBB and its sources, the different measurement techniques of IRRBB, the recent regulatory development regarding IRRBB and the main difference and similarities between the earnings and economic value perspectives. Earnings and economic value are two different perspectives to measure and manage IR-

RBB. They have different assumptions, employ different formulas and lead to different outcomes. In this research the decision was made to measure earnings perspective in terms of NII and economic value perspective in terms of EVE. These two metrics are in line with the BCBS final reporting standards. Consequently, the EVE and NII metrics were analyzed in more detail. More specifically, the underlying assumptions and computation methods were investigated and thus research question **1.4** was answered. This information forms the basis of the cash flow generator algorithm later on.

Yet, the understanding of IRRBB and the two different perspectives to measure it would have not been complete without a proper understanding of the business model of a retail bank. For that purpose research sub-question **2** was developed. This makes it clear what retail products a bank issues and what risks it incurs doing that.

Furthermore, research sub-question **3** was required to investigate which hedging techniques can be used to hedge earnings and economic value volatilities. Next to that, what is the effect of hedging economic value on earnings and vice versa. Two hedging techniques are used in practice to mitigate IRRBB volatility: notional hedging and BPV hedging. Both techniques use plain vanilla interest rate swaps. The difference lies in the determination of the notional amount of the swap. Notional hedging is applicable for hedging earnings volatility and BPV hedging is applicable for hedging economic value volatility.

After understanding the underlying assumptions in calculating NII and EVE, how it is hedged as well as how a retail bank works, a model was required to investigate the trade-off between earnings and economic value perspectives. Thus, research question **4** was needed. The developed model in this research consist of a cash flow generating algorithm that generates cash flows given a portfolio of retail products of a bank and outputs respectively the NII and EVE. To construct such an algorithm assumptions have been made regarding the modeling of the cash flows of various retail products, term structure of interest rates and prepayment risk among others.

Afterwards, the BPV and notional hedging was implemented in the model. As a result, the earnings and economic value volatilities could be hedged and the trade-off analyzed. This analysis was performed by applying the developed model to a single bullet loan and a fictitious portfolio of a bank, thereby answering research question **5**. To see the impact of changes of interest rates on earnings and economic value of a bank, six interest rate scenarios were used that were developed by the BCBS. The results showed that the BPV hedging method yields good result for the economic value as the ΔEVE was reduced substantially. However, the stability in the economic value came at the cost of increasing the volatility in the earnings and NII metrics. The notional hedging method reduces earnings volatility and stabilizes the earnings however at the same time, it increases the volatility in economic value.

Subsequently, the final research question **6** presents the implications of the results. The risk reduction from one perspective is reduced at the expense of risk increase in the other perspective resulting in a trade-off between earnings and economic value perspectives. The optimal balance between the earnings and economic value perspectives depends on the risk appetite of the bank. A bank that aims to stabilize earnings would use risk management techniques to reduce earnings volatility at the expense of economic value volatility. A bank that aims to stabilize value would use risk management techniques to reduce economic value volatility at the expense of increased earnings volatility.

Finally, the process of answering the main research question is perfectly illustrated by the quote of Imre Laktos at the beginning of this chapter that: *"More questions may be easier to answer than just one question."* This research has identified a trade-off between earnings and economic value perspectives. The economic value volatility arises when there is no earnings volatility and the earnings volatility arises when there is no economic value volatility. To find the optimal balance in between the trade-off between earnings and economic value is the task of a every bank. The optimal balance depends on the risk appetite of the bank. The bank defines which risks it is willing to accept in accordance with its strategic objectives and business plan.

9.2 Limitations

The results of this research are based on many assumptions and simplifications and thus cannot be regarded as absolute.

One of the limitations is basis risk. Basis risk is the impact of interest rate changes for financial instruments that have similar tenors but are repriced against different reference rates. Basis risk is a risk which was not described before the financial crisis of 2007. This risk is ignored in this research.

Secondly, fictitious data is used in this research. The fictitious data is generated using an algorithm. No real data from an actual bank was used. This shortcoming may pose in question the validity and reliability of these results.

Another limitation is that only two types of interest rate types are used in this research: fixed rate and floating rate. Variable rate which is a rate that is set by the bank itself, is out of scope.

Lastly, the results of this research are subject to model risk. Model risk occurs when the used model is inaccurate meaning that it does not measure what it ought to measure or when the model is used in a wrong way.

9.3 Future research

In order to expand the research done on IRRBB and in connection with the above stated limitations the following recommendations for further research are suggested:

- It is recommended to conduct a research on basis risk with multivariate yield curve analysis and its effect on earnings and value. Basis risk is a source and component of IRRBB.
- It would be suggested to investigate to what extent the earnings and economic value perspective could be combined. For instance, should the cash flows used to calculate NII be discounted as well? Australian regulations has already attempted to incorporate the combinations of these two perspectives.
- It would be recommended to research whether risk measured from earning and economic value perspectives could be analyzed simultaneously and hedges designed accordingly. It may be possible with a customized software.
- It would be interesting to investigate how banks in the Netherlands as well as in different countries approach the dilemma between earnings perspective and economic value perspectives.

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A

Funds Transfer Pricing

This appendix presents numerical examples of the various Funds Transfer Pricing approaches. Firstly, an example of single pool approach is given. Secondly, an example of multiple pool approach is provided. Thirdly, an example of matched maturity approach is illustrated. The description and examples are based on Pushkina (2013).

A.1 Example 1: Single Pool Approach

To illustrate how the single pool approach works a simple balance sheet is assumed. For reference see table A.1.

The retail bank has attracted customers who deposited their money in form of demand deposit with notional of 80, customer rate of 1% and unknown maturity as the customer may withdraw the money at any time; and term deposit with notional of 100, customer rate of 2% and maturity of 2 years. These funds are transformed into a bullet loan with notional of 100, customer rate of 8% and maturity of one year; and a mortgage

		Assets				Liabilities	
	Notional	Maturity	Coupon		Notional	Maturity	Coupon
Bullet loan	100	1	8%	Demand deposit	80	Unknown	1%
Mortgage	200	2	10%	Term deposit	100	2	2%
				Funding	120		3%
Total Assets	300			Total Liabilities	300		

Table A.1: Example balance sheet

with notional of 200, 10% customer rate and maturity of 2 years. This balance sheet, however, generates a deficit of 120. To obtain the missing funding Treasury borrows from the market at 3%. In single pool approach to arrive at the transfer prices firstly the average pool rates (APR) for liabilities and assets are computed. In case of the average pool rate of liabilities this is done by calculating the total cost of liabilities by dividing it by the outstanding liabilities:

$$AVR_L = \frac{N_i \times C_i + N_j \times C_j}{N_i + N_j} = \frac{80 \times 1\% + 100 \times 2\%}{180} = 1.55\% \tag{A.1}$$

In this example the average pool rate for liabilities is 1,4%. In case of average pool rate of assets the total income is divided by the outstanding assets. This is done in the following way:

$$AVR_A = \frac{N_i \times C_i + N_j \times C_j}{N_i + N_j} = \frac{100 \times 8\% + 200 \times 10\%}{300} = 9.33\% \tag{A.2}$$

The average pool rate for assets is 9.33%. To obtain the transfer price (TP) the average pool rate of liabilities is subtracted from the average pool of assets and divided by 2.

$$TR = \frac{AVR_L - AVR_A}{2} = \frac{9.33\% - 1.55\%}{2} = 3.89\% \tag{A.3}$$

After the TP has been obtained the transfer rates for assets and liabilities can be derived. The transfer rates for liabilities is calculated by adding the TP with APR_L. The TP for assets is calculated by subtracting TP from APR_A. In this example the transfer rates for liabilities and deposits are the following:

$$TR_L = TP + APR_L = 3.89\% + 1.55\% = 5.44\% \tag{A.4}$$

$$TR_A = APR_A - TP = 9.33\% - 3.89\% = 5.44\% \tag{A.5}$$

As the example illustrated the transfer rates for both liabilities and assets are the same: $TR_L = TR_A$. In single pool approach a single rate for transferring liabilities and assets is used.

After having obtained the transfer prices and transfer rates the profitability of each item on the balance sheet and the *NII* of the bank can be determined. The Treasury department splits the *NII* of the bank into *Commercial NII* and *Treasury NII* or *Transformation NII*. The sum of the Commercial NII and Transformation NII should be equal to the *NII* of the bank that is obtained from direct calculation by subtracting the interest expenses from the interest income. These above mentioned concepts are illustrated with numerical example. *NII* of the bank from direct calculation is as follows:

$$NII = (100 \times 8\% + 200 \times 10\%) - (80 \times 1\% + 100 \times 2\% + 120 \times 3\%) = 21.6 \tag{A.6}$$

The *Commercial NII* can be split into Liabilities and Assets and derived as follows:

$$\begin{aligned} Commercial\ NII_L &= (TR_L - APR_L) \times Outstanding\ Liabilities \\ &= (5.44\% - 1.55\%) \times 180 = 6.993 \end{aligned} \tag{A.7}$$

$$\begin{aligned} Commercial\ NII_A &= (APR_A - TR_A) \times Outstanding\ Assets \\ &= (9.33\% - 5.44\%) \times 300 = 11.67 \end{aligned} \tag{A.8}$$

The total *Commercial NII* is thus 18.663. The *Transformation NII* takes into account the required funding which arises as a consequence of 'maturity transformation'. The *Transformation NII* is calculated as follows:

$$\begin{aligned} Transformation\ NII &= (TR_L \vee TR_A - funding\ rate) \times funding\ amount \\ &= (5.44\% - 3\%) \times 120 = 2.928 \end{aligned} \tag{A.9}$$

Where:

- $\vee$ = or.

The overall bank's margin is the sum of *Commercial NII* and *Transformation NII* and should equal *NII*.

$$Bank\ margin = Commercial\ NII + Transformation\ NII = 18.663 + 2.928 = 21.6 \tag{A.10}$$

A.2 Example 2: Multiple Pool Approach

To illustrate the multiple pool approach the same simple balance sheet is assumed. Under multiple pool approach various pools are defined based on criteria such as maturity, repricing or product type. In this example the selected criteria is maturity. Therefore, two pools can be defined: *Pool 1* including products with maturity of one year; and *Pool 2* including products with maturity of 2 years. Each pool is assigned a transfer price by computing the average interest rate of assets in liabilities assigned to that pool as in the single pool approach. In this example the transfer rates for each pool are the following:

Pool 1

$$TR = \frac{AVR_L - AVR_A}{2} = \frac{8\% - 1\%}{2} = 3.5\% \tag{A.11}$$

$$TR_L = TP + APR_L = 3.5\% + 1\% = 4.5\% \tag{A.12}$$

$$TR_A = APR_A - TP = 8\% - 3.5\% = 4.5\% \tag{A.13}$$

Pool 2

$$TR = \frac{AVR_L - AVR_A}{2} = \frac{10\% - 2\%}{2} = 4\% \tag{A.14}$$

$$TR_L = TP + APR_L = 4\% + 2\% = 6\% \tag{A.15}$$

$$TR_A = APR_A - TP = 10\% - 4\% = 6\% \tag{A.16}$$

The multiple pool approach leads to different transfer rates for every pool. The transfer rates for both liabilities and assets in each pool are however still the same: $TR_L = TR_A$.

Moving to the calculation of the NII of the bank, the *NII* of the bank from direct calculation is the same as in the single pool approach:

$$NII = (100 \times 8\% + 200 \times 10\%) - (80 \times 1\% + 100 \times 2\% + 120 \times 3\%) = 21.6 \tag{A.17}$$

The calculation of the *Commercial NII* and the *Transformation NII* in the multiple pool approach differs as to the single pool approach as distinction is being made between the transfer rates of assets and liabilities based on their maturity. *Commercial NII* can be split again into Liabilities and Assets and derived as follows:

$$\begin{aligned} \textit{Commercial NII}_L &= (TR_L - APR_L) \times \textit{Outstanding Liabilities} \\ &= (4.5\% - 1\%) \times 80 + (6\% - 2\%) \times 100 = 6.8 \end{aligned} \tag{A.18}$$

$$\begin{aligned} \textit{Commercial NII}_A &= (APR_A - TR_A) \times \textit{Outstanding Assets} \\ &= (10\% - 6\%) \times 200 + (8\% - 4.5\%) \times 100 = 11.5 \end{aligned} \tag{A.19}$$

The total *Commercial NII* is thus 18.3. The *Transformation NII* also takes into account the different transfer rates. The *Transformation NII* is calculated as follows:

$$\begin{aligned} \textit{Transformation NII} &= (TR_L \vee TR_A - \textit{funding rate}) \times \textit{funding amount} \\ &= (4.5\% - 3\%) \times 20 + (6\% - 3\%) \times 100 = 3.3 \end{aligned} \tag{A.20}$$

In comparison to single pool approach the *Commercial NII* for both assets and liabilities has decreased and yet the *Transformation NII* in the multiple pool approach has increased. The overall bank's margin is again the sum of *Commercial NII* and *Transformation NII* and should equal *NII*.

$$\textit{Bank margin} = \textit{Commercial NII} + \textit{Transformation NII} = 18.3 + 3.3 = 21.6 \tag{A.21}$$

The multiple pool approach is more advanced to the single pool approach and is allows for more clear profit allocation among different business units.

A.3 Example 3: Matched Maturity Approach

To illustrate how the matched to maturity approach works the same simple balance sheet is assumed. In the matched to maturity approach a transfer curve is constructed which is the basis for determining the transfer rates. In the matched to maturity approach different transfer rates are assigned to every item on the balance sheet. The transfer rates depend on the maturity of the product under consideration. In this example the transfer curve is constructed based on EURIBOR data. The following market data is assumed: The EURIBOR for 1 days is 4%, for 1 year is 6% and for 2 years is 7%. In this methods there is no need to calculate average transfer rates as the transfer rates for the unknown maturities are 4%, for items with maturity of 1 year are 6% and for maturities of 2 years are 7%.

The NII can be determined from direct calculation and from split it into *Commercial NII* and *Transformation NII*. The NII from direct calculation is consistent with the the result obtained from the single pool and multiple pool approaches.

$$NII = (100 \times 8\% + 200 \times 10\%) - (80 \times 1\% + 100 \times 2\% + 120 \times 3\%) = 21.6 \qquad \text{(A.22)}$$

The *Commercial NII* is calculated taking into account market data as transfer rates and it is done as follows:

$$\begin{aligned} \textit{Commercial } NII_L &= (TR_L - APR_L) \times \textit{Outstanding Liabilities} \\ &= (4\% - 1\%) \times 80 + (7\% - 2\%) \times 100 = 7.4 \end{aligned} \qquad \text{(A.23)}$$

$$\begin{aligned} \textit{Commercial } NII_A &= (APR_A - TR_A) \times \textit{Outstanding Assets} \\ &= (8\% - 6\%) \times 100 + (10\% - 7\%) \times 200 = 8 \end{aligned} \qquad \text{(A.24)}$$

The total *Commercial NII* is thus 15.4. The *Transformation NII* is calculated as follows:

$$\begin{aligned} &\textit{Transformation NII} \\ &= (6\% - 4\%) \times 80 + (7\% - 7\%) \times 100 + (6\% - 3\%) \times 20 + (7\% - 3\%) \times 100 = 6.2 \end{aligned} \qquad \text{(A.25)}$$

$$\textit{Bank margin} = \textit{Commercial NII} + \textit{Transformation NII} = 15.4 + 6.2 = 21.6 \qquad \text{(A.26)}$$

B

MATLAB code

This appendix presents all the code written for the model developed in this research.

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