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DISSERTATION

Interest Rate Risk and Liquidity Risk of Banking Books in the Czech Republic

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Declaration of Authorship

The author hereby declares that she compiled this thesis independently, using only the listed resources and literature, and the thesis has not been used to obtain a different or the same degree.

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Prague, 16.4.2021

Signature

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Abstract

The thesis Interest Rate Risk and Liquidity Risk of Banking Books in the Czech Republic deals with the management of interest rate risk and liquidity risk stemming from the core banking system purpose – the maturity transformation. Across five articles, we provide comprehensive theoretical description, regulatory background, and develop models for embedded behavioural options of client products such as non-maturity deposits, with special focus on savings accounts in the Czech Republic in one of our case studies, or loans with prepayment option. We apply our models on the major Czech and Slovak banks and we calculate the exposure of those banks to interest rate risk in terms of regulatory guidelines. We derive that all banks in our analysis are positioned to benefit when interest rates increase as demand deposits like current accounts are traditionally stable sources of funding, while assets like mortgage loans or consumer loans reprice relatively quickly to new interest rates due to prepayment option as well as medium-term periods for which client interest rates are fixed. Such unified exposure of both banking systems can lead to systemic risk stemming from a squeeze in banks' profitability due to low or negative interest rates.

JEL Classification	G10, G21, G40,
Keywords	Interest rate risk, demand deposits, duration, liquidity risk, regulation, banking, embedded options

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Acronyms

AC	Analysed Countries
ADF	Augmented Dickey-Fuller
ALM	Asset and Liability Management
ALCO	Asset and Liability Committee
AR	Auto Regressive
AR	Moving Average
ARIMA	Auto Regressive Integrated Moving Average
BCBS	Basel Committee on Banking Supervision
CA	Current Accounts
CB	Central Bank
CC	Credit Cards
CEE	Central and Eastern Europe
CNII	Cumulative Net Interest Income
CNB	Czech National Bank
CZK	Czech crown
EBA	European Banking Authority
ECM	Error Correction Models
EVOE	Economic Value of Equity

HJM	Heath-Jarrow-Morton Model
IRRBB	Interest Rate Risk Management of the Banking Book
MD	Maturing Deposits
MRM	Market Risk Management
MVOE	Market Value of Equity
NBS	National Bank of Slovakia
NMD	Non-Maturity/nonmaturing deposits
OLS	Ordinary Least Squares
OVD	Overdrafts
RAS	Risk Appetite Statement
SA	Savings Accounts

1 General introduction to the thesis

The topic of the thesis entitled Interest Rate Risk and Liquidity Risk of Banking Books in the Czech Republic is the management of risks connected with the banks´ core responsibility, which is the maturity transformation of available funds. Banks are traditionally deemed to be subjects that collect funds from those who have an excess of them (usually in the form of deposits with short contractual maturities) and transfer those funds to those that are in need of them (usually in the form of long-term loans). Banks thus ensure the effective allocation of resources in the economy, which is a basis for stable economic growth. This activity, however, implies that banks´ are the owners of substantial maturity mismatches between their assets and liabilities. On top of that, almost all banks´ client products have several embedded options, such as prepayments, early termination or irregular cash flows of interest and/or nominal, due to which banks do not, in fact, know exactly how or when the product will mature or reprice. All those options must be properly understood, managed, steered and modelled by banks' analytical departments in Asset and Liability Management units (ALM) and Market Risk Measurement (MRM) units. The maturity mismatch, as well as modelling risk, result in the end in two major risks which those departments must manage in order to meet internal as well as external risk limits. Those risks are interest rate risk and liquidity risk. Interest rate risk arises from the different repricing times of assets and liabilities. Liquidity risk arises from the uncertain timing of cash flows.

Banks´ ALM and MRM units are operated to manage interest rate risk and liquidity risk properly for two main reasons. The first reason is the external regulatory guidelines that set a minimum requirement for the management of interest rate risk and liquidity risk. The two major standards followed by banks are the Interest Rate Risk Management of the Banking Book (IRRBB) guidelines issued by BCSB (2016) and

EBA (2018).[1] In the context of the European Union, EBA (2018) guidelines are incorporated into national legislation and become binding for local banks as well as internationally based bank groups. The second reason is the banks´ aim to maximize their profit under the acceptable amount of risk stated by the internal risk limit acceptance procedure (RAS – Risk Appetite Statement). The internal limits (requirements) cannot be more relaxed than external limits given by the regulatory guidelines.

This thesis aims to fill a gap in the academic research into IRRBB in the Czech Republic. Firstly, our aim is to describe the best practice methods behind IRRBB in one place and to an extent and at a level of detail not so far provided by any publication in our region, while also focusing on the specifics of our region. Secondly, our motivation is to assess the exposure of the Czech banking sector[2] to interest rate risk and liquidity risk. We undertake to do this in a total of five articles. To the best of our knowledge, we are the first to analyse this topic in the case of Czech banks from both a theoretical as well as a practical point of view to such an extent and in such a detail. The contribution of our thesis is, therefore, twofold. Firstly, our comprehensive description provides a full overview of the best IRRBB methods on the level of different banking products, and could, by itself, be used as an interesting methodological chapter in a textbook. Secondly, and in line with our aim, we calculate the amount of interest rate risk and liquidity risk Czech banks are exposed to, at the same time inherently assessing their compliance with the external regulatory guidelines and also possible threats stemming from the large commoditization of and similarities between Czech banks.

The Czech banking sector is largely focused on the commercial banking and quite competitive. Even though there is a mixture of large, medium-sized and small banks,

[1] We would like to point that this thesis, as a compilation of articles, refers to both new guidelines EBA (2018) and BCBS (2016) as well as to their previous versions. The most recent updates of guidelines are comparable to the older ones in major aspects.

[2] In our thesis, the majority of the research is dedicated to the Czech Republic, but we also closely analyse Slovakia in the last article *The Application of Interest Rate Risk Regulation on the Czech and Slovak Banking* Sectors and other neighbouring countries in the fourth article *Liability Risk Management of Central European Banks under New Regulatory Requirements*.

they all offer relatively alike bundle of products for households such as very similar unsecured consumer loans, housing loans, current and savings accounts. For corporate clients, the offer is more individually based on the asset side and depends on the client-bank relationship, but generally it covers basic short-term financing needs such as an overdraft facilities or a longer-term financing needs like investment loans and the project financing. On the liability side, corporate clients usually demand standard current accounts. Diversification through products on offer is thus not present to a large extent. Furthermore, the Czech banking sector is populated by 3 major players (Česká spořitelna, ČSOB and Komerční banka) and several medium-sized and small banks. Large banks define their own pricing strategies, but given the relatively large level of competition[3], the pricing mechanisms in each bank are always dependent on assumptions of what the competition would do or already does. Smaller banks often come with their own diversified pricing offers, but they are usually used as a short-term campaigns to attract clients. The Czech banking sector closely resembles a commoditized market (Teplý, 2014), where products on offer are very similar and clients decide which bank to select either based on their personal preferences or purely based on the price. To build a client-bank relationship, Czech banks aim in their campaigns to appeal to the personal preferences of clients and the close relationship with them through bringing more value than just the traditional banking – such advisory services to optimize financing, family financing, customized savings offers and other. This is very similar to the whole CEE region and the overall trend in the banking industry. The strong commoditization of the Czech banking sector implies challenges for IRRBB for local banks as they need to be aware of the client's response in case a competitor provides substantially better offer. This is mainly a concern in the relation to the embedded option like prepayments. Which we also analyse in this thesis. Table 1.1 summarizes the share of main product, which Czech banks had between 2015-2020 on their balance sheets.

[3] According to the CNB (2011) database, Herfindahl-Hirschman Index that measures levels of concentration has descreased to 1500 points, where it remains since end 2016.

Table 1.1: Balance sheet items of the Czech banking sector period 2015-2020

Assets	% share	Liabilities	% share
Cash and Balances with CBs	29%	Current accounts households and corporate	36%
Loans to customers	44%	Savings accounts	10%
Other loans (financial institutions)	5%	Term deposits households and corporate	16%
Investments	17%	Other deposits and liabilities (own issues, deposits from financial institutions and other)	28%
Other assets	5%	Capital	10%

Source: Author based on the CNB (2021) data

Internationally, there are several recent studies dealing with IRRBB and related to our research. For example, Chaudron (2020), Boungou (2019) and Gnan and Beer (2015) assess the validity of assumptions behind regulatory as well as banks' internal IRRBB methods and they discuss the effect of a low-rate environment on the banks' interest rate risk management. There is also a bundle of studies that investigate the effect of interest rates on a bank's profitability that is measured by bank's margins, for example, Alessandri and Nelson (2015), Borio, Gambacorta and Hofmann (2017), Molyneux et al. (2019), Bikker and Vervliet (2017), Claessens, Coleman and Donnelly (2017) and Demirgüç-Kunt and Huizinga (1999). Furthermore, Hoffmann et al. (2019), Chaudron et. al. (2018) and Ballester et. al (2009) calculate interest rate risk exposures of European banks. Additionally, there is also the research study published by the European Banking Authority EBA (2017a) in which they focus on risks coming exactly from the maturity transformation. Finally, there is a comprehensive survey by Delloite (2019) which delivers important insights regarding the practice in ALM units in European banks.

We will now briefly introduce the thesis articles: Firstly, three articles in this thesis focus on the interest rate risk and liquidity risk of the major source of funding for Czech banks – deposits. The first article, entitled *Duration of demand deposits,* was published as a part of the conference proceedings and is a theoretical article. In this article we describe how to model the behaviour and calculate the interest rate risk of demand deposits (current accounts and savings accounts) using the replicating portfolio approach. Compared to the original published version, the version in the thesis has been reworked and includes more details regarding demand deposits' models as well as more details regarding the replicating portfolio method. Secondly, we also outline the difference between the stability and riskiness of current accounts on one hand and savings accounts on the other. We discuss the fact that, by nature, savings accounts are less stable than current accounts, and we mention that, as such, savings accounts pose higher risk (in relative terms) than current accounts. This is why the second article, *Why are Savings Accounts Perceived as Risky Bank Products?* focuses only on savings accounts. It provides a comprehensive analysis of their interest rate risk. We decided to dedicate one full article to this topic as our aim was to test our hypothesis of the high level of riskiness of savings accounts and to evaluate the exposure of Czech banks to this risk. This article was prepared with data support from an anonymous Czech bank. In the third article, *Risk Management of Demand Deposits in a Low Interest Rate Environment,* we continue with our research, with a focus on the liquidity risk of deposits in the Czech Republic, and we pay special attention to the effects of a prolonged low-rate environment. While the first two articles are predominantly focused on demand deposits (current accounts and savings accounts) and their interest rate risk, in the third article we analyse liquidity risk by using a time series analysis and simulations and add an analysis of term deposits, which are also a relevant bank's balance sheet item.

The fourth and fifth articles in this thesis are dedicated to IRRBB of the entire balance sheet of the banks. In the fourth article, *Liability Risk Management of Central European Banks Under New Regulatory Requirements,* we analyse the structural risk drivers on the liability side of banks' balance sheets in the CEE region (Central and Eastern Europe), namely in the Czech Republic, Slovakia, Poland, Austria and Hungary, and we discuss the IRRBB regulation and its implications for the banking sectors in the CEE region. At the time of the publication of this article, this topic was relatively new and banks were dedicating extensive projects to bring themselves into the compliance with new guidelines. Currently, it is both a state of the art and the best practice to follow the guidelines we describe in this article.

The fifth article, *The Application of Interest Rate Risk Regulation in the Czech and Slovak Banking Sectors,* concludes this thesis and, as such, it not only puts together all the research inputs we gathered concerning the topic of our thesis, but also provides a comprehensive and detailed overview of IRRBB in the Czech Republic and Slovakia. It estimates the Interest Rate Risk of the Banking Book in terms of the Market Value of Equity (MVOE) and Economic Value of Equity (EVOE) of three selected major banks in the Czech Republic and three selected major banks in Slovakia. We model and evaluate the interest rate risk of banks' balance sheets, including the know-how gained from our previous research (and the articles presented here) for demand deposits, and we add an analysis of an early loan termination (loan prepayment in advance of a scheduled maturity, in part or fully), and its significant implications for a bank's interest rate risk and liquidity risk. We employ the methods set by the regulatory guidelines EBA (2018) and BCSB (2016) to obtain the Market Value of Equity (MVOE) and Economic Value of Equity (EVOE) of banks in both countries in order to assess if any of them could be potentially considered to have issues with compliance with guidelines, given the structure of their client assets and client liabilities. Apart from that, we assess whether banks will gain or lose under increasing/decreasing market interest rates. To sum up, this article not only presents the current state of IRRBB in the form of an academic research paper, but it also gives insights into the development of the profit of the banking sector in the Czech Republic based on the significant decrease in interest rates in 2020 due to the Covid-19 pandemic.

The remainder of the thesis is structured as follows. Each article has a dedicated section, which always starts with an introduction to the article (where it was published, an abstract and keywords) and later presents the article itself. The article entitled *Duration of Demand Deposits in Theory* is in Section 2. The impact factor article *Why are Savings Accounts Perceived as Risky Bank Products* is in Section 3.

The article *Risk Management of Demand Deposits in a Low Interest Rate Environment* is in Section 4. The article *Liability Risk Management of Central European Banks under New Regulatory Requirements* is in Section 5, and the impact factor article *The Application of Interest Rate Risk Regulation on the Czech and Slovak Banking Sectors* is in Section 6. Section 7 concludes the thesis and Sections 8 provides references. Additionally, Section 9 includes summary of the pre-defense reports and lists major changes in articles compared to the original published versions.

2 A Duration of Demand Deposits in Theory

2.1 Introduction to the article

Published as: Džmuráňová, H. and Teplý, P., (2015). Duration of Demand Deposits in Theory. Procedia Economics and Finance, 25, pp.278-284.

Abstract

This paper deals theoretically with the estimation of the interest rate risk of demand deposits, which are defined as non-maturing products without any liquidity or interest rate behaviour defined by a contract (unlike maturing products). Due to this fact, banks estimate liquidity and interest rate characteristics, including the duration of demand deposits, using their internal models. We also describe the procedure called "replicating portfolios" that can be used to estimate the duration of demand deposits.

Keywords: non-maturing accounts; demand deposits; duration; ALM; interest rate risk

JEL classification: C150, G21, G11

2.2 The article: The Duration of Demand Deposits in Theory

2.2.1 Introduction

This paper deals with the theoretical description of the estimation of interest rate risk of a subgroup of non-maturing products - demand deposits. Non-maturing products are banks' liabilities and assets that do not have defined contractual characteristics, i.e. their maturity is unknown and their interest rate behaviour (duration) is also unknown. Due to this, the interest rate risk management of non-maturing products is an art as well as a science. Maturing products, by contrast, have defined maturity and interest rate behaviour, and their interest rate risk management is therefore less complicated than the interest rate risk management of non-maturing accounts.

Typical maturing products on a bank's balance sheet are mortgages and consumer loans on the asset side and term deposits on the liability side. Typical non-maturing products on the asset side are overdrafts and credit cards, and current and savings accounts on the liability side. In this paper we focus on current accounts and savings accounts, and we denote both as demand deposits.

One of the principal responsibilities of Asset and Liability Management units ("ALM") in a bank is to estimate the market value of a bank in a changing interest rate environment. To do so, ALM needs to know all the liquidity (maturity) and interest rate characteristics (duration) of the products on the bank's balance sheet. In the case of maturing products, ALM uses contractual characteristics plus embedded options such as early withdrawals and prepayments to generate future cash flows from these products. Using these cash flows and using standard formulas for present value and effective duration, ALM is then able to estimate the market value and duration of maturing products, i.e. the interest rate risk of maturing products. On the other hand, in the case of non-maturing products, ALM must somehow estimate the maturity and interest rate behaviour of non-maturing products in the first place, as these are unknown. This paper describes the procedure how to estimate maturity and duration, i.e. the level of the interest rate risk of non-maturing products, particularly of demand deposits.

The main contribution of this paper is a theoretical description of the management of demand deposits, something that is, somehow, lacking in the Czech academic research, which is interesting, as the Czech commercial bank environment is one where demand deposits form a major source of funding. The following text is structured as follows: Section 2.2.2 presents the characteristics of demand deposits. Section 2.2.3 explains in detail demand deposits models and the procedure known as a replicating portfolio approach, and Section 2.2.4 concludes the paper.

2.2.2 Characteristics of demand deposits

Demand deposits are deposits redeemable on notice. In the Czech Republic, the main portion of demand deposits consists of current accounts (transactional accounts), even though lately the volumes of savings accounts (savings deposits) have increased rapidly, which is mainly driven by the low-rate environment and the entry on the market of small banks that make a bid for client deposits (and the client information) by offering relatively high yield bearing savings accounts. Demand deposits constitute a main source of a stable funding for Czech banks (46% of liabilities of Czech banks were demand deposits in period 2015-2020 (CNB, 2011)), especially current accounts (36%). The fact that these deposits are redeemable on notice means that a client has an option to withdraw a deposit on demand (the legal duration is one day). The bank, on the other hand, has an option to change the deposit rate on demand deposits as it wishes. This means that demand deposits are subject to embedded options. These embedded options make the risk management of demand deposits difficult.

But how, then, can we say that demand deposits, particularly current accounts, represent a stable source of funding for banks? It is because current accounts are transactional accounts; their main purpose is to provide transactional services to a client. Many of these transactions take place within one bank, and outflows are compensated by inflows, as transactions from other banks come to the bank. This is mainly true for large banks. Due to this, current accounts have a stable core, and due to this stable core balance, current accounts represent a stable source of funding for banks. This also implies that, even though the legal duration of current accounts is one day, the true duration of current accounts is much longer. Savings accounts, by contrast are savings instrument, not transactional ones. Due to this, savings accounts are a less stable source of funding for banks; more on this topic can be found in Džmuráňová and Teplý (2014) and Džmuráňová (2013)[4] and later in this thesis in Section 3. The main reason why savings accounts are a less stable source of funding lays in the fact that people expect some rate of return on their savings and if this is not provided, they may easily select different provider/bank.

2.2.3 Replicating portfolios and beyond

As a bank is a rational investor on the market, it does not invest demand deposits according to their legal maturity and duration which are on demand, but, rather, according to their estimated effective/modelled maturity and duration. Replicating portfolios are one of the procedures for the estimation of the duration and maturity of demand deposits. To construct a replicating portfolio, a bank needs to first estimate the liquidity and the pricing behaviour of demand deposits. To do so, a bank needs sufficient data history and to build 3 models: (i) a series of historical volumes of demand deposits that serves as an input to fit the volume model, (ii) historical observations of deposit rates that serve as an input to fit the deposit rate model, and (iii) historical market rates that serve to define a yield curve environment which may be necessary in case a bank wants to estimate effect on the maturity and

[4] For more details on the risk management in the financial services industry see, for instance, Resti and Sironi (2007), Diviš and Teplý (2005), Cimburek and Řežábek (2008), Stavárek and Vodová (2010), Rippel et al. (2012), Buzková and Teplý (2012), Janda et al. (2013), Jakubík and Teplý (2011), Mejstřík et al. (2014), Stádník (2013; 2014), Klinger and Teplý (2014), Zamrazilová (2014) or Teplý and Tripe (2015).

the duration of demand deposits under different interest rate environment. Replicating portfolios, however, are not the only way how to derive the duration and the maturity of demand deposits. Replicating portfolios are based on a principle of finding instruments with known maturity and duration that behave similar as demand deposits subject to wished conditions like margin maximization or its volatility minimization. The duration and the maturity of the replicating portfolio defines then the duration and the maturity of demand deposits. A bank can, however, use three models mentioned above directly to derive the maturity and the duration of demand deposits as well. Even though the focus of this article is to show the replicating portfolio approach, we will briefly outline the second option in this article too, and later in this thesis we will focus in more detail on this procedure. In the following text, firstly, we describe all these three models and then we describe the construction of the replicating portfolio and the estimation of the maturity and ultimately, duration of demand deposits.

2.2.3.1 Market rate model

A bank must calibrate a market rate model to a relevant benchmark rate or rates, as market rates are used as the main explanatory variables in deposit rate models and volume models and are also used to generate yield curve scenarios needed in case a bank wants to simulate realizations of market rates to see effect of different level of interest rates on the volume of demand deposits and deposit rates. Last but not least, discount factors are derived as well from the term structure models.

There are numerous interest rate models, and their full listing is beyond the scope of this paper. We therefore briefly list market rate models that have been used by the authors who modeled the duration of demand deposits. Each interest rate model has its advantages and disadvantages, and each is adequate for a different data series. Authors tend to use different models; many of them, for example, Brigo, et al. (2007) use the Vašíček (1977) model or the CIR model. On the other hand, Kalkbrener and Willing (2004) find that the two-factor Vašíček model does not adequately fit their data, and better calibration results were obtained by nonparametric HJM models. Nystrom (2008) also uses some extension of the Vašíček (1977) model, or more precisely of the Hull and White (1990) model, as the mean-reversion parameter is time dependent. Frauendorfer and Schurle (2006) fit the market rate to the two-factor Vašíček model.

We focus in more detail on the description of the one-factor Vašíček (1977) model. The Vašíček (1977) model is a one-factor differential and continuous expression of a short-term mean-reverting interest rate that is driven by one factor (in an environment with a constant market price of risk that is independent of time and interest rate – a risk neutral probability space) that follows the Ornstein-Uhlenbeck (OU) process proposed by Vašíček (1977):

$$\mathrm{dm_t} = \mathrm{a(b - m_t)dt} + \sigma \mathrm{dW_t} \qquad \textbf{Eq. 2.1}$$

In the equation Eq. 2.1, $\mathrm{m_t}$ is market rate, a is a speed at which market rate mean reverts to equilibrium b, σ is a volatility, t is a time period measured in months and $\mathrm{W_t}$ is a Wienner process which is a random process representing market risk factors. Brigo, et al. (2007) describe in the detail how to calibrate Vašíček (1977) to historical series of market rates, and the reader can refer there for a description of the procedure as well as for a description of how to derive yield curve scenarios and forward rates from Eq. 2.1 in Brigo and Mercurio (2001) as well as in Section 3.2.5. Despite its simplicity, we consider Vasicek's one-factor model as a sufficient model when its use is intended to simulate market interest rates and see the effect of changes in market interest rates on the volume of demand deposits and deposit rates. The focus is on the changes in such an analysis, not on the exact levels of interest rates.

2.2.3.2 Deposit rate model

The deposit rate model describes the dynamics of the primary expense of demand deposits - the interest rate cost paid to a client. Deposit rates are usually modelled with the following explanatory variables: current or lagged market interest rates, lagged values of deposit rates and product characteristics (savings, transactional, corporate, households). Deposit rates on demand deposits are characterized by an asymmetric adjustment as banks have a tendency to adjust deposit rates downwards earlier in a decreasing interest rate environment than in an increasing interest rate environment). Another common feature us the lagged reaction to market rates. A bank waits before changing deposit rates, as adjustment is costly and a bank wants to be sure that a trend in the change of market rates is a long-term rather than a short-term effect, as mentioned also in Mester and Saunders (1995). In addition, deposit rates are changed in discrete steps. This implies that estimated parameters for market rates are expected to be higher for decreasing market rates and smaller for increasing market rates and have an opposite sign. There are numerous empirical applications of deposit rate models that aim to assess these characteristics and the dynamics of deposit rates and we briefly mention some of them: the asymmetric adjustment and lagged adjustment feature is modeled using asymmetric adjustment models by Paraschiv and Frauendorfer (2011), Frauendorfer and Schuerle (2006), Maes and Timmermans (2005) and also in O'Brien (2000). Bloechlinger (2018), by contrast, fits the deposit rate using a logit model, which is a proper model as well in case a bank would wish to have many discrete characteristics like product types, for example, in the model. Finally, the deposit rate paid on demand deposits, which are deposits to households, is having an implicit floor, usually equal to 0 or 0.01% or the defined legal value by the jurisdiction. This is important embedded option in a low-rate environment that introduces stickiness in the pricing of otherwise interest rate sensitive deposit rates. Presence of the floor implies that banks cannot transfer negative interest rate environment costs to a client and even variable deposits behave as fixed products in the negative rates environment, with high values of convexity as shown also by Bloechlinger (2021). The effect of an embedded liability floor on banks' profitability have been recently often mentioned in studies that estimate the effect of the low or the negative interest rate environment on bank´s profitability, for example, in Borio, Gambacorta and Hofmann (2017) or Molyneux et al. (2019).

We would like to include into this list of possible models and focus in more detail on the cointegration analysis and ECM (Error Correction Models), as also done recently by Wang et al. (2019). We expect that banks aim to keep stable margins to limit the exposure to the interest rate risk. The stable margin assumption implies that there should be a long-term relationship between a deposit rate and a market rate. If this relationship does not exist, we can claim that the deposit rate is independent of movements in market rates, which is often valid for a transactional class of demand deposits (current accounts). We also should mention that this relationship may get distorted in the presence of the embedded floor of 0, which introduces challenging tasks for banks during a low-rate environment.

Cointegration analysis and ECM model belong standard time series methods and it is well described, for example in Hamilton (1994) and originally, in Engle and Granger (1987). First, we need to find a proof of the existence of the long-term relationship. If this fails, we can conclude that the deposit rate is independent from market rates and a bank can treat this product as a fixed product, which implies that demand deposits will reprice at the moment of the maturity. The long-term relationship must satisfy both a deposit rate and a market rate being integrated of order 1 and their linear combination being integrated of order 0. The model for the deposit rate is one of the general forms of the ECM equation where residuals u_t are integrated of order 0 and the deposit rate d_t is a linear combination of the market rate m_t.

$$\Delta d_t = k + \beta * \Delta m_t + \rho * (d_{t-1} - \delta - \alpha * m_{t-1}) + u_t \qquad \textbf{Eq. 2.2}$$

Coefficients α, β, δ, k and ρ are estimated (they does not need to be all significant), the second part of the equation includes the correction term that drives the long-term equilibrium and is estimated separately. β is a coefficient of changes in market interest rate. The model can also be extended for more lags and for positive and negative changes in interest rates. The term t is a time period measured in months. The easiest form of this model in practice would be to assume that changes in the market rate are immediately and fully transferred to the deposit rate. In such a case, a deposit rate model would simplify into the case where $\beta = 1$ and all other coefficients would be 0. This would exactly ensure a stable spread for the bank. This would, definitely, work only if the assumption of an embedded floor is ceased. However, not all changes in a market rate are immediately and fully transferred. Once a bank has the deposit rate model, the bank knows how it would price demand deposits under different interest rate environments.

2.2.3.3 Modelling of the dynamics of volumes

The main explanatory variables in a model that describes the dynamics of volumes are market rates, deposit rates, client characteristics (age, sex, occupation, region), product characteristics (deposit type, type of a client) and the macroeconomic variables such as the gross domestic product, inflation or monetary aggregates. Product characteristics are usually translated to models by a proper segmentation in which the model clusters are created based on the product characteristics. When it comes to other explanatory variables, in practice, only market rates or spreads between market rates and deposit rates are usually used as explanatory variables. Otherwise a bank would also need models to describe the dynamics of the macroeconomic variables. More models mean a higher model risk exposure. Again, we provide a brief literature overview of papers that deal with modelling of volumes on demand deposits: Bloechlinger (2018), Dewachter et al. (2006), Frauendorfer and Schuerle (2006), Kalkbrener and Willing (2004), Maes and Timmermans (2005), and O'Brien (2000) all fit volumes to a linear model. In contrast, Paraschiv and Frauendorfer (2011), fit volumes to a VAR model.

The volume dynamics of demand deposits can be driven by several factors such as increase in the monetary base, a number of clients or an increase in the average outstanding balances of clients since there are no other better reinvestment opportunities. The latter is mainly valid for the low-rate environment. One could argue that such a natural growth like an increase in the monetary base or a number of clients can be easily fitted by the time series analysis. The increase driven by the number of clients can be separated from the data by modelling the average balance per 1 client. Time series models are often used by the researchers as they can fit the volume dynamics quite well on the aggregate level. We do so as well in our analysis in Section 4. It is not so straightforward to take care of the dynamics that is driven by other factors such as transfers between products, leaving clients, incoming clients or factors resulting from interest rate environment. Time series models thus may not be the best approach, when it comes to modelling of dynamics of volumes on the microeconomic level. For the internal bank modelling, one would argue that banks' internal models should investigate such important microeconomic drivers that influence the development of the outstanding demand deposits balances.

The main purpose of the volume model is to enable the estimation of the maturity of demand deposits. The second objective can be a need to simulate possible development of volumes, which is an approach used in the dynamic replicating portfolio approach. To derive the maturity of demand deposits, a bank needs to derive the liquidity profile of the expected future cash flows. This means we talk here about forecasting. We denote the future forecast periods as t_p. Note that so far in the equations presented earlier, t was used to describe the modelling horizon. In contrast to this, the forecast period t_p is the time after the modelling horizon, when the forecast is done.[5] Kalkbrener and Willing (2004) propose to simulate different volume paths and to take always the worst possible case of the volume development. By this approach, they derive the minimum time during which a deposit stays on the balance. The liquidity profile is constructed from this minimum path of volumes and the monthly differences in forecasted volumes are considered as outflows. The weighted average maturity of these cash outflows is then defined as the maturity of demand deposits. The detailed procedure of this approach is described in Section 4, which investigates the problem also empirically. This approach, in our opinion, is more appropriate on the aggregate demand deposit

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[5] There are two types of periods in this paper. First, there is a period t, which is the period over which a model is done. It is measured in months and inherently, it are calendar dates, where the first month in the samle has index 1. We thus define $t = 1, \dots, T$. Second, there is the forecast period t_p. It is a period over which forecasts are done, where units are measured as months too. It may start right after t=T, but it is not a necessary condition. In practice, banks do projections every month using models with parameters that are calibrated usually on a yearly basis. We define $t_p = 1, \dots, P$.

level. Banks, however, have access to the deal level data and as we argued above, on the micro level, more appropriate methods should look in the detail on the development of the outstanding balances in relation to effects we mentioned above. The natural candidate in this case is the model that investigates development of the outstanding balances of single accounts.[6] Banks can already by default segment demand deposits by a client and the product characteristics and create different models for those. The model for the single account balances is combined with the model that derives how many accounts are surviving at the forecast period to derive the liquidity profile. Such a probability can be empirically estimated by the standard survival analysis, see for example Chapter 5 in Bohn and Elkenbracht-Huizing (2014) for one of the possible applications. In the survival analysis, the event of the closure of the account is considered as the account dead. The probability that an account will be closed can be modelled by a logistic regression. Using the fitted probabilities of the closure, a bank can create a standard survival function, which provides the amount of surviving bank accounts. The change in the number of surviving accounts is multiplied by the expected average balance. The result of it determines the outflow from a demand deposit portfolio. The average maturity *M* of demand deposits is than defined as the weighted sum of maturities of all outflows. The sum of all outflows is assumed to be equal to the initial balance *B* and regulatory limits are imposed if required. Formally, the liquidity profile of demand deposits using the survival analysis and the average balance model is constructed as follows:

[6] For the description of modelling of volumes, in terms of combining a survival analysis with the average balance model, not in terms of the actual presented average balance model, we were also inspired by our expert know-how, which enabled us to provide the description more on the micro-level – a bank level. This brings value added beyond usual academic research, that provides theoretical models for volume modelling only on the aggregate level. There is an exception of Chapter 5 of Bohn and Elkenbracht-Huizing (2014), though, where similar approach as we describe theoretically in this article, is used.

$$M = \sum_{t_p=1}^{P} \frac{O_{t_p}}{B} * \frac{t_p}{12}$$

$$O_{t_p} = \left(\widehat{S_{t_p-1}} - \widehat{S_{t_p}}\right) * N * AV_{t_p} \qquad \textbf{Eq. 2.3}$$

$$\widehat{S_{t_p}} = \prod_{i:t_{p_i} \le t_p} \frac{n_{i-}c_i}{n_i}$$

$\widehat{S_{t_p}}$ stands for a Kaplan-Meier estimator of a survival function of a portion of surviving accounts at t_p and it is assumed it equals to 1 at period 0. n_i is the number of accounts surviving at the beginning of the period t_p and c_i is a number of accounts closing at the period t_p. A period t_p is assumed to be expressed in months, but this can be customized. O_{t_p} is an outflow at the period t_p, *N* is the initial amount of accounts in a portfolio which is modelled. *B* is the initial balance in a portfolio that is modelled and AV_{t_p} is the forecasted average balance on a single account. The average balance itself is modelled over the modelling horizon, where t is again a period expressed in months, assuming we focus at dependence on market interest rates, for example as $g_t = \varepsilon + \tau * \Delta m_t + u_t$, where g_t is the monthly relative change in the average single account balances. One can also assume that the growth can be dependent on a previous growth or exhibit a trend, for which the proposed equation can be adjusted. AV_{t_p} is forecasted as $AV_{t_p} = AV_{t_p-1} * (1 + \varepsilon + \tau * \Delta m_{t_p})$. The forecasted market rate m_{t_p} is derived from the market rate model. ε is the natural growth of deposits and u_t are residuals that must meet criteria given the estimation method that would be used. This example of the average balance model assumes that differences in the average balance are driven by a drift coefficient and by changes in market interest rates. Particularly the coefficient τ is of importance as it defines a response of average balances to changes in the economic cycle. We expect an inverse relationship. Volumes on demand deposits are expected to increase when interest rates decrease as other reinvestment opportunities become scarce and people tend to gather larger balances on demand deposits. The opposite applies to increasing interest rates.

2.2.3.4 Replicating portfolio

Finally, we describe how the replicating portfolio can be constructed using the three models described above in the two possible applications. First, a bank aims to replicate future (forecasted) cash flows, which is an approach we describe as first. Second, a bank looks for the optimal replicating portfolio based on the history or based on the simulated historical data, which is a usual standard approach mentioned in the literature. This we describe as a second application. In both cases, banks aim to stabilize the interest rate risk of demand deposits.

Replicating portfolios that focus on replicating the forecasted cash flows are ideally constructed to replicate cash flows from demand deposits in such a way that the replicating portfolio consists of instruments with known maturities (and durations), whose cash-flows replicate cash-flows from non-maturing liabilities. Banks invest in these instruments under different weights in such a way that the margin is maximized or the least volatile. The maturity and the duration of the replicating portfolio is then calculated as the weighted maturity and duration of these instruments, and the interest income from the replicating portfolio is used to cover interest expense and provides income to the bank. To ensure liquidity, banks usually divide volumes into core and volatile parts. The core part is reinvested in medium-term and long-term instruments. The volatile part represents the amounts that change on demand deposits on a daily or monthly basis. The volatile part of a demand deposits is invested in short-term instruments which mature ideally in such a way that the maturing tranches cover daily withdrawals. This means that in practice, banks derive reinvestment weights in such a way that the maturity of the shortest liquidity outflows matches the maturity of the shortest reinvestment tenors in the replicating portfolio. For example, if an expected modelled outflow in the first forecast period is 10%, then a bank would replicate 10% of volumes as a 1-month reinvestment asset. If a bank finds out during a deposit rate modelling that the deposit rate does not exhibit dependence on market rates, then also the duration of those 10% of cash flows would be almost 1-month. If a bank finds an evidence for the dependence of the deposit rate on market rates, then it must be reflected accordingly. Assuming that a bank finds out that immediately one day after a market rate changes, the deposit rate changes, then the maturity of 10% of volumes would still be representable by the 1-month maturity reinvestment, but the duration would be 1-day. A relevant theoretical reinvestment asset would have to copy this set up too.

To derive the expected modelled outflows and the cost of deposits, a bank needs to use jointly all three models described above. The market rate model is used to derive interest rate scenarios for the forecast. The deposit rate model defines if there is a dependence on market interest rates and the deposit cost is simply defined as the outstanding volume multiplied by the deposit rate. The model for volumes determines the liquidity profile of demand deposits and it also brings insights if volumes are interest rate sensitive or not. Both the deposit rate model and the volume model can be dependent on market interest rates. This means both those models can provide different outcomes for different interest rate forecasts. Ultimately, a bank predicts future cash flows in the forecast periods t_p and their price from demand deposits using those models.

Once a bank derives the liquidity profile and the pricing profile of demand deposits, it may need to find out how to hedge it. The replicating portfolios approach provides answers for this. As Maes and Timmermans (2005) define, a bank may wish to either: (i) minimize the standard deviation of the margin or (ii) maximize the margin. This method assumes that demand deposits are reinvested into bullet (zero-coupon) instruments in such a way that weights of the shortest bullet reinvestment cover the short-term outflows of volatile demand deposit volumes while long-term bullet instruments have maturities equal to the time of outflow of stable deposits. The volatile demand deposit volume can be derived, for example, by simulating development of the demand deposits volume model under different interest rates and deriving minimums like we do in Section 4. Another option is to derive the volume that is expected to outflow as a result of the adverse interest rate shocks[7], such as those 10% outflowing in the first month we mentioned above. This portfolio as total generates reinvestment yield at each point in time. The margin from this portfolio equals to the reinvestment yield from the replicating portfolio minus how much a bank pays on the deposit portfolio. No short selling is assumed as weights of the reinvestment are expected to cover properly expected cash outflows as the replicating procedure is limited by the derived average maturity from the model – the procedure does not assume higher outflows than given by the model. The average duration and maturity of demand deposits are obtained as the weighted average duration and maturity of the replicating portfolio.

We will now provide an example of the first possible application of the replicating portfolio method, which is a simplified version of the procedure as it assumes the replication of the future liquidity profile only. On the other hand, the benefit of this example is that it well explains the idea behind this approach to the reader. Let's assume we have a demand deposit portfolio, for which following characteristics were established from the deposit rate model and the volume model: (i) 5% of volumes outflows each month in 12 months, (ii) 3% outflows afterwards each month, (iii) 7% outflows at 24 months (the final maturity) and (iv) the deposit rate is stable regardless market interest rates and equal to 0.1%. Volumes are stable and independent of market and deposit interest rates too.

First, we can conclude that all reinvestment instruments would be fixed to a maturity as the deposit rate is not dependent on market interest rates. This means that the duration is almost equal to the maturity. The average maturity of this demand deposit portfolio is 11.5 months. A bank aims to optimize the margin; this means a bank needs to look for the optimal reinvestment weights assuming a

[7] For example, the demand deposit volume model estimates that if interest rates increase by 1 unit, deposits decrease by 20% of 1 unit. A bank can decide to hedge the possibility of a large adverse shock of +2%. This shock would imply outflow of 40% of deposits immediatelly. This 40% of deposits should be considered as volatile and distributed to the shortest reinvestments in the replicating portfolio (up to 12 months).

condition that a bank can always cover at least outflowing volumes from the deposit portfolio with incoming maturing assets. For our simple example, we assume stable interest rates for three scenarios as given in CASE 1 – CASE 3 (Table 2.1) in the future and the will of the bank to achieve the maximum margin possible given the liquidity constraints.

Table 2.1: Reinvestment weights for the example of the replicating portfolio

		CASE yields 1		*CASE yields 2*		*CASE yields 3*	
Forecast periods t_p (months from now)	outflow demand deposit portfolio	yields - bullet	reinvestment weight	yields - bullet	reinvestment weight	yields - bullet	reinvestment weight
1	5%	4%	75%	0.3%	5%	0%	5%
2	5%	3.8%	0%	0.3%	5%	0%	5%
3	5%	3.6%	0%	0.4%	5%	0%	5%
4	5%	3.4%	0%	0.4%	5%	0%	5%
5	5%	3.2%	0%	0.5%	5%	0%	5%
6	5%	3%	0%	0.5%	5%	0%	5%
7	5%	2.8%	0%	0.6%	5%	0%	5%
8	5%	2.6%	0%	0.6%	5%	0%	5%
9	5%	2.4%	0%	0.7%	5%	0%	5%
10	5%	2.2%	0%	0.7%	5%	0%	5%
11	5%	2%	0%	0,8%	5%	0%	5%
12	5%	1.8%	0%	0,8%	5%	0%	5%
13	3%	2.1%	0%	0,9%	3%	0%	3%
14	3%	2.4%	0%	0,9%	3%	0%	3%
15	3%	2.7%	0%	1%	3%	0%	3%
16	3%	3%	0%	1%	3%	0%	3%
17	3%	3.3%	0%	1.1%	3%	0%	3%
18	3%	4.1%	3%	1.1%	3%	0%	3%
19	3%	4.4%	3%	1.2%	3%	0%	3%
20	3%	4.7%	12%	1.2%	3%	0%	3%
21	3%	3%	0%	1.3%	3%	0%	3%
22	3%	2%	0%	1.3%	3%	0%	3%
23	3%	1%	0%	1.4%	3%	0%	3%
24	7%	5%	7%	1.4%	7%	1%	7%
Average maturity	11.5		5.9		11.5		11.5
margin			4.07%		0.68%		-0.03%

Source: Author

Table 2.1 shows how the replicating/reinvestment portfolios should look like to ensure that a bank would maximize the margin. Our example in CASE 1 intentionally includes twice inverted yield curve to show the interesting outcome this procedure would lead to. To maximize the margin of a bank, it would look optimal to invest 75% of the demand deposits volumes into the shortest asset. The average maturity of this replicating portfolio would be 5.9 months, which is much less than what the model derives for this portfolio of demand deposits. Under the normal interest rate environment (the increasing yield curve) a bank reinvestment would not be so targeted to only some maturities/tenors and would much closely reflect the maturity structure of deposits – like in CASE 2. This shows that the replicating portfolio approach may lead to ambiguous results and that the set-up of the optimization procedure directly determines the possible outcome. Last but not least, the CASE 3 shows that given the liquidity constraints, a bank has to make some short-term reinvestments even if those do not provide relevant rate of returns, to properly hedge the liquidity risk of demand deposits. This can lead to the substantial margin squeeze, mainly during a low-rate environment.

The example above solely focused on the replication of the liquidity profile. It thus provides insights only regarding the average maturity. A similar procedure can be applied to derive the duration. Let us assume that the deposit rate model introduced in Section 2.2.3.2 shows that the deposit rate response to the market rate is lagged by 1-month and equal to 20%. This means if the deposit rate is currently 1% and market interest rates change by 1% immediately now, the deposit rate will be 1.2% after 1 month. This can be approximated by assuming that 20% of deposits has a repricing period (duration) in 1 month and 80% of deposits are considered as fixed, for example in the same way like in our example above. The duration profile[8] for our examples in CASE 1 – CASE 3 would look like as shown in Table 2.2. Similar pass-through approach is used in Wang et al. (2019), who derived it directly from the effect of changes (shocks) in market rates on deposit rates and considered also the effect of the lagged response.

[8] Please note this is not the duration in terms of interest rate risk – a discounted value change but rather a very simple approximation of time to reprice.

Table 2.2: The duration profile example 1 of the replicating portfolio

	Average maturity	Duration profile in months
model	11.5	9.42
CASE 1	5.9	4.95
CASE 2	11.5	9.42
CASE 3	11.5	9.42

Source: Author

In our example, we assumed stable interest rates also in the future. This implies potential reinvestments would be made at same rates and the banks' margin would be stable (not volatile). One can assume interest rates will not be stable as interest rates always exhibit some volatility, which can be quite significant in periods of stress. This would lead to margin volatility, potentially a lot in CASE 1, which is why such a strategy, even though resulting from the optimization procedure, may not be the best one. This issue is partially overcome by the fully fledged replicating portfolio approach, which we will describe in the following text. Nevertheless, other issues might arise, which we are going to comment on as well.

In the second application of the replicating portfolio procedure we focus on the standard replicating portfolio approach. There are two classes of the replicating portfolio models. Firstly, the static replicating portfolio models are based on a one-off calculation of amounts/weights of demand deposits reinvested in pure-discount instruments with different maturities (Maes and Timmermans, 2005; Kalkbrener and Willing, 2004). Then there are dynamic replicating portfolio models (Frauendorfer and Schuerle, 2006 and Dewachter, et al. 2006). The dynamic replication includes changes in the reinvestment weights based on simulations. Weights changes are based on the joint development of the simulated market rates, deposit rates and balances on demand deposits. The replication procedure is applied numerous times to the simulated models and optimums are selected. Frauendorfer and Schuerle (2006) claim that the dynamic replicating portfolio approach leads to a more optimal division into different reinvestments in such a way that the margin can be substantially larger under the dynamic approach than under the static approach. This is a natural conclusion as simulations can help to uncover outlier cases as well as to optimize the expected average returns.

We now in detail explain our proposal to the replicating portfolio method. The bank aims to minimize the volatility of the margin as well as to achieve the best possible return at the given level of risk. The replicating portfolio is constructed for t = 1, ...T periods, which correspond to the modelling horizon of all three models described above (not to the forecast periods t_p as we did in our first example). The aim is to find an optimal portfolio of zero-coupon bonds that ensures the lowest margin volatility while achieving the best return at this volatility. First important assumption is that banks do not invest deposits at one moment, hence we work with moving averages of zero-coupon bond yields. For example, the yield of the 5-year bond portfolio at the period t is a moving average of yields up to t-60 months. To derive moving averages for long maturities/tenors, we need to go more in the history than what would be implied by the modelling horizon. Using moving averages stems from the natural assumption that a bank will not invest all demand deposits at once. In practice, a bank continuously reinvests inflows and outflows from demand deposits. Moving averages work perfectly as a proxy for such a portfolio reinvestment. In the static replication, those yields are defined by the real historical development moving averages. In the dynamic replication, those yields are a combination of the real observed yields before the modelling horizon (before t=1) and n-times simulated yields derived from the simulation of the market rate model. The replication of demand deposits (both static and dynamic) is a subject to the following constraints and assumptions:

- A bank is constructing the replicating portfolio from moving averages of money market interest rates and moving average of zero coupon bonds with yield y_{it} and with maturities mat_i, where *i = 1, ..., n*. Each reinvestment has a weight w_i, which is stable in time. Reinvestments are assumed to be linear and continuous, as naturally covered by using the moving average yields. All demand deposit volumes are reinvested at each point in time ($\sum_{i=1}^{n} w_i = 1$). As opposed to our first example, reinvestments weights w_i cover both liquidity and interest rate risk. The duration of the selected replicating portfolio thus directly defines the duration of demand deposits.

- The average maturity of the replicating portfolio is same or lower as the average maturity of demand deposits M. M is derived from the model, as for example in Eq. 2.3. In the static replication, this is one of a time input. In the dynamic replication, it is an outcome of one simulation round. This implies the following condition: $\sum_{i=1}^{n}(w_i * mat_i) \leq M$. Maximum allowed value mat_i is also a subject to a constraint. It cannot be more than the maturity of the last cash flow of demand deposits. It is assumed that the model covers liquidity risk of demand deposits fully and no further outflows are expected – the average maturity estimation is defined as conservative. This implies no short selling is assumed in the procedure, not even in the dynamic replication approach given the condition described in this paragraph. We should point out that this constraint is added by us, we did not see it used by other researchers. We see it as a natural condition for the reinvestment. Otherwise, the procedure cannot meet the constraints of liquidity risk, which we see as the primary condition that must be met. Furthermore, the procedure would tend to select the highest and the lowest volatility reinvestments, which are usually the long-term assets. Such replicating portfolio would not consider the liquidity profile of demand deposits at all. The results presented by Maes and Timmermans (2005) and Dewachter, et al. (2006) seem to be exactly the subject to this issue. This is a problem in terms of the liquidity risk management. Due to this, we add the maturity constraint to our application. Some other authors proceed similarly, for example, Kalkbrener and Willing (2004).

- The bank aims to optimize the expected margin under the optimum level of risk. The margin *mr* is calculated in each period t as a return from the portfolio minus a deposit rate expense: $\sum_{i=1}^{n}(w_i * y_{it}) - d_t$. The expected margin is defined as the average margin: $E(mr) = \frac{\sum_{t=1}^{T}(\sum_{i=1}^{n}(w_i * y_{it}) - d_t)}{T}$. The deposit rate d_t is either the directly paid deposit expense during times or, in case of the dynamic replication, the simulated expense coming from simulations of the deposit rate model.

- The replicating portfolio procedure consists in finding the optimal weights w_i such that a Sharpe ratio[9] $\frac{E(mr)}{\sigma}$ is maximized. In other words, the maximum expected margin over the given level of risk represented by the margin volatility σ is selected as the best outcome. This iteration is done by looking for maximum Sharpe ratio for all possible combinations of w_i subject to the constraints defined above. In the static replication, it is done once given the constraints. In the dynamic replication, constraints themselves are dynamic and simulated and afterwards, for the given simulation outcome of constraints, the replicating procedure is concluded.

- For the sake of receiving reasonable replicating portfolios and to ensure that the optimization reaches solution, further constraints are defined as:

  - The margin should be positive.

  - The number of n-reinvestment assets is limited to the selected maturities a bank wishes to reinvest into.

  - Weights w_i are expected to reach rounded values like 5%, 10%, etc.

There are certain limitations to the replicating portfolio method. It has been argued that the static replicating portfolio methods provide ambiguous results and are prone to model risk. Under different stress tests, the duration estimate (as well as the average maturity) is found to differ substantially in Maes and Timmermans

[9] Sharpe ratio is used also by Maes and Timmermans (2005) in one of their applied cases, as well as in Dewachter, et al. (2006).

(2005). This is also shown in our example. The underlying liquidity outflow (the maturity of deposits) differed significantly from the optimized replicating portfolio average maturity in CASE 1. To account for this limitation, Maes and Timmermans (2005) propose relying on several models at once, not only on the static replication. Another possibility is to employ the dynamic approach. The dynamic replicating portfolios, apart from a historical estimation, include simulations. This enables a bank to obtain an expected margin for several scenarios of the market rate, as each market rate scenario results in different deposit rates and volumes, which subsequently means different reinvestment. This ensures more advantageous reinvestment than the static replication, where deposits are redistributed based on the one-off calculation of weights. On the other hand, the dynamic models' results are prone to same issues as the static models, even though simulations can indeed uncover sources of potential risk better as several hundreds of cases are analysed.

In our view, the big drawback of the replicating portfolio approach is not the ambiguous outcome itself, but the set-up of constraints which directly influence this outcome. Including the constraint on the volatility of the expected margin inherently implies that the procedure will tend to select corner cases like (i) a yield with significantly lower volatility in case of the deposit rate that is fixed (i.e. does not depend on interest rates – for example in case of transactional current accounts) or (ii) a yield with the most stable spread to deposit rate (in case of the deposit rate that is changing in relation to development of market rates), regardless if such a case provides good rate of return or not. Volatility of the moving average yields will not significantly differ between different maturities and the procedure will tend to select relatively properly, but it can fail in the two cases mentioned above and lead to ambiguous outcomes. Such outcomes may not be the best reinvestment opportunity and it may also not be the optimal hedge for the interest rate risk of demand deposits. It is solely a hedge for margin stability and as such it should be used and understood.

Apart from the class of replicating portfolio models, there are different approaches mentioned in the literature how to derive the maturity and the duration of demand deposits. These are for example the net present value Monte Carlo simulation approach, the Option Adjusted Spread mentioned by Maes and Timmermans (2005) or the valuation model developed by O'Brien (2000). Additionally, Dewachter, et al. (2006) estimate simultaneously the dynamic replicating portfolio model and the no-arbitrage multi-factor flexible-affine term structure model. The authors argue that the no-arbitrage multi-factor flexible-affine term structure model can estimate the value of non-maturing liabilities, which is its main advantage when compared to the dynamic replication as well as the static replication. These models do not directly look for the optimal instruments to precisely hedge the interest rate risk and the liquidity risk of demand deposits, but rather estimate the maturity and the duration of demand deposits directly from models. Same models as described in this article are still used to derive the liquidity and the interest rate profile of demand deposits. We also argue that the maturity and the duration of demand deposits can be directly derived from the three models mentioned above. The liquidity profile of demand deposits is defined by volumes model and future cash flows are known in each period t_p. The deposit rate model defines the interest expense and the market rate model defines yield curve environment. The present value of demand deposits is than calculated as the discounted value of all future cash flows of the interest and the nominal from demand deposits. We opt for this approach in our following article in this thesis in Section 6 as we consider it as a superior approach to the replication procedure, mainly in terms of an estimation of interest rate risk of demand deposits within IRRBB.

One should however mention that there is a significant area in a bank where the replicating portfolio approach can be used. The benefit of the replicating portfolio approach is its clear connection between the risk of liabilities and the risk of assets. The approach enables a bank to find a set of assets that are optimal to hedge the volatility of margin. For this reason, it makes sense to employ the replication approach internally in a bank as a tool to ensure a stable margin for business units while the unit responsible for interest rate risk and liquidity risk (ALM) manages those risks separately. This separation is done through the Funds Transfer Price System and the replicating portfolio approach that aims to stabilize the margin is one of possible tools how to approach this.

2.2.4 Conclusion

In this paper we describe non-maturing products with primary focus on demand deposits. Demand deposits are non-maturing products redeemable on notice with inherited embedded options – a client's right to withdraw a deposit on notice and a bank's right to change a deposit rate on these deposits as it wishes. Embedded options make the interest rate risk management of demand deposits difficult.

This paper describes theoretically the procedure called replicating portfolios that can be used to assess the interest rate risk management of demand deposits. A bank must construct internal models for volumes, deposit rates and market rates to be able to estimate maturity and duration of demand deposits, which is one of principal responsibilities of ALM and MR units in banks. However, ALM and MR must construct all models used for the estimation of the maturity and the duration of demand deposits with special care, as these are prone to high model risk. We have also discussed briefly the benefits of different methods and we concluded that the replicating portfolio approach method is more appropriate as a tool to hedge margin stability that a tool to manage the interest rate risk and the liquidity risk of demand deposits in the traditional IRRBB view.

3 Why are Savings Accounts Perceived as Risky Bank Products?

3.1 Introduction to the article

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Abstract

Risk management for banking products can be challenging in general, but is even more risky during a global, low interest rate environment. This paper deals with the risk management of savings accounts, a bank product defined as a non-maturing account with embedded option that bears a relatively attractive rate of return. We focus on the interest rate risk of savings accounts. By constructing the replicating portfolio and simulating market rates and client rates, we show that under the severest scenario, some banks in the Czech Republic might face a significant capital shortage in next two years if market rates start to increase dramatically from recent low levels. We conclude that savings accounts are riskier liabilities than current accounts and term deposits for banks. Moreover, we propose imposing stricter regulation and supervision on these bank products since they might increase systemic risk of the Czech banking sector in coming years.

Keywords: bank, demand deposits, interest rate risk, replicating portfolio, risk management, savings accounts, simulations

JEL classification: C150, G21, G11

3.2 The Article: Why are Savings Accounts Perceived as Risky Bank Products

3.2.1 Introduction

Banks are financial intermediaries that are engaged in a financial process focused on a maturity transformation from short-term funding to long-term financing. Banks usually collect money from retail customers through standard channels: sight deposits (current accounts), term deposits, and a new channel: savings accounts. In this paper, we focus on the risk management of the latter and follow Maes and Timmermans (2005) stating that savings deposit accounts raise important financial stability issues in Belgium because they represent a significant proportion of bank liabilities leading to huge maturity mismatching.

The significance of savings accounts has been increasing in the Czech banking sector and their volume amounted approx. CZK 400 billion or 15% of total banks´ deposit funding as of 31 May 2015. Such high volume is alarming mainly since it happened during a low interest rate environment starting in 2012. This means that banks collecting large amounts of funds through savings accounts can reinvest the deposits only into low yield bearing instruments (either on the financial market or as loans and mortgages). Despite this limitation, savings accounts are characterized by a relatively high deposit rate stemming from client's expectations on the one hand and banks´ offensive marketing strategies to attract and maintain clients on the other.

The aim of this paper is to describe the interest risk management of savings accounts from both theoretical and practical points of view. We aim to show that low market rates and the aggressive acquisition of clients through a high deposit rate bearing savings accounts will result in significant interest rate risk in some Czech banks in the future when market rates increase. In our research we follow conclusions of Bank of England (2013) and International Monetary Fund (2013) warning that suddenly increasing market rates resulted from central banks´ monetary policy actions will have a negative impact on banks and other financial institutions. On a related note, the recent following works underpins the importance of our research topic. Mandel and Tomšík (2014) analyse the interest rate transmission mechanism of monetary policy and credit channel, while Zamrazilová (2014) discusses implications of non-conventional monetary policy instruments during a global, low interest rate environment. Finally, the theoretical part of this article fills the gap in the lack of academic research. As far as we know, only Strnad (2009) focused on interest rate risk of demand deposits in Central and Eastern Europe. The following text is structured as follows: Sections 3.2.2, 3.2.3 and 3.2.4 discuss the characteristics of savings accounts, their risk management and dynamics in the Czech Republic. Section 3.2.5 describes the model and Section 3.2.6 provides empirical research of the interest rate risk management of savings accounts in the Czech Republic. Section 3.2.8 concludes the paper. Additionally, Section 3.2.9 adds more details on models used in Section 3.2.5.

3.2.2 Theoretical background

3.2.2.1 Savings accounts

We define savings accounts as a deposit on demand characterized by unlimited disposability, high deposit rates and low fees for the maintenance and account operations. Savings accounts are non-maturing liabilities that combine the common features of current accounts (withdrawal on a notice or with a limited notice period) with the common features of long-term deposits (higher deposit rates). These characteristics are embedded in the structure and operations of savings accounts, which transforms them essentially into a product with embedded options, i.e. a product with uncertain timing of future cash flows and uncertain pricing (i.e. a savings accounts´ deposit rate can be changed at any time by a bank). The possibility of changing a deposit rate increases the flexibility of a bank since it can quickly react to changes in market rates/competition. However, in reality, deposit rates are not changed immediately due to administrative and transaction costs.

Savings accounts differ from current accounts mainly in the price behaviour and the restrictions imposed on transactions. Price for savings accounts is higher, as the product is meant to be used for savings. On current accounts, depositors receive a very low rate of return as current accounts are not expected to be used for savings, but for transactions. Depositors cannot usually do transactions directly on savings account, but they can easily on demand transfer their funds between savings and current accounts. This bring 1-day delay (or a couple of days) in the depositors' ability to do the transactional banking with funds deposited on savings account, which is a minimal time and implies that savings accounts could be potentially quite volatile deposits whenever depositors decide to remove their funds due to different investments, expenditures or transfer to another bank which offered a higher rate of return. From this perspective, savings accounts are riskier liabilities than current accounts.

3.2.2.2 Behavioural patterns hidden behind savings accounts

We distinguish two types of agents and their behavioural patterns: banks' bidding for clients and interest rate sensitive and financially aware clients bidding for the highest return.

First, we focus on banks' bidding for clients. Savings accounts with relatively high deposit rates have become attractive acquisition instruments, especially for newly established financial institutions. This is due to several reasons: (i) acquisition of the client information, (ii) cross-sell, (iii) an attractive instrument bearing a relatively high return in time when yields are rather low (potential inflows of money from clients who would otherwise invest elsewhere when market rates would be higher) and (iv), a liquidity to boost a balance sheet.

We can observe three types of different pricing strategies of banks that offer savings accounts: a low-cost bank, a traditional bank and a third type bank. First, many new (low cost) banks have entered the market during 2010-2015 in the Czech Republic.

Those banks focus on offering low-cost (a zero-fee policy) deposit products with relatively high rate of return that can be operated entirely or almost entirely through the internet. Their approach reflects the strategy mentioned by Humphrey (1990), who says that some banks may decide for the business model without branches, as it enables to optimize costs, which on the other hand can translate into their ability to pay more on deposits. We observe that new banks focus on savings accounts as on a primary source of funding (in the extreme case, savings accounts may amount up to 90% of bank's liabilities as documented by results of some small banks in the Czech Republic, see Table 3.1). A high share of savings accounts in liabilities implies higher cost of funding. Furthermore, these banks need to attain relatively high deposit rates on savings accounts; a high deposit rate is the most important factor that attracts and retains their clients. For these banks, in our analysis, we expect aggressive pricing of savings accounts. Second, a traditional bank is a well-established bank that has a diversified funding source. Clients are usually more loyal to the traditional bank as the traditional bank can offer them a wide portfolio of services and products. This loyalty implies higher stability of deposits in the traditional bank. Additionally, the traditional banks usually charge higher fees compared to the low-cost banks, which represents an important source of income. For this type of the bank, we assume less aggressive deposit pricing. Third, a third type bank is a residual category since not all banks are either the low-cost or the traditional banks.

Table 3.1: Representative balance sheets of banks as of 31 December 2013

Air Bank		CSOB		Ceska Sporitelna	
Assets	Liabilities	Assets	Liabilities	Assets	Liabilities
Bonds 43%	CA 5%	Bonds 43%	CA 29%	Bonds 28%	CA 26%
Retail Loans 5%	SA 83%	Retail Loans 31%	SA 21%	Retail Loans 34%	SA 5%
Other 51%	Other 12%	Other 26%	Other 50%	Other 38%	Other 69%

Source: Authors based on Air Bank (2014), CSOB (2014) and CS (2014).

Note: CA are current accounts and SA are savings accounts from retail customers. Other on the liability side includes all other deposits. By loans we mean loans to retail and in some cases, to small enterprises. Other on the asset side includes all other assets.

Second, depositors of savings accounts exhibit strong behavioural patterns. We observe increasing interest rate sensitivity of bank clients, on the liability as well as on the asset side. This increased interest rate sensitivity is closely connected to an easily accessible information (internet) about bank´s products and their pricing. People actively use several internet sites that enable them to compare different pricing of same products by different banks. Tůma (2013) provides evidence that many savings accounts´ owners are sensitive to deposit rates on savings accounts and that these clients actively transfer their deposits between bank to the one that provides them with the highest return. Teplý (2014) explains that such clients´ behaviour follows the recent trend of the commoditization of money in banking, i.e. clients perceive bank products as commodities and therefore they choose these products solely based on their prices rather than other product features.

3.2.3 Interest rate risk management of savings accounts

In terms of interest rate risk management, savings accounts are risky liabilities that cannot be hedged by standard risk mitigation techniques used for other bank liabilities such as sight or term deposits. The following two important issues arise. First, savings accounts have zero contractual maturity like current accounts. However, as opposed to current accounts, the savings accounts´ deposit rate is usually much higher than the current accounts´ deposit rate. Furthermore, a deposit rate on current accounts is, in the majority of Czech banks, absolutely independent from the market development (i.e. the rate remains usually at 0.01% regardless whether government bonds yield at 2% or 5%, based on the market practice, see pricing list of most commercial banks in the Czech Republic). On the contrary, the deposit rate on savings accounts reflects movements in market rates and is therefore subject to supply-and-demand pressures. The earnings income from savings accounts reinvestment is thus more volatile and can potentially squeeze quickly due to changes in the deposit rate. Without any competition and transactional costs, savings accounts' interest rate risk would be minimal as all banks would price savings accounts in such a way that their margin would be absolutely stable in time as all changes in market rates would be directly transferred to a client. In the competitive environment with transactional costs, however, deposit rates are not adjusted immediately and are derived not only from underlying market rates (cost of funding), but also from competitors´ pressures and expectations about clients´ response. This makes the interest rate risk management of savings accounts different from current accounts.

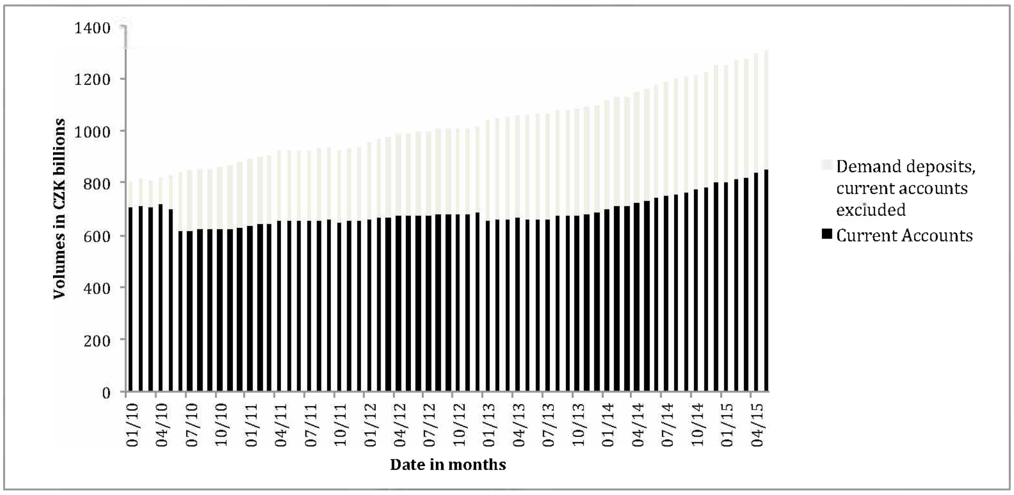
Savings and current accounts do not differ only in pricing, but also in different dynamics of balances of individual accounts, which rises mainly from different purpose of both types of deposit instruments. Current accounts are transactional accounts and as such they have relatively easily predictable development of individual outstanding amount during the month (balances increase when wages come and then decrease during the whole month). On the contrary, savings accounts´ balances are not predictable. Depositors may or may not deposit some savings each month; they may or may not withdraw a balance to go on vacation and so on. This makes the liquidity risk management of savings accounts more difficult than the liquidity risk management of current accounts.

The approximation of the maturity of savings accounts presents risks as well. Even though the contractual maturity of savings accounts is zero, the reinvestment or the effective maturity of savings accounts is higher as a large portion of depositors leaves their balances in a bank. A rational bank therefore redistributes the core of savings accounts into medium-term and long-term investments and provides a positive maturity transformation. However, a bank should estimate the reinvestment maturity of savings accounts properly to ensure that it retains available funds to simultaneously cover unexpected withdrawals and to attain relatively stable margins from savings accounts. Ideally, the margin from savings accounts should compensate a bank for a higher deposit rate, transactional costs and for risks that arise from savings accounts. To ensure positive margins, a bank reinvests savings accounts into a variety of instruments. In this article, we focus on estimating those margins (in a form of net interest income) in the model where three types of banks we described above price savings accounts based on their pricing mechanism strategies and reinvest them based on their investment strategies. We derive inputs for those strategies from the real behaviour of banks on the market.

3.2.4 Saving accounts in the Czech banking sector

The importance of savings accounts in the Czech Republic has been increasing recently. Figure 3.1 shows a decrease in current accounts resulting from the transfer of savings accounts from current accounts to savings demand deposits as of 30 June 2010. Since then, the volume of savings accounts in the category Demand deposits, current accounts excluded, has been growing steadily due to rising demand for savings accounts. We estimate (we cannot fully say how much savings accounts are in the category savings demand deposits) savings accounts (households) at approximately CZK 400 billion as of 31 May 2015. We expect increase in savings accounts to continue due to their ongoing attractiveness and stable high yields in the comparison with other deposit products.

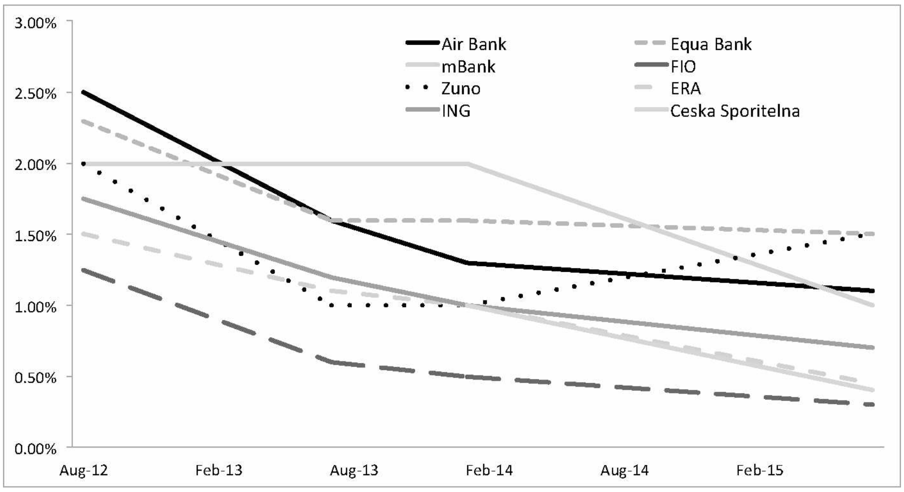
Figure 3.1: The savings account volumes from 31 January 2010 to 31 May 2015 (in CZK billions)



Source: Authors based on the data from ARAD time series database provided freely by CNB

Concerning deposit rates, generally, the peak in savings account deposit rates occurred during the end of 2011 and the first half of the year 2012, influenced by the introduction of Air Bank with its commitment to have the deposit rate among TOP 3 banks on the Czech market. Since then, we observe the gradual decrease in deposit rates (see Figure 3.2), which is an obvious consequence of historically low market rates during this period, however, yields on savings accounts remain persistently high and even higher than reinvestment opportunities on the market, as we show in Section 3.2.6.

Figure 3.2: Dynamics of savings accounts deposit rates in selected bank in recent years



Source: Authors based on pricing lists provided by respective banks

3.2.5 The model

We create reinvestment portfolios to investigate whether a similar investment strategy (which means defining the reinvestment strategy of a bank) results in different outcomes for the capital in banks that use different risk management of savings accounts (differences in the risk management are driven by banks' pricing strategies, see Section 3.2.2.2) under random simulations as well as under different scenarios for the market rate.[10]

Our analysis requires defining four models.

i. A model for market rates that represents an interest rate environment and yields into which a bank can reinvest deposits, see equation (Eq. 3.1).

ii. The deposit rate model that represents a banks´ interest rate cost of deposits, see equation (Eq. 3.3).

[10] For simplicity, we focus on market risk only in our model. Obviously, credit risk is of great importance in banking as highlighted by, for instance, Dvořák (2005), Janda et. al (2013), Šůtorová and Teplý (2013) or Mejstřík et al. (2014).

iii. Models describing how much savings accounts' deposits a bank has available to reinvest in each point in time, see equation (Eq. 3.2).

iv. The reinvestment portfolio, i.e. a portfolio of assets into which deposits are reinvested, see Table 3.2.

Using (i) – (iv) we can derive banks´ net interest income from deposits as the difference between the yield from the reinvestment portfolio and the interest rate cost paid to clients.

Market rate model

$$dm_t = a(b - m_t)dt + \sigma dW_t$$
$$B(t,T) = \frac{1}{a}\left[1 - e^{-a(T-t)}\right]$$
$$A(t,T) = \exp\left\{\left(b - \frac{\sigma^2}{2 * a^2}\right)[B(t,T) - T + t] - \frac{\sigma^2}{4a}B^2(t,T)\right\} \quad \textbf{Eq. 3.1}$$
$$\text{yield}(t,T) = -\ln\left[A(t,T)e^{-B(t,T)m_t}\right]/T$$

Deposit rate model

$$\Delta d_{i,t} = \rho_i \quad \text{if } \left|d_{i,t-1} - m_t\right| \geq \alpha_i \text{ and } (m_t - m_{t-1}) > 0$$
$$\text{and } m_t > 0$$
$$\Delta d_{i,t} = -\tau_i \quad \text{if } \left|d_{i,t-1} - m_t\right| \geq \beta_i \text{ and } (m_t - m_{t-1}) < 0$$
$$\Delta d_{i,t} = 0 \quad \text{if } \left|d_{i,t-1} - m_t\right| < \beta_i \text{ and } (m_t - m_{t-1}) < 0 \quad \textbf{Eq. 3.3}$$
$$\Delta d_{i,t} = 0 \quad \text{if } \left|d_{i,t-1} - m_t\right| < \alpha_i \text{ and } (m_t - m_{t-1}) > 0$$
$$\Delta d_{i,t} = 0 \quad \text{if } (m_t - m_{t-1}) = 0$$
$$d_{i,t} \geq \mu_i, \beta_i \geq \alpha_i > 0$$

Dynamics of volumes

$$V_{i,t} = \left(\sqrt[1/12]{1 + d_{i,t}}\right)V_{i,t-1} \quad \textbf{Eq. 3.2}$$

In the equation Eq. 3.1, we denote *t* as time, which is either an index for a time for which a model was calibrated or a period in simulations and a scenario analysis. It develops in monthly steps. A market rate m_t is a short-term interest rate, a is the speed at which the interest rate returns to its mean b, σ is volatility at time t, W_t is a Wiener process. In equation (Eq. 3.3) *i* stands for a bank *i*, $d_{i,t}$ is the deposit rate, ρ_i defines the adjustment upwards in each bank and τ_i defines the adjustment downwards. The α_i is the threshold value that defines the maximum limit of the absolute difference between the deposit rate and the market rate in each bank during increasing market rates, β_i is the threshold value that defines the maximum limit of the absolute difference between the deposit rate and the market rate in each bank during decreasing market rates. The bank adjusts the market rate when this limit is exceeded. Finally, μ_i is the downward limit value for the deposit rate in the bank and $V_{i,t}$ in equation (Eq. 3.2) is the volume on savings accounts.

The market rate model was obtained by the calibration of the Vašíček model[11] to the daily historical values of the 2-week repo rate from 1 January 1999 to 28 February 2013 using the procedure in Brigo et al. (2007). The reader can refer to Section 3.2.9 for details. The yield curve representing reinvestment opportunities is derived from the market rate using the procedure in Brigo and Mercurio (2006). The deposit rate adjustment to the market rate is based on the calibrated asymmetric adjustment model, see Section 3.2.9 for details.

Due to the lack of the data, we cannot exactly assess the aggregate development of savings accounts balances in the Czech Republic. Therefore, we let the savings accounts´ volumes to grow only at the deposit rate, i.e. by the recapitalization, with the starting value being CZK 100 million for all types of banks. Our aim is to access interest rate risk of savings accounts in the relation to a potential loss of capital stemming from the adverse effects in market interest rates. This implies that the simplification that deposits grow only by the capitalization is not affecting the validity of the analysis as. If we would assume more deposits, for example, we would always reinvest them into assets in our analysis, and consequently as the

[11] See Vašíček (1977) and Witzany (2013).

balance sheet would be increasing, a capital would be increasing as well. Thus, in the relative terms, we would receive similar outcomes as with deposits growing only by the interest rate capitalization. We also do not assume decrease of deposits as liquidity risk is not the aim of this estimation, hence we assume banks are keeping deposits and the deposit rate pricing mechanism ensures that depositors receive a deposit rate at which they leave their deposits in a bank (given that banks' reprice savings accounts to ensure this). This is a rational assumption as banks would face the depletion of deposits only to the bearable extent given by the liquidity risk limit. Our assumptions regarding volume behaviour are close to the static balance sheet definition of IRRBB guidelines EBA (2018).

The pricing (a deposit rate) and the reinvestment of savings accounts defined in the model is based on the pricing and reinvestment in Czech banks (Table 3.1). More details regarding the model coefficients are described in Section 3.2.9.2. We divide banks into three categories (i.e., i = i, ii, iii) based on their pricing strategies, defined in Section 3.2.2.2. In our model, each bank type reinvests savings accounts volumes into the reinvestment portfolio under weights w_i defined in Table 3.2 with the condition that $\sum_{i=1}^{n} w_i = 1$ and that no short selling is allowed. The reinvestment portfolios are based on the real bank portfolios in the Czech Republic. For the low-cost bank, we define two types of portfolios: non-aggressive and aggressive. The aggressive portfolio aims to show that a riskier investment of savings accounts results in positive net interest income even under a relatively high deposit rate, but at the cost of a risky position in high-yield instruments, such as consumer loans or mainly corporate bonds.[12]

[12] When creating the aggressive portfolio, we were inspired by results of an interview undertaken by Tinl (2012), where CEOs of several banks in the Czech Republic discussed investment strategies of their banks.

Table 3.2: Weights of different reinvestments in the reinvestment portfolio for scenarios

The traditional and the *third type bank*	*The low-cost bank* non-aggressive portfolio	*The low-cost bank* aggressive portfolio
10% of deposits is invested into O/N rate.	10% of deposits is invested into O/N rate.	10% of deposits is invested into O/N rate.
10% of deposits is invested into 3M.	10% of deposits is invested into 3M.	10% of deposits is invested into 3M.
40% of deposits is invested into 10Y.	40% of deposits is invested into 10Y.	33% of deposits is invested into 10Y.
40% of deposits is distributed as loans and mortgages to clients: 1. 13.3% of deposits is invested into 1Y fixed rate consumer loans for CZK 30,000 with r = 20%. 2. 13.3% of deposits is invested into 5Y fixed rate consumer loans for CZK 100,000 with consumer loans' interest rate of r =15%. 3. 13.3% of deposits is invested into 20Y fixed rate (fixing for 5 years) mortgages for CZK 1,000,000 with 4% rate.	40% of deposits is distributed as loans and mortgages to clients: 1. 13.3% of deposits is invested into 1Y fixed rate consumer loans for CZK 30,000 with r = 15%. We let consumer loans' interest rate r in *the low-cost bank* being lower than in *the traditional bank* and *the third type bank* as we found that these are lower on average. 2. 13.3% of deposits is invested into 5Y fixed rate consumer loans for CZK 100,000 with r =10%. 3. 13.3% of deposits is invested into 20Y fixed rate mortgages (fixing for 5 years) for CZK 1,000,000 with 4% mortgage rate.	14% of deposits is distributed as loans and mortgages to clients: 1. 5% of deposits is invested into 1Y fixed rate consumer loans for CZK 30,000 with r = 15% 2. 5% of deposits is invested into 5Y fixed rate consumer loans for CZK 100,000 with r =10%. 3. 4% of deposits is invested into 20Y fixed rate mortgages (fixing for 5 years) for CZK 1,000,000 with 4% rate. 33% of deposits is invested into long-term (maturity higher than 5 years) foreign-owned corporate bonds that provide 10% annual yield.

Source: Authors. Note: Corporate bonds have maturities longer than 5 years.

3.2.6 Empirical analysis

We firstly focus on the low-interest rate environment as it raises several concerns in the sound risk management of savings accounts. The pending low market interest rates imply that banks de facto cannot achieve high margins from the reinvestment of savings accounts and should therefore provide lower deposit rates. Figure 3.3 illustrates that the banks that started to offer savings accounts during decreasing market rates (as denoted by time *T*) have lower yields from savings accounts than the other banks that were able to reinvest savings accounts during the period of high market rates (especially in time *T-9*). This means that the sound risk management of savings accounts in banks that enter the market (or start to offer savings accounts) during low market rates should be based on the strategy that the deposit rate is lower than long-term market rates.

In managing the interest rate risk exposure, it is the common practice to derive effective pricing of demand deposits based on the relationship between banks' deposit rate and market rates. Therefore, we investigated the historical pricing of saving accounts by a simple reinvestment portfolio assuming only the reinvestment on the market as demonstrated in Table 3.3).

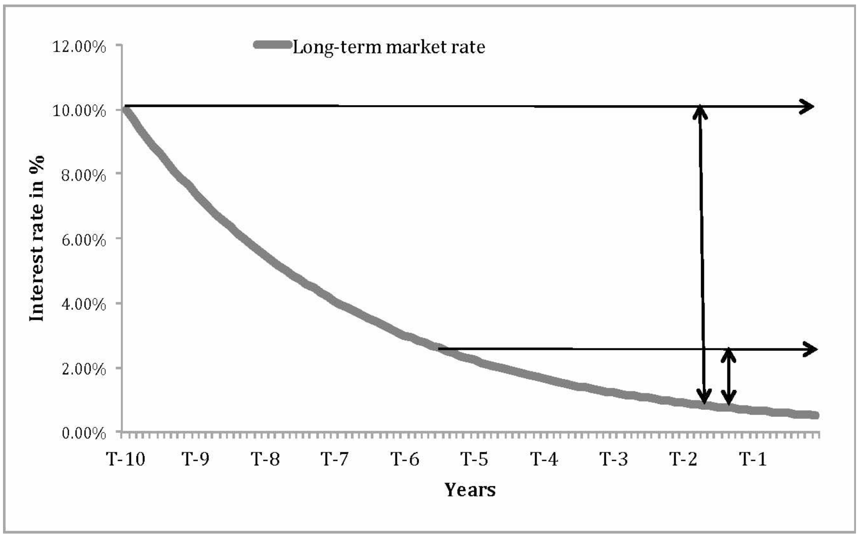
Table 3.3: A simple reinvestment portfolio

Maturity (Reinvestment)	Weights in %
O/N money market deposits	13
3M money market deposits	13
6M money market deposits	13
1Y money market deposits	13
5Y bonds	23
10Y bonds	23

Source: Authors

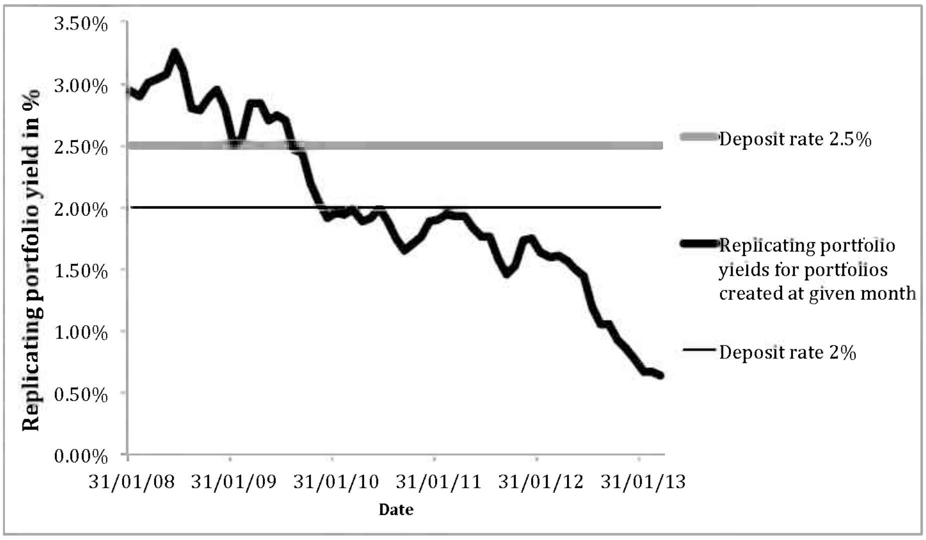
Figure 3.4 shows sustainable yields from the reinvestment of savings accounts into the simple reinvestment portfolio in the recent years. Evidently, any deposit rate higher than 2% would result in the net interest rate loss after 2010 given a bank would invest only on the market even before the inclusion of an obligatory deposit insurance expense. We stress that many deposit rates were above 2% during 2011. The situation was similar during 2014-2015, even though deposit rates decreased significantly.

Figure 3.3: Theory: bank's yield under low and high market rates



Source: Authors based on the CNB.

Figure 3.4: Reality: the yield achievable on the market in 1 January 2008 - 31 March 2013



Source: Authors based on the CNB.

3.2.6.1 Impact on the net cumulative interest income of banks

To investigate possible future development of the net interest income from savings accounts in Czech banks we simulated the development of the net interest income from savings accounts from the simple portfolio under a random development of market rates (random simulations of the equation (Eq. 3.1)) that starts during a low-yield period using our set of models and reinvestment strategies defined in Section 3.2.5. We employed 1000 runs over a horizon of 2 and 5 years in our three different types of banks (Table 3.4 summarizes results). We find that for any type of analysed banks, it is feasible to reinvest savings accounts only on the market. This indicates that the reinvestment of savings accounts that bear a high or a moderate deposit rate would be feasible only if banks would invest in other investment, such as consumer loans or mortgages. However, these instruments are less liquid and secure than the reinvestment on the market.

Table 3.4: The average cumulative net interest income from the reinvestment of savings accounts

CZK ths	The traditional bank	The low – cost bank	The third type bank
2 years	-1,296	-4,332	-2,808
5 years	-1,702	-13,480	-6,944

Source: Authors' calculations

We provide evidence that savings accounts are riskier liabilities, as the risk-free reinvestment cannot generate positive net interest income to a bank. We find three challenges pertaining to the risk management of savings accounts in the Czech Republic: (i) insufficient hedging of interest rate risk, (ii) competition and aggressive acquisition of new clients through high deposit rates and (iii) the lack of adequate regulation. Due to this, we investigated the impact of increasing market rates on banks´ net interest income from savings accounts using our reinvestment portfolio approach defined in Section 3.2.5. In this case, market rate m_t is not randomly simulated as before, but follows a predefined scenario defined in Table 3.5.

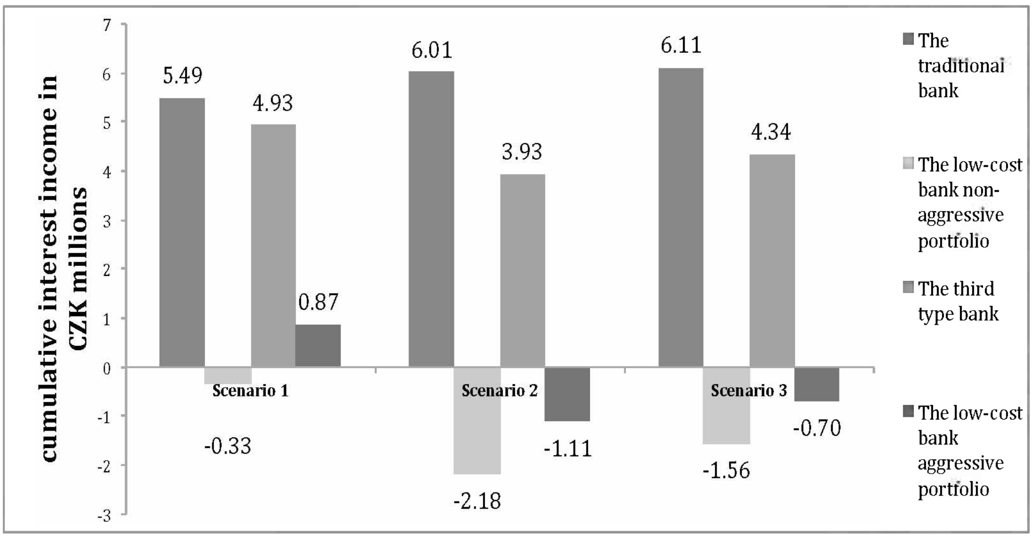
Table 3.5: Market rate scenarios

Scenario	Final market rate value	Time to final value
1	0%	2 years
4	0%	5 years
2	2%	2 years
5	2%	5 years
3	5%	2 years
6	5%	5 years

Source: Authors

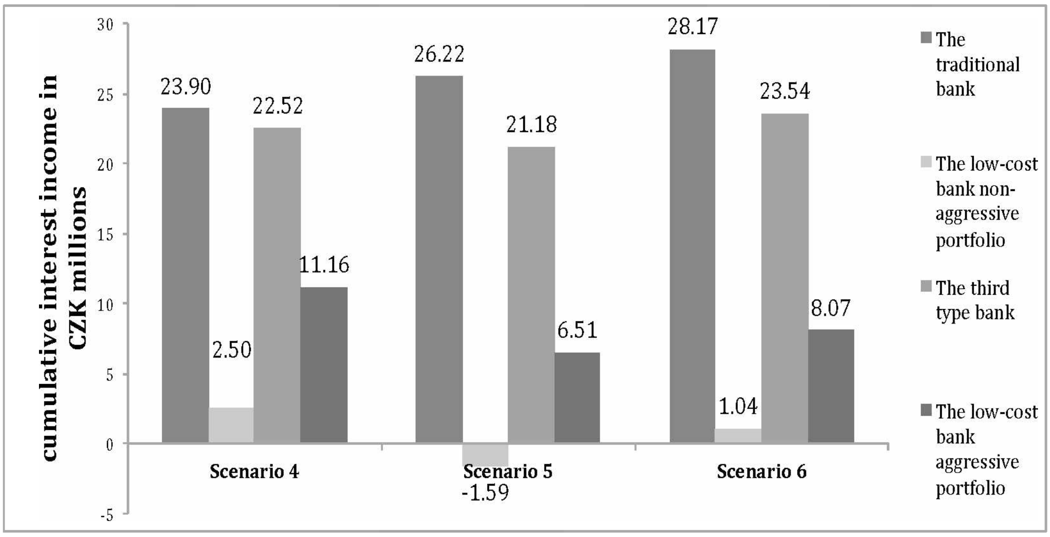
For better transparency, we divide results into two groups: (i) the net cumulative interest income of the bank (CNII) and (ii) the impact on the capital of the bank. First, Figure 3.5 and Figure 3.6 show CNII, which a bank is able to generate from savings accounts deposits for each out of six scenarios. Evidently, the low-cost bank is able to generate positive CNII only for the aggressive reinvestment strategy under Scenarios 1, 4, 5, and 6 while Scenarios 1, 2, 3 and 5 for the conservative portfolio of the low-cost bank generate negative CNII in the observed periods and Scenarios 4 and 6 very low positive CNII. On the contrary, both the well-established bank and the third type generate positive CNII from savings accounts in all scenarios.

Figure 3.5: Cumulative net interest income for Scenarios 1-3



Source: Authors

Figure 3.6: Cumulative net interest income for Scenarios 4-6



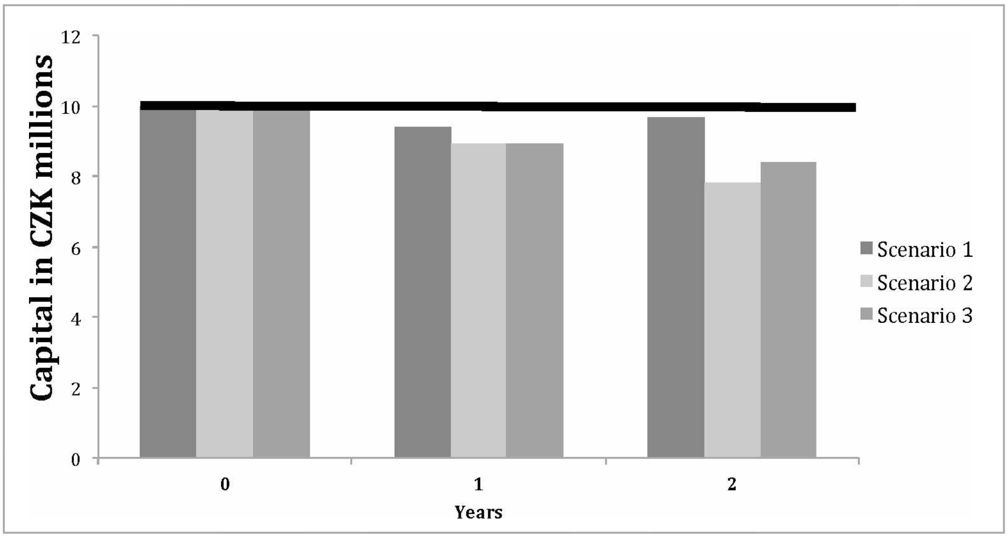
Source: Authors

3.2.6.2 Impact on banks´ capital

Second, in banks with common zero-fee policies, the net interest rate loss from savings accounts would have to be absorbed directly by their capital. For simplicity, we assume that initial value of the capital is CZK 10 million, what corresponds to 10% capital adequacy[13] and we exclude all other costs and revenues such as taxes, obligatory deposit insurance or charged fees. Figure 3.7 shows the impact on the capital of the non-aggressive strategy for 2-year scenarios). Evidently, the capital decreases in all scenarios, even though we find that a quick increase in the market rates to 5% in Scenario 3 leads to slightly lower loss than an increase to 2% in Scenario 2. This is a result of increasing consumer loans´ interest rates and yields on bonds.

[13] For more details on capital adequacy rules set by Basel III for global banks and by Capital Requirements Directive IV (CRD IV) for EU banks we refer to, for instance, BCBS (2011), Mejstřík et al (2014) or Šútorová and Teplý (2014a and 2014b).

Figure 3.7: The impact on banks´ capital



Source: Authors

We find that rapidly increasing market rates after a prolonged period of low market rates are a crucial factor for bank´s profitability from savings accounts. This result is in line with International Monetary Fund (2013) and Bank of England (2013). We show that potential losses stemming from the portfolio of long-term low yield assets[14] are substantial for banks with business model built upon a high deposit rate bearing savings accounts in order to attract new clients. Even if we would consider lower costs due to small number of or none branches, we claim that the profit from the product itself should not be negative. Even if costs are lower, the negative net interest income from the reinvestment of savings accounts will still eat up a capital. We also show that savings accounts, even when hedged properly, are riskier liabilities than current accounts only because they are costlier and require a higher yield reinvestment, which is obviously connected with higher risk. Adding competitive pressures, we conclude that savings accounts are indeed riskier instruments in banks´ balance sheets than current accounts and term deposits. We argue that we find enough evidence that banks´ relying on funding in the form of savings accounts are obviously risky. Second, Maes and Timmermans (2005) stress

[14] When savings accounts are repriced more quickly, what results from both maturity and duration mismatch.

that savings deposits raise stability issues in Belgium due to difficult risk mitigation stemming from embedded options. We provide evidence that savings accounts are risky liabilities for banks. As the importance of savings accounts in the Czech banking sector increases, so may increase potential stability issue stemming from unsound interest rate risk management of savings accounts.

3.2.7 Policy recommendations

Based on our results, we propose stricter regulation of savings account including variable caps on deposit rates or longer notice periods on withdrawals that exceed a certain amount (savings accounts are regulated instruments in Belgium, Austria, Germany and France). Stricter regulation would discourage banks from offering unsustainably high deposit rate savings accounts. Another possibility is to focus on the moral hazard behind savings accounts. Clients' deposit their savings on a high deposit rate bearing savings accounts without taking into the account the risk as all deposits are, by law, insured, as all banks are required to pay 16 bps[15] per annum to the Deposit Insurance Fund. Should savings accounts be excluded from the obligatory insurance scheme, many risk-averse clients would rather place their funds into less risky instruments. Still, this might lead some banks to increase the deposit rate even more. The other solution would be to have more levels of an obligatory deposit insurance cost depending on the riskiness of a bank. Naturally, a higher deposit insurance cost in riskier banks would decrease the profitability of the product, which would push banks to decrease the deposit rate. Third, the regulator should be able to assess a degree to which individual banks are exposed to savings accounts' risks. Maes and Timmermans (2005) point out the need of unified models used for modelling of savings accounts. A unified approach would enable the

[15] At the time of defending this thesis (year 2021), Deposit Insurance Fund was re-worked into the Resolution Fund schema plus Deposit Insurance Fund. At the moment, annual contribution to the Deposit Insurance Fund is lower than 16 bps, but banks have to contribute to the Resolution Fund as well.

regulator to compare the risk management of savings accounts in different banks.[16] Finally, we argue that we find sufficient evidence that savings accounts are risky instruments in banks´ balance sheet and the banks relying on this type of funding are obviously risky. We doubt that business models of some banks in the Czech Republic, which report savings accounts as a primary source of their funding, are sustainable and viable in the long-term horizon.

Bases on previous policy recommendations, we see several further research opportunities. For example, liquidity risk remains at the center of regulator's attention these days and should be addressed accordingly by future research focusing, for example, at European Banking Authority (2013) stable and non-stable division of deposits. Second, reputational risk can be tested when assuming deterioration in bank´s brand followed by outflows of bank's deposits or even by bank runs. Third, a deeper comparative study of savings accounts with other banking sectors such as Austria, Belgium, France or Germany might shed light on these products from a regulatory perspective.

3.2.8 Conclusion

This paper focused on the risk management of savings accounts defined as non-maturing accounts bearing a relatively attractive rate of return. We highlight two assumptions in the structure and operations of savings accounts that lend an "embedded optionality" to savings accounts: a customer's option to withdraw money at any time and a bank's option to set the deposit rate freely. As a result, the risk management of saving accounts remains an art as well as a science and simultaneously raises serious concerns by some regulators (particularly in Belgium). We focused on the interest rate risk management of savings accounts in the Czech Republic and provided evidence that many high deposit rates offered on savings accounts have not been in accordance with sound pricing recently. We argue that in

[16] At the time of defending this thesis, this has been partially done by EBA (2018) IRRBB guidelines. Still, those guidelines leave enough space regarding pricing mechanims of the individual banks.

order to attain high deposit rates, banks will have to either opt for risky reinvestments or to increase its capital to cover the net interest rate loss from savings accounts, especially when market rates increase. To conclude, we propose stricter regulation and supervision of savings accounts as highly risky banking products in order to maintain financial stability of the Czech banking sector.

3.2.9 The market rate model and the deposit rate model: details

3.2.9.1 Market rate model

The values of parameters a, b and σ were obtained by the calibration of historical daily values of the 2-week repo rate from 1 January 1999[17] to 28 February 2013.[18] It is also possible to directly use the values of a, b and σ from the historical time series. However, as we obtain estimates in accordance with the original series, we decided to use calibrated parameters rather than to derive parameters directly from the series. The 2-week repo rate is found to be a stationary series on this sample (the ADF test statistics with constant and trend for 9 lags is -4.86, which falls below the 1% confidence band of -3.96 and the ADF test statistic only with constant and 9 lags is -4.85 which falls below the 1% critical value of -3.43 as well. This allows us to reject the null hypothesis of the unit root presence.). As the mean-reversion is not strongly rejected, we can calibrate the 2-week repo rate using the Brigo et al. (2007) procedure. The calibrated market rate model is as follows: $d\mathrm{m_t} = 0.44(1.31\% - \mathrm{m_t})d\mathrm{t} + 0.063d\mathrm{W_t}$.[19] Parameter b=1.31% is the estimated mean value of the 2-

[17] The period before 1999 is excluded due to unprecedented volatility.

[18]

Summary Statistics for 2-week repo rate from 1 January1999 to 28 February 2013			
Mean	Median	Minimum	Maximum
0.027745	0.025000	0.00050000	0.095000
Std. Dev.	C.V.	Skewness	Ex. Kurtosis
0.018410	0.66355	0.82399	0.19338

[19] We find that residuals are not normally distributed and become autocorrelated after 9th lag. However, we can easily address this as: (i) parameters we obtained are consistent with the market, therefore yields we derive are consistent with real yields and (ii) in simulations we draw random errors

week repo rate, which slightly underestimates the true mean value of the sample, but has no significant impact on the final outcome of our analysis due to even distribution of the reinvestment. In the first step of the calculation of the yield from the reinvestment, we do not calculate those yields using the equation Eq. 3.1. We rather use average monthly observable values of PRIBOR rates and government bonds from 31 March 2013 as is the common practice. We highlight that the calibrated model tends to underestimate true long-term market yields for rapidly increasing market rate. This stems from the low estimated mean value, which is a direct consequence of low average repo rate of 1.5% during recent years.

For simulations, we use the discretized version of the market rate equation in the form of: $\mathrm{m_t} = \mathrm{m_{t-1}} + \mathrm{a}(\mathrm{b} - \mathrm{m_{t-1}})dt + \delta\sqrt{dt}$ and to derive yields, the equation Eq. 3.1 is used. For scenarios (stress testing), we define the market rate development as a gradual increase and use only calibrated coefficients and the equation Eq. 3.1 to derive yields. Calibrated parameters are in their annual value, which implies that we can simulate monthly steps as our analysis requires. To do so, we let dt = 1/12. The initial value of the market rate for both simulations and scenarios is 0.05%, i.e. the 2-week repo rate value from 31 March 2013.

3.2.9.2 Deposit rate model

Here we derive dynamics of deposit rates in relation to the 2-week repo rate in typical representatives of three types of banks in the Czech Republic until spring 2013 as well as their expected dynamics in case of increasing market rates in case of low-cost banks. For the traditional banks, dynamics of deposit rate in ING (freely available) and anonymous bank (The Bank, belonging to three biggest banks in the Czech Republic) that provided its deposit rate were used. We have taken history of deposit prices in the Czech Republic and we have derived model parameters from it as average observable behaviour. We assume banks aim to attain as stable spread (income) over market rate as possible in a long-term (if possible – negative interest

from N(0,1) and (iii) the estimation by OLS can be done also by using robust statistics, which results in equal estimates, but not correlated and homoscedastic errors.

rate environment implies this may not be possible or a short-term dynamic may highly distort this relationship temporarily) to stabilize bank's long-term interest rate margin (difference between interest income of assets and interest income of liabilities). This implies banks are adjusting deposit rates once interest market interest rate change enough, i.e. when the spread increases/decreases too much. For the low-cost banks, dynamics of deposit rates in Air Bank, Zuno and Equa bank were mainly used to set up aggressive pricing behaviour we observed on the market. The third type bank is defined as a mid-step between those two types of banks.

As Table 3.6 shows, the traditional banks (represented by ING and the Bank) adjust the deposit rate when the difference between the market rate and the deposit rate for both an increasing and decreasing 2-week repo rate is more or equal to 100 bps. Therefore, we find that for the traditional banks, $\alpha_i = \beta_i$. From the historical data we also derive that average decreases τ_i are 30 bps and average increases ρ_i are 25 bps. During 2012-31 March 2013, the deposit rate among traditional banks varies from 1% to 1.5% in most cases. Therefore, we set the downward restriction for the traditional banks μ_i equal to 1%. Figure 3.8 shows the fit of our model to the deposit rate in the Bank and the ING deposit rate. Our general model provides a good fit, mainly for the Bank. There are periods when our modeled deposit rate differs from the observed values significantly. This is due to sudden large changes in deposit rates, which depend on a sudden and temporary change in the adjustment process in both banks, i.e. banks suddenly decide to adjust the rate by more or less than 25/30 bps. Our model can fit the development of deposit rates in the Bank as well as in ING bank, which is our aim. To make the traditional bank less elastic to changes in the market rate, when this is very low and close to zero, we let the traditional bank to adjust the deposit rate only if the market rate is higher or equal to 1%. Thus, we ensure that the traditional bank increases the deposit rate only if market rates increase sufficiently to cover the increase in the deposit rate. This reluctance is observed characteristics of deposit rates in the well-established banks and needs to be included in the model.

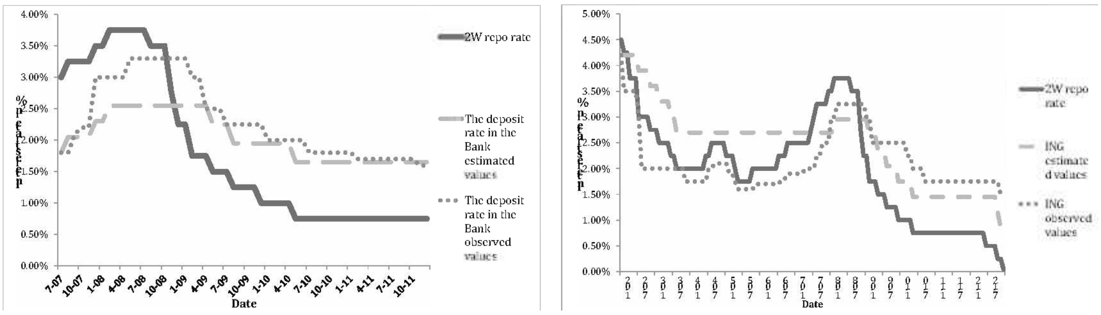
Table 3.6: The derivation of parameters for the deposit rate model in the traditional bank

	The Bank	ING	The traditional bank
The average difference between the deposit rate and the increasing 2-week repo rate for which a bank adjusts the deposit rate	116 bps	58 bps (78 bps if only after 2007)	100 bps
The average difference between the deposit rate and the decreasing 2-week repo rate for which a bank adjusts the deposit rate	119 bps	75 bps (116 bps if only after 2007)	100 bps
The average difference between the deposit rate and the 2-week repo rate for which a bank adjusts the deposit rate	118 bps	66 bps (95 bps if only after 2007)	100 bps[20]
The average magnitude of the adjustment upwards	38 bps (23 bps if an outlier of 80 bps excluded)	20 bps	25 bps
The average magnitude of the adjustment downwards	24 bps	36 bps	30 bps

Source: Authors' own calculation based on www.ing.cz, www.cnb.cz and the Bank. The calibration of the data (monthly values of the 2-week repo rate since 1 January 2002 to 31 December 2012, monthly values of deposit rate in ING bank since 1 January 2002 to 31 December 2012 and monthly values of the deposit rate in the Bank since 1 July 2007 to 31 December 2011) was done simply in excel by obtaining average values of changes in deposit rates and the average difference between the deposit rate and the 2-week repo rate. The adjustment in the traditional bank is defined as the average of adjustments in both banks with higher importance of 2007 and later period + stylized facts about adjustment strategies. Therefore, the parameters derived for the traditional bank are not exact averages derived from ING and the Bank. The interested reader may also notice that both ING and the Bank are slightly more sensitive to increasing market rates, which contradicts stylized facts. However, given the data, this sensitivity is very low and can be easily explained by the competitive environment in the Czech Republic.

[20] We stress that the average difference (of both banks) between the deposit rate and the 2-week repo rate derived from 118 bps and 66 bps would be 92 bps. However, we define it as 100 bps for the traditional bank. This is due to the fact that the adjustment strategy in ING differs until 2007 and after 2007. As we consider of greater importance a later period when ING bank faces competition as more savings accounts are on offer, we opt for 100 bps.

Figure 3.8: The fit of the estimated deposit rate in the Bank to the observed deposit rate in the Bank and the fit of the estimated ING deposit rate to the observed ING deposit rate



Source: Authors. 2W stands for the 2-week repo rate.

Considering adjustment parameters τ_i and ρ_i in the low-cost bank, we define them as the exact opposite of the well-documented interest rate adjustment behaviour in well-established banks. The pure low-cost bank is heavily dependent on savings accounts and is therefore more sensitive to market rate increases than decreases. The low-cost bank must signal to its clients that it is different than other banks, i.e. it adjusts the rate upwards sooner and more often when market rates increase and decreases the deposit rate less and later than the traditional bank when market rates decrease.

To summarize, we define that the low-cost bank in our analysis adjusts the deposit rate when the difference α_i between the market rate and the deposit rate for increasing market rate is more or equal to 50 bps and that the magnitude of the adjustment upwards ρ_i is 30 bps. We define the threshold α_i value to be lower than for the traditional bank to reflect that the low-cost bank adjusts the rate with higher sensitivity to the market rate increases than the traditional bank. We argue that 50 bps is a meaningful value; as soon as the repo rate starts to increase; the low-cost banks must be the first ones increasing deposit rates. Since October 2012, the repo rate is 0.05% and the average of the three highest rates offered on savings accounts was around 2.3% during August-December 2012, 2.2% during January-February 2013 and 2.1% during March 2013. It means that as soon as the repo rate starts to increase, the low-cost bank will increase the deposit rate as the difference between the deposit rate and the market rate is already higher than 50 bps. One may argue that the low-cost bank will not increase the deposit rate as soon as the market rate starts to increase since the deposit rate around 2% is already high when compared to market rates. Still, in a competitive environment, at least one low-cost bank, the one with strong liquidity needs, will increase the rate.

Under prevailing decrease in market rates, we define that that the low-cost bank in our analysis adjusts the deposit rate when the absolute difference β_i between the market rate and the deposit rate for the decreasing market rate is more or equal to 200 bps. We argue that this value is observable in the market as repo is almost zero and many banks during 2012 and the beginning of 2013 offer rates around 2%. We define average decreases τ_i to be 20 bps. For example, Air Bank decreased the rate from 2.5% to 2.4% in November 2012, following the decrease of the 2-week repo rate by 25 bps in October 2012. In January 2013, Air Bank further decreased the deposit rate by 30 bps to 2.1% and the same as of 19 March 2013 to 1.8%. Due to prevailing low rates since January 2013, other small banks (the low-cost banks) decreased deposit rates as well. Equa Bank decreased the rate by 20 bps, Axa bank by 30 bps and Zuno by 20 bps. Based on this, we derive that the average value of decreases in small banks is around 20 bps, which is less than for the traditional bank and consistent with our assumptions. The downward restriction for the deposit rate in the low-cost bank is defined as 2% - the three highest rates among banks' savings accounts in the Czech Republic are over 2% in 8 March 2013 and the market rate is almost zero, hence 2% value is a meaningful value.[21]

We summarize parameters for the adjustment process in all types of banks in Table 3.6.

[21] By 19 March 2013, Air Bank decreased the rate to 1.8%. Still, for example Equa bank holds the rate at 2.1% by 31 March 2013 and rates above 2% were common until March 2013, even during low market rates. We stress that the market is developing quickly and we base our analysis on the development until 31 March 2013.

Table 3.7: Dynamics of the deposit rate

	The traditional bank	The low-cost bank	The third type bank
$\boldsymbol{\rho}$	25 bps	30 bps	20 bps
$\boldsymbol{\tau}$	30 bps	20 bps	25 bps
$\boldsymbol{\alpha}$	100 bps	50 bps	75 bps
$\boldsymbol{\beta}$	100 bps	200 bps	150 bps
$\boldsymbol{\pi}$	100 bps	200 bps	150 bps
Initial value (spring 2013)	150 bps	220 bps	180 bps

Source: Authors´ own calculations.

4 Risk Management of Demand Deposits in a Low Interest Rate Environment

4.1 Introduction to the article

Published as: Džmuráňová, H. and Teplý, P. (2016b): *Risk Management of Demand Deposits in a Low Interest Rate Environment*. Institute of Economics Studies, Faculty of Social Sciences, Charles University in Prague Working Paper No. 10/2016.

Abstract

In this paper, we focus on the liquidity characteristics (stability and maturity) of retail deposits in the Czech Republic and changes in the structure of retail deposit products that occurred because of a low interest-rate environment. Retail deposits are a primary source of funding for banks in the Czech Republic. In simplicity, we divide retail deposits into two main groups: (i) demand deposits are products with non-maturing features as maturity (timing of cash flows) is not known by a bank as a client can withdraw a deposit on notice while in reality deposits remain in a bank for a longer period; (ii) term deposits are products with maturing characteristics, i.e. a timing of cash flows is known. Bankers deem retail deposits as a largely stable and cheap funding source. Our research shows that demand deposits are a stable funding source with much higher maturity than term deposits. Moreover, we conclude that the transfer of term deposits to demand deposits that accelerated in recent years resulted from a low interest rate environment. This transfer implies increasing liquidity risk of the Czech banking sector. However, we argue that banks should be able to hedge this risk properly.

Keywords: asset and liability management, demand deposits, term deposits, liquidity risk, interest rate sensitivity

JEL classification: *G21, C22, C53*

4.2 The Article: Risk Management of Demand and Term Deposits in a Low Interest Rate Environment

4.2.1 Introduction

Asset and liability management (ALM) departments in a bank are, apart from other things, responsible for the liquidity and interest rate risk management of assets and liabilities (Mejstřík et al, 2014). Bank assets and liabilities affecting client products, can be divided into two main groups: (i) maturing and (ii) non-maturing products. Maturing products are products that have defined contractual characteristics. In other words, the timing of cash flows is defined in the contract as well as their price (interest). Non-maturing products, on the other hand, do not have defined timing of cash flows, and the price (interest) behaviour is not fixed. A bank has the embedded optionality to change the price without changing the contract with a client. Both maturing and non-maturing products' liquidity and interest rate risk management require sound internal models defined by each bank to ensure that: (i) a bank has enough liquidity to cover the withdrawal of deposits as well as to ensure that (ii) the excess liquidity is managed in the most effective way.

In the case of maturing products, even though a bank knows the timing and the price of its cash flows, the bank must still model them, as there are embedded clients' options such as prepayments and defaults on the asset side, or early withdrawals from term deposits on the liability side. These facts imply a need to model these products in such a way that a bank can estimate the probability that a contractual maturity will differ from the realized/effective one. The need to estimate this probability is emphasized by the regulator (EBA, 2015 and BCBS, 2015). Nevertheless, banks normally impose high fees on prepayments and the early withdrawal option in the case of maturing products in order to discourage clients. Due to this feature, the contractual maturity of maturing products should be close to the realized maturity. However, increased competition combined with price wars on the asset-side of the banks in the over-liquid environment of the Czech Republic leads, in fact, to higher discrepancies between the contractual maturity and the effective maturity of loan contracts. Consequently, it has resulted in the increasing liquidity and interest rate risk of individual banks' balance sheets (an analysis of that topic is, though, beyond the scope of this paper).

For non-maturing products, the need for proper modelling is even more important, as the embedded optionality of non-maturing products is an inherent part of the contract. In the case of non-maturing products, as their name suggests, the effective or realized maturity (cash flow profile) differs from the contractual (legal) maturity and is unknown. The legal maturity of non-maturing products is overnight, or very short – a client has a right to withdraw his/her deposit on notice or use a credit card within an approved loan limit as he/she wishes. However, in reality, and, for example, in the case of transactional deposits such as current accounts, these cash flows do not happen each day, and, importantly, they cancel each other out on the aggregate level (national level). In other words, each transaction has a creditor and a debtor, and the total amount of deposits remains unchanged. On the banks' level, if a bank is rather large, the cancelling out works as well. If one client debits his/her account, another client's accounts is credited. This results in the stability of demand deposits, and, as the bank gets larger, a stable core of demand deposits is formed, and to this core, banks largely, and correctly assign a much longer maturity than is specified by the law. We call this maturity the effective maturity, and it is limited by a regulator in such a way that the average modelled effective maturity of demand deposits should not be longer than 5 years (EBA, 2015). Assumption of more stable core in larger banks is related to economies of scale as well.

In this paper, we focus on the liquidity risk of demand deposits and the term deposits of households (i.e. retail deposits), as these form a major part of banks' funding in the Czech Republic. Firstly, we discuss differences between the liquidity management of demand and term deposits. Secondly, we show how term deposits are slowly dying out in the Czech Republic, which is a long-term process that has mostly accelerated during recent years due to the low-rate environment. Thirdly, we compare the maturity profile of term deposits and demand deposits in the Czech banking sector and we discuss how the liquidity management of these products will be affected when market rates increase. We should point out that we do not focus on a traditional analysis of demand deposits aimed at deriving the effective duration (defined as the change in the value of demand deposits when market rates change by x basis points) of demand deposits using the procedures described, for example, in Džmuráňová and Teplý (2015). Moreover, the analysis of the effective duration of demand deposits is mainly important for an individual bank, as it shows what the value of demand deposits is, and how much this value is sensitive to changes in market rates. On the aggregate level, however, we are more interested in estimating the liquidity characteristics of volumes, i.e. we focus not on their value and interest rate risk, but on their cash flow profile and liquidity risk. In other words, we only aim to estimate when cash flows will happen, but not at which price (the interest). Another reason why we opt only for liquidity behaviour is the common feature of transactional demand deposits mentioned, for example, by Maes and Timmermans (2005). It is a fact that transactional deposits are mostly insensitive to changes in market rates, as clients need to make transactions regardless of whether market rates are 0 or 5%. Due to this, the effective duration of transactional demand deposits is close to their maturity, and, as transactional demand deposits such as current accounts still form a major part of demand deposits in the Czech Republic (even though the share of savings accounts is tending to increase rapidly), we can arbitrarily assume that the duration of aggregate demand deposits will be close to their effective maturity.

The main contribution of this paper is the further development of an analysis of demand deposits in the Czech Republic as a case study. As far as we know, we were the first to analyse this topic practically in relation to savings accounts in the Czech Republic in Džmuráňová and Teplý (2014). Given that Czech banks rely on funding from demand deposits, with our research we aim to fill this relative gap in the analysis of demand deposits in the Czech Republic. Last but not least, this topic is also closely related to recent regulatory issues. For instance, EBA (2015) and BCBS (2015)[22] focus largely on the modelling of non-maturing products, advising banks how they should properly model them. Both regulators also aim to harmonize modelling practices to ensure that banks are comparable on an international basis.

The following text is structured as follows. Section 4.2.2 discusses the basic characteristics of retail demand and term deposits and their implications for the liquidity risk management. Section 4.2.3 provides an analysis of the dynamics of retail demand and term deposits in the Czech Republic, focusing on interactions between these two. It also discusses the results of the analysis presented in the light of an environment of increasing market rates. Finally, Section 4.2.6 concludes the paper.

4.2.2 Main Characteristics of Retail Deposits

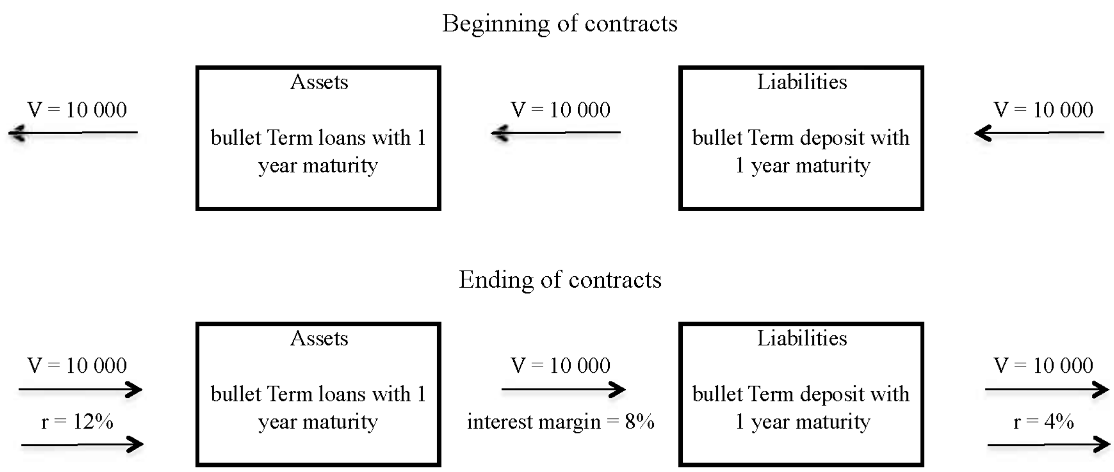
Retail (household) deposits form a major source of funding for Czech banks, which use them to provide loans to the retail as well as the corporate sector. In this paper, we focus on the liquidity management of demand deposits and term deposits. Demand deposits can be further divided into two main groups - current accounts and other deposits redeemable on notice (mainly savings accounts and passbooks available on notice).

Term deposits are contractual products. A client leaves a deposit in a bank for a given period and at a given interest rate. After this period ends, a client either withdraws the balance or rolls a deposit over at a new price or the same price, depending on the bank's pricing decision. From the liquidity point of view, all nominal and interest rate cash flows arising from a term deposit are known, and a bank can easily hedge them. (We can ignore the possibility of earlier withdrawals, as banks tend to impose high fees on this option, and clients are thus discouraged.)

[22] As well as in updates EBA (2018) and BCBS (2017).

Given that all interest rate cash flows are known, a margin, which is a bank's interest income from a term deposit, defined in the internal pricing (Fund Transfer Pricing system) as the difference between a reinvestment gain on the market (=mixture of short-term rates and government bonds yields and long-term rates), is fixed for the whole term of a deposit. Due to this, term deposits are a relatively easily manageable product for a bank. The liquidity management of term deposits is straightforward, as the timing of all cash flows is known and a deposit can be rolled over to assets with the same cash flow (and pricing) characteristics, as depicted in Figure 4.1.

Figure 4.1: Liquidity Management and Reinvestment of Term Deposits



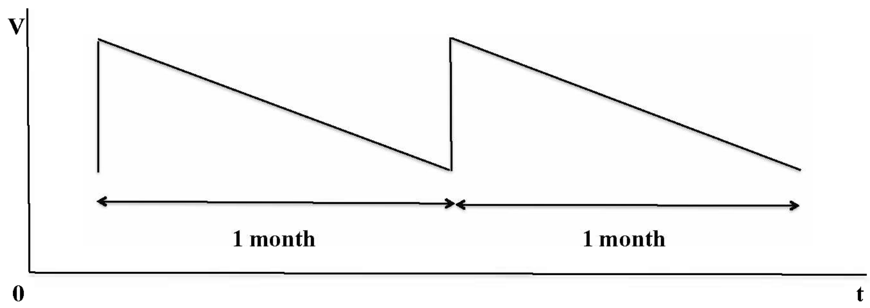
Source: Authors.

Note: V is volume and r is interest rate.

The liquidity risk management of demand deposits is not as straightforward as the liquidity risk management of term deposits. Firstly, we discuss the liquidity management of transactional deposits – current accounts, and secondly, of savings deposits – savings accounts and some types of passbooks available on notice.

Transactional accounts are deposits that clients use to cover their daily liquidity needs – salary is paid to the account, a client pays bills and invoices and sends spare money to a savings deposit from the account and so on. Due to this, an account used purely as a transactional account has a predictable development over the month. Figure 4.2 depicts how salary comes in at the beginning of the month, which results in the peak in the balance of the account. After that, the balance of the transactional account declines during the month until the moment the next salary arrives during the next month. We can also see that there is a stable non-zero balance held by a client on the account to cover unexpected liquidity needs if necessary, and if this balance is not enough, a client may even fall below a 0 balance without a penalty if he/she has an overdraft contract signed with a bank. Finally, a typical feature of transactional accounts is the minimal deposit rate paid on them (usually 1 basis point or even less).

Figure 4.2: Liquidity Development of a Typical Transactional Account



Source: Authors.

Note: V stands for volume and t for time.

The predictability in the development of balances on transactional accounts and the fact that many transactions happen between two transactional accounts implies that, especially in a large bank and definitely on the aggregate level, volumes on transactional accounts will exhibit high stability, as clients need to keep balances there to cover their daily liquidity needs (Maes and Timmermans, 2005). Nevertheless, the timing of cash flows is unknown; some cash flows like salaries and bill payments tend to occur on a regular basis, but others, such as paying for clothes, a vacation or a car, do not.

As well as transactional deposits, there are also savings deposits, such as savings accounts. Savings deposits are deposits available on demand that have a relatively attractive deposit rate. Unlike transactional deposits, savings deposits do not serve transactional purposes. Banks do not allow clients to make transactions from savings accounts, apart from transactions in which a client either sends money to or withdraws money from his/her savings deposit. Concerning the development of liquidity on savings accounts, we cannot observe any typical features arising from the liquidity behaviour of transactional deposits. Due to this, the development of balances on a savings deposit is not easily predictable. A bank cannot predict when a client will stop sending regular savings to a deposit or when a client will buy a house. However, there are certain ways a bank can at least estimate the overall dynamics of savings deposits. One way is an interest rate sensitivity analysis – a bank needs to know to what extent clients are sensitive to deposit rates, especially when a bank decides to reprice or not to reprice accounts (either as a reaction to changes on the market or to changes in competitors' deposit rates). If a bank's clients are sensitive to a price, and a bank prices below the market or the peer competitors' average rate, then a bank can expect an outflow of savings deposits, and vice versa. The second way is to acquire a knowledge of the observed characteristics of savings deposits in other countries, such as the fact that savings deposits typically increase when rates are low, as other investment opportunities are low or riskier (Maes and Timmermans, 2005).

A bank must define internal models to estimate when cash flow will happen from both transactional and savings deposits, i.e. to assign some liquidity profile to those deposits and derive their effective maturity. The outcome of these models is the maturity profile of demand deposits, which is then used as an input in the analysis of the sensitivity of demand deposits to changes in market rate (duration), and to derive the value of demand deposits. In the next Section, we describe a model for the liquidity profile estimation in the theory as well as in the practice.

4.2.3 The Liquidity Profile of Retail Deposits in the Czech Republic

The aim of this paper is to assess the liquidity characteristics of retail deposits in the Czech Republic. In this analysis, we divide deposits into the two main groups theoretically described above – term deposits and demand deposits. In this chapter, we first analyse their liquidity features and we compare them. Secondly, we highlight important changes in the structure of deposits in the Czech Republic in recent years. Finally, we come to a conclusion about what might happen if market rates eventually increase.

4.2.3.1 Liquidity Characteristics of Term Deposits

The liquidity profile of a portfolio of term deposits is the sum of all cash flows that are scheduled based on the contract between a client and a bank. These cash flows are known and have given contractual maturities at each date while the deposit is in the bank's portfolio. The maturity of a portfolio of term deposits (M_{TD}) comprising of deposits V_i where *i = 1, .., n* with the total volume of $V = \sum_{i=1}^{n} V_i$, under an assumption of negligible earlier withdrawals, is equal to a sum of the weighted residual (remaining time to the maturity M_i) the maturity $tmat_i$ of each individual term deposit in a portfolio:

$$M_{TD} = \sum_{i=1}^{n} tmat_i$$

Eq. 4.1

$$tmat_i = \frac{V_i}{V} * M_i$$

Using the equation Eq. 4.1 and the data for term deposits (all deposits deemed to be a term deposit, including building savings and passbooks with notice periods) we aim to calculate the average residual maturity of aggregate term deposits in the Czech Republic. We face two problems concerning the freely available data. Firstly, The Czech National Bank ("CNB") provides data for term deposits based on their contractual maturities, not residual ones. Secondly, term deposits based on their contractual maturities are divided into five time buckets only – up to 3 months, 3 months – 12 months, 1 year – 2 years, 2 years – 5 years and 5 years and more. To solve the second problem partially, we can say, quite simply, that the average contractual maturity of term deposits in each of the first four time buckets can be half of a time, i.e., for example, the average contractual maturity of deposits in the bucket 2 years – 5 years is 3.5 years. However, we cannot use this in the case of the last bucket - 5 years and more, but we decided to be conservative and take the average contractual maturity of all the term deposits to be 5 years. The solution to the second problem would be to obtain the residual maturities, which is, given the freely available data, unfortunately not possible. Due to this, we will calculate the average contractual maturities of aggregate term deposits in the Czech Republic, and we can say that the average residual maturity of aggregate term deposits in the Czech Republic must be strictly lower than the average contractual maturity.

As interest in maturity is always centred on the last available information on the portfolio, we calculated the average contractual maturity of aggregate term deposits in the Czech Republic as of May 2015 to be 1.75 years. This implies that the average residual maturity of term deposits lies between 0 – 1.75 years and is strictly lower than 1.75 years.

Secondly, for the purposes of investigating the changes in the structure of deposits in the Czech Republic in recent years, we are also interested to see the dynamics of the development of the average contractual maturity of aggregate term deposits. Recently, we could observe a structural change in deposit products in the Czech Republic – a transfer from term deposits to demand deposits. This transfer is driven by the low rate environment, which directly translates into low rates offered on term deposits. We expect changes in the contractual maturity of term deposits due to this. By contrast, demand deposits, particularly savings accounts, have better return and liquidity (on demand) characteristics than short-term term deposits. To demonstrate this, we provide Table 4.1 with deposit rates offered on term deposits and savings accounts in the major large, medium and small banks in the Czech

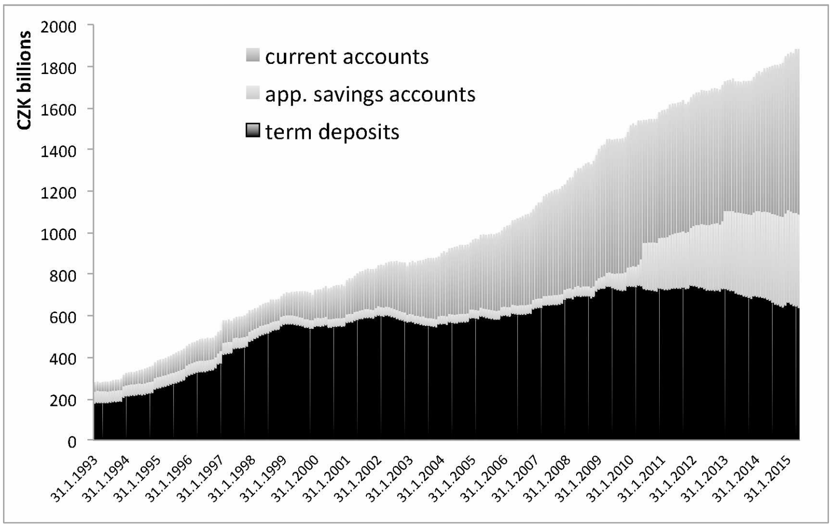
Republic. Evidently, only long-term term deposit rates can match savings accounts rates, while short-term term deposit rates fall far below savings accounts rates. This indicates that the interest rate-sensitive clients who do not want to save on a long-term basis, i.e. they want to have quick access to their money, would rather opt for a savings account than for a short-term term deposit. Secondly, Figure 4.3 shows the stagnation and even decrease in the outstanding aggregate balances of term deposits and increasing volumes of demand deposits, especially savings accounts. Finally, Figure 4.4 demonstrates that the average contractual maturity of term deposits has been increasing recently. This suggests that only the long-term term deposits of clients with low liquidity needs such as building savings remain in banks' portfolios, as these are the only ones that provide a return at least comparable to savings accounts, whereas short-term term deposits do not. In other words, the average contractual maturity of aggregate term deposits in the Czech Republic is getting longer, since the interest rate-sensitive clients prefer savings accounts (due to the low return available on short-term term deposits).

Table 4.1: Deposit Rates on Savings Accounts versus Term Deposits as of August 2, 2015

in %	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*
demand deposits - savings accounts (available on demand)	0.40	0.45	0.12	0.30	1.30	1.10	1.50	1.50	0.30	0.45	0.70
term deposits - 1M	0.01	0.10	0.01	0.01	0.01	NA	NA	0.60	0.40	0.01	NA
term deposits - 1Y	0.10	0.15	0.05	0.10	0.01	NA	0.50	1.10	0.75	0.15	0.50
term deposits - 2Y	0.20	0.20	0.05	0.10	0.01	NA	0.70	1.25	1.05	0.20	NA
term deposits - 3Y	0.30	0.25	0.05	0.15	0.01	NA	1	1.25	1.35	0.30	NA
term deposits - 4Y	0.40	NA	0.05	NA	0.01	NA	1.20	NA	1.55	NA	NA
term deposits - 5Y	NA	NA	0.05	0.25	NA	NA	1.50	NA	1.75	NA	NA

Source: Authors, using interest rate lists of selected banks. Bank numbering: 1 – Ceska sporitelna, 2 – CSOB, 3 – Komercni banka, 4 – UniCreditBank, 5 – Raiffeisenbank, 6 – Air Bank, 7 – Equa bank, 8 – Zuno bank, 9 – Fio bank, 10 - Era bank, 11 – ING bank.

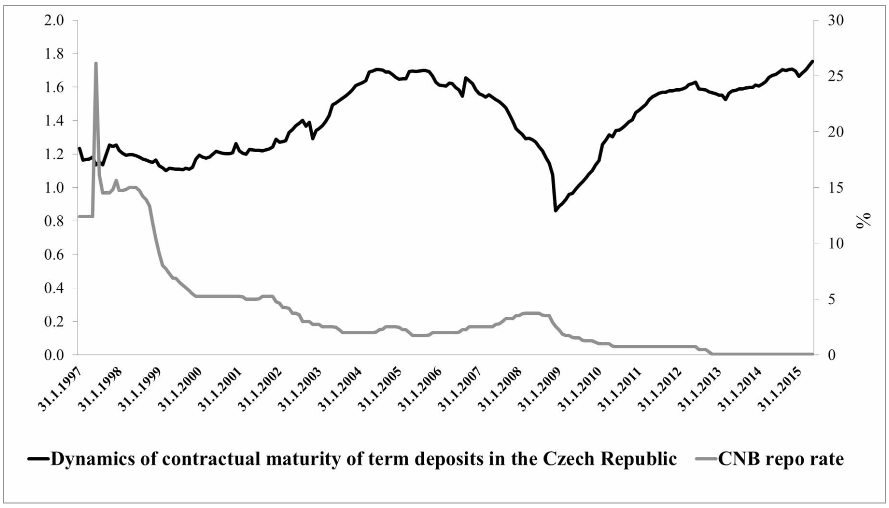
Figure 4.3: Development of Aggregate Volumes of Deposits in the Czech Republic in January 1993- January 2015



Source: Authors, based on the data provided by the Czech National Bank (CNB).

Note: Figures include all household deposits in CZK in the Czech Republic. Savings accounts are only approximated, as the CNB does not provide them separately from the figures for savings deposits which are available on demand. Nevertheless, savings accounts form most of the savings deposits available on demand. Term deposits include all deposits classified as term deposits (including building savings).

Figure 4.4: Dynamics of the Contractual Maturity of Term Deposits in the Czech Republic in January 1997 - May 2015



Source: Authors' own calculation using data from CNB.

4.2.3.2 Liquidity Characteristics of Demand Deposits

Deriving the maturity of demand deposits is a much more complex exercise than deriving the maturity of term deposits due to their non-maturity features described in Section 4.2.2. The maturity estimation of demand deposits in this paper consists of two major steps: a time series analysis of outstanding aggregate volumes, and an outflow profile (maturity) estimation. The outcome of these two steps is the liquidity profile of the outstanding aggregate demand deposits in the Czech Republic and their effective maturity calculated as of May 2015. To obtain this liquidity profile, we employ a similar approach to Kalbrener and Willing (2004).

4.2.3.2.1 Time Series Analysis of Volumes - Theory

The aim of a time series analysis is to fit a model describing the dynamics of volumes. The estimation of a proper representative model of volumes in this paper follows the Box and Jenkins (1976) procedure. Firstly, we discuss the summary statistics of the analysed time series. Secondly, we test for the presence of a unit root using an augmented Dickey-Fuller test (Dickey and Fuller, 1979) and considering the deterministic seasonality terms that make sense economically for our analysed time series. For example, we can expect a tendency towards lower growth, or even a decrease in the outstanding volume during certain periods such as vacations or Christmas, given that the Czech economy is an open economy and retail customers spend their money abroad. Thirdly, we adjust the analysed series to obtain a mean-reverting process that is fitted with AR and MA terms - see, for example, Box and Jenkins (1976). The method of estimation that is used in this paper is the non-linear least squares method. Fourthly, we ensure that the best fitting model fulfils all necessary criteria, namely the normality of residuals, no autocorrelation of residuals and the stable variance of residuals.

The method used in this paper is a general autoregressive integrated moving average process with seasonal terms ARIMA. Since we employ monthly data like the time series analysed in the macroeconomic studies, we do not need to account for the intra-month volatility. Aggregate demand deposits in a whole economy that is developed are not expected to be highly volatile, especially when the data used is on a monthly basis. There can be a potential intra-month volatility, but that is not a focus of this model and of the standard approach to the modelling of demand deposits.

4.2.3.2.2 Time Series Analysis of Volumes – Application to Czech Demand Deposits

Table 4.2 shows the summary statistics of aggregate demand deposits from January 2001 to May 2015 (173 observations including all demand deposits, including savings accounts) in the Czech Republic. Furthermore, Figure 4.3 illustrates the dynamics of the analysed time series.

Table 4.2: Summary statistics and final model

	volumes in levels	*volumes in log-levels*	*volumes in log-levels seasonally adjusted*	*volumes in log-levels seasonally adjusted and first differenced*
mean	640 152	13.24	0.12	0
maximum	1 248 495	14	0.2	0.03
minimum	205 551	12.23	0.06	-0.02
std. deviation	305 519	0.52	0.03	0.008
normality	0.001419*	0.002*	0.001*	0.25*
seasonal lag	0*	0*	0.001*	0.001*
stationarity	0.99*	0.58*	0.43*	0*
deterministic trend	0.96*	0.6*	0.62*	Not tested
Final model statistics	not used in the final model	not used in the final model	not used in the final model	Normality of e_t: 0.24* Correlation e_t: 0.54* Heteroskedasticity: 0.5* Prob of the coefficient α being different from 0: 0.627

*Source: Authors' own calculations. * The null hypothesis for normality is that a series is normally distributed. The null hypothesis for the seasonal lag is that a seasonal lag of 12 is not significantly different from zero. The null hypothesis for the stationarity is that there is a unit root process, while the alternative hypothesis is that there is a stationary process. The null hypothesis for the deterministic trend is that the series is a unit root process, while the alternative hypothesis is that it is trend stationary. The null hypothesis of the correlation test is no correlation. The null hypothesis of the heteroskedasticity test is homoskedasticity.*

We find that the best fitting model for aggregate demand deposits in the Czech Republic is an autoregressive moving average process with deterministic seasonality terms $v_t = \alpha + e_t$, where v_t is a process of the first differences of the seasonally adjusted volumes of logarithmically transformed aggregate demand deposits, α is a constant with the value of -0,000313 (which is not statistically different from 0) and e_t are errors with zero mean value and standard deviation of 0.008133. As we can see, after all adjustments, the series is a random walk. As there is evidence of a log-normal distribution of volumes, we use the log of volumes. The deterministic seasonality was supported by unit root test and by the presence of significant seasonal lags, and it is consistent with our expectations. Seasonal AR and MA terms were also tested in a model, but the model including them did not significantly outperform the selected model. The best fitting model also satisfies all necessary criteria (residuals are normally distributed, random and homoscedastic, as shown in Table 4.2.).

4.2.3.2.3 Maturity of Demand Deposits in the Czech Republic

We employ Monte Carlo simulations of the process of the equation $v_t = e_t$ to obtain *s* = 1000 possible realizations of aggregate demand deposits' volumes (for more details on the use of the Monte Carlo simulation method in finance see, for instance, Brigo and Mercurio, 2006 or Jorion, 2007). v_t is transformed back to volumes in levels after each simulation round to create simulated series of volumes. We order all simulations by calendar date and we construct the so-called minimal path of volumes by selecting the 5th percentile across all simulated observations of volumes V_t for each calendar date/modelling horizon with *t = 1, …, T* periods where particularly in our example the period T = 173. In other words, we find a volume that remains in the portfolio for all 1000 observations with 95% probability for each period. 95% probability is selected to ensure that we can define a stable liquidity structure from the outstanding volume. We call this minimum path of volumes $minV_t$. From this minimal path of volumes, we order the probabilities of volumes being in a portfolio for a given maturity. For example, when a global minimum is 100 across 173 observations, then 100 is expected to remain in a portfolio for 173 periods. The ordered series is a forecast of volumes V_{t_p}, it starts at period $t_p = 1$, which is exactly the first period after the last periods T=173 with the initial balance *B* in this period being equal to the ending balance in the period T=173. This enables us to assign cash outflow O_{t_p} to each future period after May 2015, as we know the most restrictive estimated cash flow profile. For the sake of consistency with the regulatory requirements, we focus on outflows only up to ten years after May 2015. All the remaining outstanding balance in May 2025 is expected to outflow immediately. This implies our forecast horizon is $t_p = 1,..,P$ and the last period $P = 120$. Finally, we calculate the weighted average effective maturity *M* of all outflows, which is equal to the effective maturity of the aggregate demand deposits in the Czech Republic. We obtain the result that the effective maturity is equal to 9.3 years. Formally, using the variables defined above, we define the derivation of the effective maturity as follows:

$$M = \sum_{t_p=1}^{P} \frac{O_{t_p}}{B} * \frac{t_p}{12}$$

$$\sum_{t_p=1}^{P} O_{t_p} = B \qquad \textbf{Eq. 4.2}$$

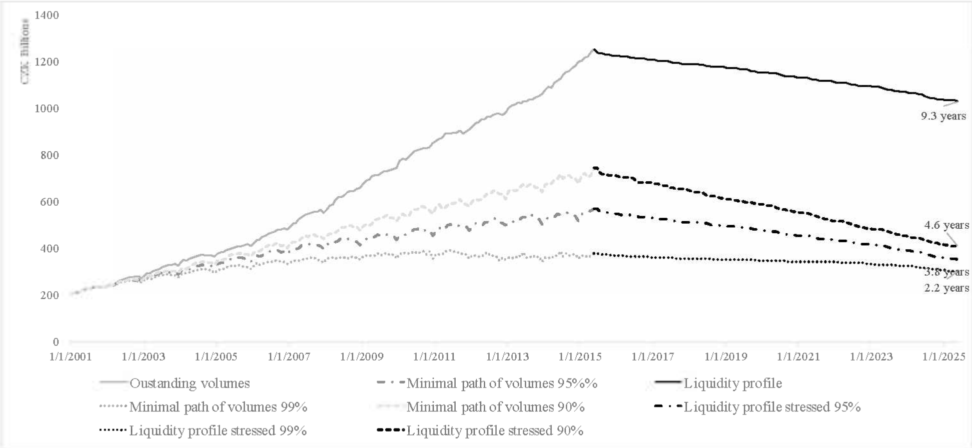
$$O_{t_p} = V_{t_p} - V_{t_p-1}$$

$$V_{t_p} = min\left\{t_p : minV_t \leq \frac{t}{T}\right\}$$

$$minV_t = min\{t : V_t \leq 5\%\}$$

Figure 4.5 shows our results graphically. It includes the outstanding volume of aggregate demand deposits in the Czech Republic from January 2001 to May 2015 together with the minimal path of volumes for 95% probability ("Minimal path of volumes 95%" line) in these dates and the estimated outflow profile of demand deposits ("Liquidity profile" line). As we can see, the outflow profile of demand deposits is very slow, and most of a portfolio remains even after 10 years. Hence, the obtained maturity of 9.3 years is driven by our assumption that all remaining volume will outflow immediately in May 2025. Without this limitation, maturity is much longer. Nevertheless, we opt to limit maturity in order to be consistent with the common bank practice and regulation. The result for the effective maturity is consistent with the fact that retail demand deposits are stable, and, on the aggregate level, transactions cancel each other out. However, our result contrasts with the restrictive unified regulatory approach that requires 5 years in EBA (2015) and only 1.8 years in BCBS (2015). The EBA (2015) requirement may be considered to be reasonable at the individual bank level, as it accounts for risk other than liquidity risk, mainly interest rate risk, which is not touched on by this paper, but we argue that, given our results, the BCBS (2015) proposal is too restrictive.

Figure 4.5: Dynamics of Volumes of Demand Deposits in the Czech Republic 1/2001 - 5/2015, their Liquidity Profile and Maturities



Source: Authors' own calculations using data provided by the CNB. The "Liquidity profile stressed 90%, 95% and 99%" lines show the liquidity profile of demand deposits if we assume that all money above the minimal path of volumes constructed from volumes that do not fall below 90%, 95% and 99% of all volumes will flow out in the first period. In this case, the maturity of demand deposits would be 4.6 years for 90%, 3.8 years for 90% and 2.2 years for 99%. The dynamics of these results are in line with the results obtained by Kalkbrener and Willing (2004). However, such scenarios are very unrealistic, i.e. to assume that almost half of the outstanding demand deposits in the whole Czech economy would be transferred somewhere else within one month does not have any reasonable economical explanation, given that most demand deposits are transactional accounts that people use on a daily basis and that cannot be easily substituted by any other kind of payment instruments. Due to this, the outflow profile "Liquidity profile" with maturity equal to 9.3 years is used as a basic result in our analysis, while the rest serves to show the sensitivity of a stressed result to a probability selection, under which we expect that volumes, in the case of the minimal path of volumes, will not fall.

4.2.4 Implications of a Low Interest-rate Environment for the Management of Retail Deposits in the Czech Republic

In the analysis above, we discussed the following points, from which we will derive conclusions in this section. Firstly, we discussed the proposition that term deposits' liquidity risk can be hedged relatively easily due to the defined contractual features of the product. We also provided reasoning why non-contractual products like transactional and savings accounts cannot be as easily hedged, due to their lack of contractual features. Secondly, we showed that the effective maturity of term deposits in the Czech Republic is 1.75 years at most, while the effective maturity of aggregate demand deposits in the Czech Republic is beyond 10 years if no regulatory limits are imposed. Thirdly, we showed the evidence of a structural transfer of volumes from term deposits to demand deposits resulting from the low-rate environment in the Czech Republic. Now the question remains as to what will happen when market rates increase. Džmuráňová and Teplý (2014) show that banks dependent on funding from savings accounts will face capital losses when market rates increase due to the high interest rate sensitivity of their depositors. The evidence of this interest rate sensitivity is also evident in the above-mentioned structural transfer from term deposits to demand deposits. Due to this, to put it simply, when market rates increase, we may except that money which is sensitive to interest rates and which currently lies in demand deposits, as no other product provides a better return, will leave those demand deposits as soon as term deposits provide a relatively better investment opportunity. On the aggregate level, this may be seen just as a change in the structure of deposits without significant impact, but this is not so at the level of individual banks.

As we show in our paper, the effective maturity of aggregate demand deposits is many times longer than the effective maturity of term deposits. Assuming the same holds for single banks, which is definitely true for large banks in the Czech Republic, due to the structure of their balance sheets, then banks are currently overestimating the true effective maturity of demand deposits (as a part of the volumes now there will move to term deposits as soon as market rates increase sufficiently). However, most large banks tend to take the interest rate sensitivity of volumes into account. This means that the overestimation should be minimized and poses no significant threat to the sector, if banks do indeed take into account the interest rate sensitivity of volumes.

We would also like to comment on another potential factor that could influence the stability of demand deposits in banks in the future, which would be more a topic for the possible future research. There are rising concerns regarding the potential effects on the banking sector stemming from the entrance of the non-banking institution providers, like Apple Pay or PayPal. This could destabilize demand deposits in banks as people would use more options to proceed with their day to day transactional banking using the non-banking institution providers' solutions. Banks need to closely monitor liquidity behaviour of their clients to be able to notice those effects in advance and adjust their internal assumptions for demand deposits accordingly.

4.2.5 Further Research Opportunities

Concerning further research opportunities, we aim to continue with our analysis of deposits in the Czech Republic for the following reasons. Firstly, this topic is focused on the Interest Rate Risk in the Banking Book (IRRBB) management regulations (EBA, 2015 and BCBS, 2015). Secondly, the deposit market might become an important issue related directly to the stability of the Czech banking sector. Finally, the deposit side of banks remains a relatively unexplored area, academically speaking, in the Czech Republic, because of a limited data availability. In the near future, we plan to assess in detail the interest rate sensitivity of deposit volumes to show how volumes would develop under different scenarios and simulations.

4.2.6 Conclusion

In this paper we have focused on retail deposits, as these form the major part of banks' funding in the Czech Republic. We discussed the differences in liquidity risk management between term deposits (contractual products) and demand deposits (on-demand products without contractual features). The term deposits' liquidity risk can be relatively easily hedged, due to the fact all interest and principal cash flows are defined by the contract between a client and a bank. Demand deposits, on the other hand, are not as easily hedged, as their effective maturity is dependent on the behavioural characteristics of clients and no contractual cash flows are defined.

Using the data freely provided by the Czech National Bank, we discovered that term deposits' effective maturity is much shorter than that of demand deposits, because most demand deposits are transactional products that have a large stable part consisting of core deposits. Our findings are consistent with the stylized facts verified by Kalkbrener and Willing (2004). Secondly, we showed that aggregate balances on term deposits are decreasing due to the current low interest rate environment, and that these volumes are being transferred to demand deposits. We detect a potential concern for a banks' stability, since a part of the money that is currently placed in demand deposits may have a liquidity profile shorter than the long one traditionally found for demand deposits. However, we do consider this threat to be rather theoretical, as many banks incorporate this risk in their internal models.

5 Liability Risk Management of Central European Banks under The New Regulatory Requirements

5.1 Introduction to the article

Published as: Džmuráňová, H., Hejdová, M. and Teplý, P. (2018). Liability Risk Management of Central European Banks Under New Regulatory Requirements. In: The Impact of Globalization on International Finance and Accounting. Springer Proceedings in Business and Economics. Springer, Cham.

Abstract

This paper describes the liability risk management of Central European banks located in the Czech Republic, Slovakia, Poland, Austria and Hungary. We find that the liabilities of the analysed banks have similar features and report similar exposure to both liquidity and interest rate risks. Additionally, we discuss the share of demand and term deposits in the bank's funding and its implications for liquidity and interest rate risk in relation to the new regulatory requirements set by the Basel Committee for Banking Supervision. We conclude that these requirements might be challenging for the analysed banks because of their liability structure.

Keywords: Demand deposits; term deposits; liquidity risk; interest rate risk

JEL classification: *G10, G21*

5.2 The Article: Liability Risk Management of Central European Banks under New Regulatory Environment

5.2.1 Introduction

A classical asset and liability management focuses on a balance sheet view of a firm and the control of two key balance sheet risks: interest rate risk and liquidity risk (Skoglund and Chen, 2015). In this paper, we focus on the liquidity and interest rate risk of the liability side of banks in the Czech Republic, Slovakia, Poland, Austria and Hungary, hereafter denoted as ACs (Analysed Countries), in relation to the new Interest Rate Risk in the Banking Book (IRRBB) guidelines. The aim of this paper is to assess the banks' readiness for those guidelines using a comparative analysis of the balance sheet structure.

The following text continues as follows: Firstly, we discuss the sound principles of the liability management of banks and the new regulatory requirements related to this. Secondly, we investigate the structure of the liabilities in the ACs and we derive conclusions on how this structure will influence the interest rate and liquidity risk of the liabilities in those banks under the new regulatory requirements. Finally, we present our concluding remarks.

5.2.2 Methodology

Bank client liabilities can be divided into two major groups: (i) Non-maturity deposits (NMDs), which are deposits redeemable on a notice (typical examples of NMDs are current accounts and savings deposits without a defined maturity), and (ii) maturing deposits (hereafter denoted as MDs), which are deposits with a given maturity. A typical example of MDs are term deposits.

Both NMDs and MDs are the centre of the regulators' attention, as both are a source of liquidity and interest rate risk due to their embedded options. The liquidity crisis that started in 2007 clearly showed the importance of stable funding sources for banks (Skoglund and Chen, 2015), and the regulators' pressure in that area since that time is a logical consequence of those events.

5.2.2.1 Regulatory requirements – overview for NMDs and MDs

In 2015, the European Banking Authority published the final version of the IRRBB guidelines (Interest Rate Risk Management of the Banking Book), in which they largely focus on interest rate risk arising from NMDs and set general rules for their risk management. EBA (2015) has been binding for banks since 1.1.2016. In 2016, the Basel Committee on Bank Supervision released its update of the IRRBB guidelines as well. BCBS (2016) goes beyond EBA (2015) in its stricter treatment of NMDs. BCBS (2016) will come into force on January 1st, 2018[23]. Banks are expected to comply with those guidelines at the discretion of the local regulator. For example, the Czech National Bank approved compliance with EBA (2015) on February 11th, 2016 (CNB, 2016). Table 5.1 summarizes both guidelines in relation to NMDs and MDs. Last but not least, during 2017, EBA is expected to publish a consultation document dedicated to the updating of the IRRBB guidelines from 2015 (EBA, 2017b). This consultation document will take BCBS (2016) into the account.

[23] Please note that this artcile was published in 2018 and concluded in 2017. This implies we refer in the article to the future, which is oviously in the past at the time of the publication of this thesis.

Table 5.1: Summary of regulatory requirements linked to the modelling of deposits

EBA (2015)	BCBS (2016)	Impact on the liability risk management
NMDs must be modelled, special attention must be paid to the interest rate sensitivity of volumes.	NMDs must be modelled, special attention must be paid to the interest rate sensitivity of volumes. NMDs must be segmented according to the client type into retail transactional, retail non-transactional and wholesale. Furthermore, deposits must be divided into stable and non-stable and core and non-core. The aim of this division is to separate liabilities that are expected to reprice from those that are not expected to reprice under any conditions. Caps are set on minimum amounts in the given category and on their average maturities.	Banks need to establish properly models describing the relationship between market rates and deposit volumes. This can be demanding for some banks from the resources perspective and might imply additional costs of technical resources as well as human resources
Maximum average duration[24] of deposits is 5 years.	Maximum average maturity of deposits is 4.5 years for retail transactional, 3.15 years for retail non-transactional and 2.25 years for wholesale. Duration is thus always strictly lower than maturity.	In Džmuráňová and Teplý (2016b) we show that the effective maturity of NMDs in the Czech Republic is far beyond the limit defined by EBA (2015). This limit might therefore force banks to change their product structure to ensure compliance with regulation. The BCSB (2016) paper is even more restrictive
Disclosure	Disclosure	Banks need to assess models in internal as well as in external validation runs.
Data reliability	Minimum requirement of 10-year length of analysed data in internal models and data reliability.	To estimate relationship between volumes and interest rates, banks would ideally need at least one full economic business cycle of falling and rising rates. However, for banks this could be a problem, as data may not be available in many cases.
MDs risk management must take embedded options into account.	MDs risk management must take embedded options into account. The paper defines in detail how early termination rates are to be modelled under different interest rate shocks.	

Source: Authors based on EBA (2015) and BCBS (2016)

[24] By duration we mean the measure of sensitivity to market rate changes.

5.2.2.2 Non-maturity deposits

The embedded option of NMDs related to liquidity risk is the fact that a client can withdraw his/her balance on a request. The legal maturity of NMD is one day, while its effective maturity is, however, much longer, as discussed by Džmuráňová and Teplý (2016b). Banks need to employ internal models to estimate this effective maturity. EBA (2015), BCBS (2016) and Bohn and Elkenbracht-Huizing (2014) also point out that banks have to have proper functioning statistical models that take into the account the interest rate sensitivity of volumes when assessing the liquidity risk of NMDs, mainly in relation to the low-rate environment.

The embedded option of NMDs related to interest rate risk is the fact that deposit rates are administered, and banks can change them at will. Some types of NMDs exhibit very sticky pricing, for example transactional accounts. Transactional accounts are used for daily liquidity needs of a client, not for savings. Due to this, deposit rates on transactional accounts are generally very low and do not respond to changes in market rates - see, for example, Hejdová et al. (2017). In the case of insensitive sticky deposit rates, the interest rate risk arises from the nature of liquidity risk, as repricing takes place as NMDs mature. By contrast, in the case of NMDs with pricing derived from the market, i.e. NMDs with deposit rates that are adjusted according to the market rate development, interest rate risk arises earlier than liquidity risk. A typical example of NMDs with the deposit pricing related to market rates is savings deposits. Interest rate risk is also a source of earnings risk, as the whole outstanding portfolio´s deposit rate of NMDs is adjusted according to changes in market rates, which exposes the bank to the maturity mismatch under increasing market rates, assuming that assets reprice less quickly than liabilities.

5.2.2.3 Maturing deposits

MDs have, in contrast to NMDs, defined a maturity and a pricing behaviour in their contract. Their liquidity risk and interest rate risk are, thus, straightforward. BCBS (2016) as well as EBA (2015) require banks to consider the two major embedded options of MDs in their internal models. Those options are: (i) the early termination and (ii) the roll-over of short-term deposits. Early termination in terms of liquidity risk implies that a bank needs to be ready to provide funds to a client earlier than the date of maturity, while the roll-over option implies that a bank should internally estimate the maturity of MDs as longer than defined in the contract. Interest rate risk arises under the early termination option during increasing market rates, when a client might like to get rid of low-interest liabilities. In the case of a roll-over, interest rate risk is not present, as the bank can reprice liability at the moment of a maturity and the rolled-over MDs are priced according to the current market conditions.

5.2.2.4 Differences in the risk management of NMDs and MDs

The logical conclusion of the description given above is that NMDs are riskier instruments for a bank than MDs. In the case of MDs, exposure to risk is defined by the product's deviance from contractual characteristics, while in the case of NMDs, a bank has to fully establish behavioural models of the product.

5.2.3 Empirical analysis

We define the liquidity development of deposits as follows:

$$M = \sum_{t_p=1}^{P} w_{s,t_p} * \frac{t_p}{12} \qquad \textbf{Eq. 5.1}$$

In Eq. 5.1, s defines the interest rate scenario, M is the (average) maturity, w_{s,t_p} is the weight of each cash outflow O_{s,t_p} in the forecast period $t_p = 1, \dots, P$ for a given scenario s for which the average maturity is calculated. This cash outflow can be given by the model or by contractual characteristics. Eq. 5.1 for different scenarios s gives the measure of liquidity risk, i.e. it shows possible changes in the maturity under different interest rates. Cash outflows may or may not be conditional on interest rates (scenarios s). For example, for the contractual term deposits without any embedded option, maturity would be equal for all scenarios. We define the interest rate risk of deposits as in Bohn and Elkenbracht-Huizing (2014), i.e.:

$$ED = -\frac{V_s - V_{FWD}}{V_{FWD} * \Delta m}$$

Eq. 5.2

$$V_s = \sum_{t_p=1}^{P} \frac{O_{s,t_p}}{(1 + m_{s,t_p})^{t_p}}$$

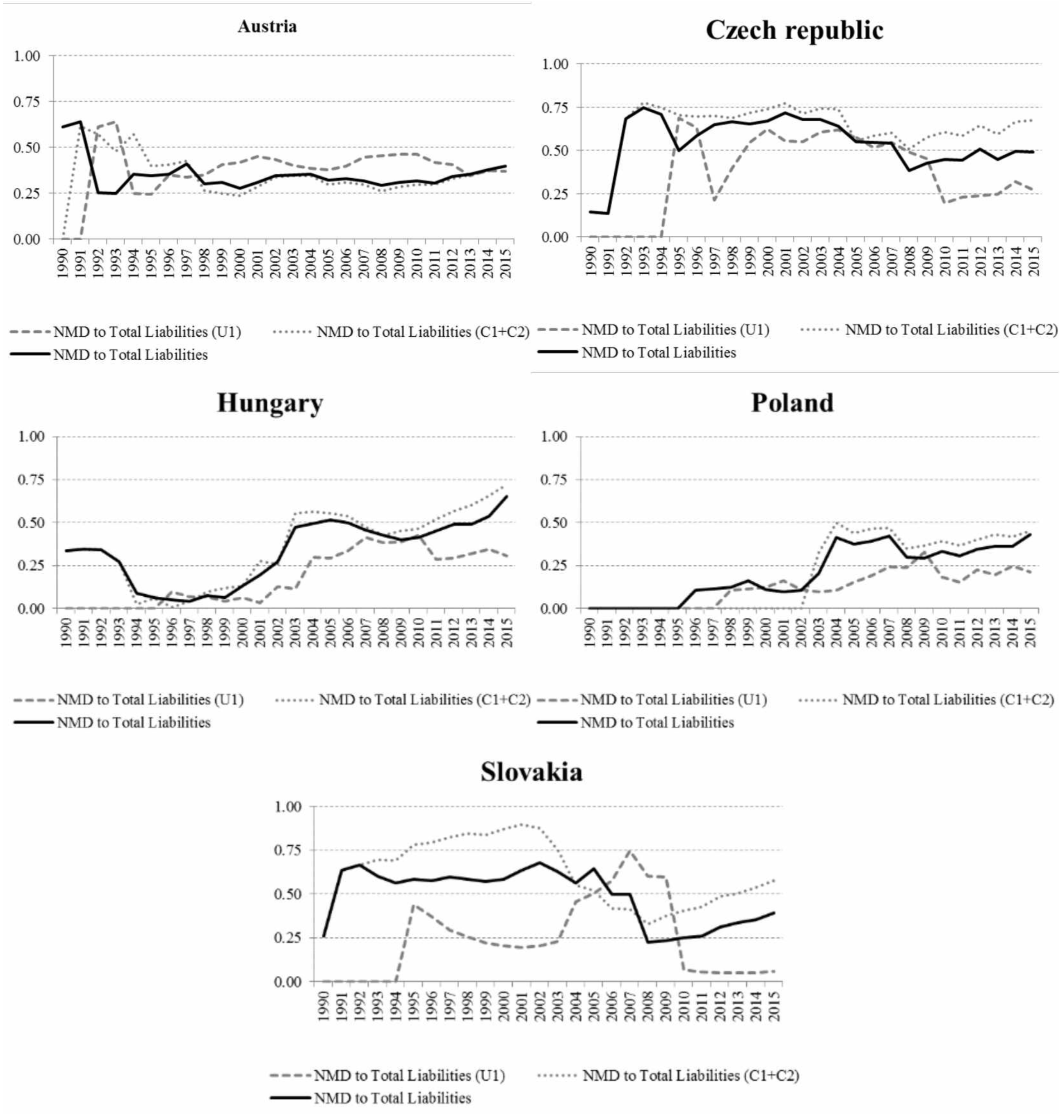
In Eq. 5.2, ED is the effective duration and m_{s,t_p} are values of market rate (usually the risk free-yield curve) for the scenario s. The scenario $s = FWD$ is a scenario of forward rates and it is considered as a baseline scenario. All other scenarios are shocks to a baseline scenario and the difference between the forward rate scenario and the shocked scenario is Δm. V_s stands for the present value of MDs and NMDs under each scenario. The measure of s sensitivity as presented in Eq. 5.2 is, thus, the measure of the magnitude of value changes. The further away from the present day, the greater the value change is. As described in Bohn and Elkenbracht-Huizing (2014), the change in value can be hedged by an appropriate selection of hedging instruments under the condition that the sensitivity of a hedge is the same as the sensitivity of MDs or NMDs[25]. Under this assumption, the bank could theoretically achieve zero sensitivity on the balance sheet level – i.e. a bank would be fully hedged against movements in interest rates, and liabilities would be fully hedged by assets with the same interest rate risk. However, such a strategy may not be a viable business strategy, given that a major purpose of the banking system is the maturity transformation of funds from subjects with an excess of funds to subjects with a lack of them.

[25] In a real situation, a first order derivation like the one presented in Eq. 5.2 must be accompanied by convexity measures and adjustment for basis risk. For details see Bohn and Elkenbracht-Huizing (2014).

5.2.4 Results and discussion

We analysed the yearly structure of the liability side of the balance sheet of all the banks in the ACs using the data from the BankScope database from 1990 to 2015. Our aim is to see the driving factors of interest rate risk and liquidity risk based on the balance sheet structure. Our empirical analysis is thus a comparison of the balance sheets of banks, which gives us a clear picture regarding the exposure of banks to both liquidity and the interest rate risk of deposits. Firstly, we investigate the structure of the funding of banks in terms of MDs and NMDs. Figure 5.1 shows the relative share of demand deposits to total liabilities. The dynamic within the last 10 years, which are of the primary concern, is clearly visible – the share of NMDs to total liabilities is substantial. This implies that banks in the ACs are more exposed to the liquidity risk of NMDs than MDs, and the liability side is riskier due to the differences in the risk management of demand and term deposits discussed earlier. The BankScope database distinguishes between different levels of consolidation: Statement of a mother bank integrating the statements of its controlled subsidiaries or branches with no unconsolidated companion (C1)/with an unconsolidated companion (C2); Statement not integrating the statements of the possible controlled subsidiaries or branches of the concerned bank with no consolidated companion (U1).

Figure 5.1: Share of NMDs to total liabilities



Source: Authors based on the data from the BankScope database

Secondly, we investigate the maturity structure of deposits in the ACs. As we showed in Eq. 5.1 and Eq. 5.2, liquidity risk is directly derived from the timing of cash flows, while interest rate risk is related to changes in the present value of those cash flows under different interest rate scenarios. In Table 5.2 we show the maturity structure of deposits in the ACs. For MDs, we apply the bucket average contractual maturities as in Table 5.2, while for NMDs (bucket Deposits < 3 months), we apply caps from BCBS (2016) to define their maximum average effective maturities, assuming equal distribution of the types of deposits in all banks. As we can see, NMDs generally drive the liability side of assets to larger maturities, given their large share and long effective maturities, which, given Eq. 5.2, implies that the change in the value of liabilities is quite large, and that the interest rate risk of the liabilities of banks in the ACs is high.

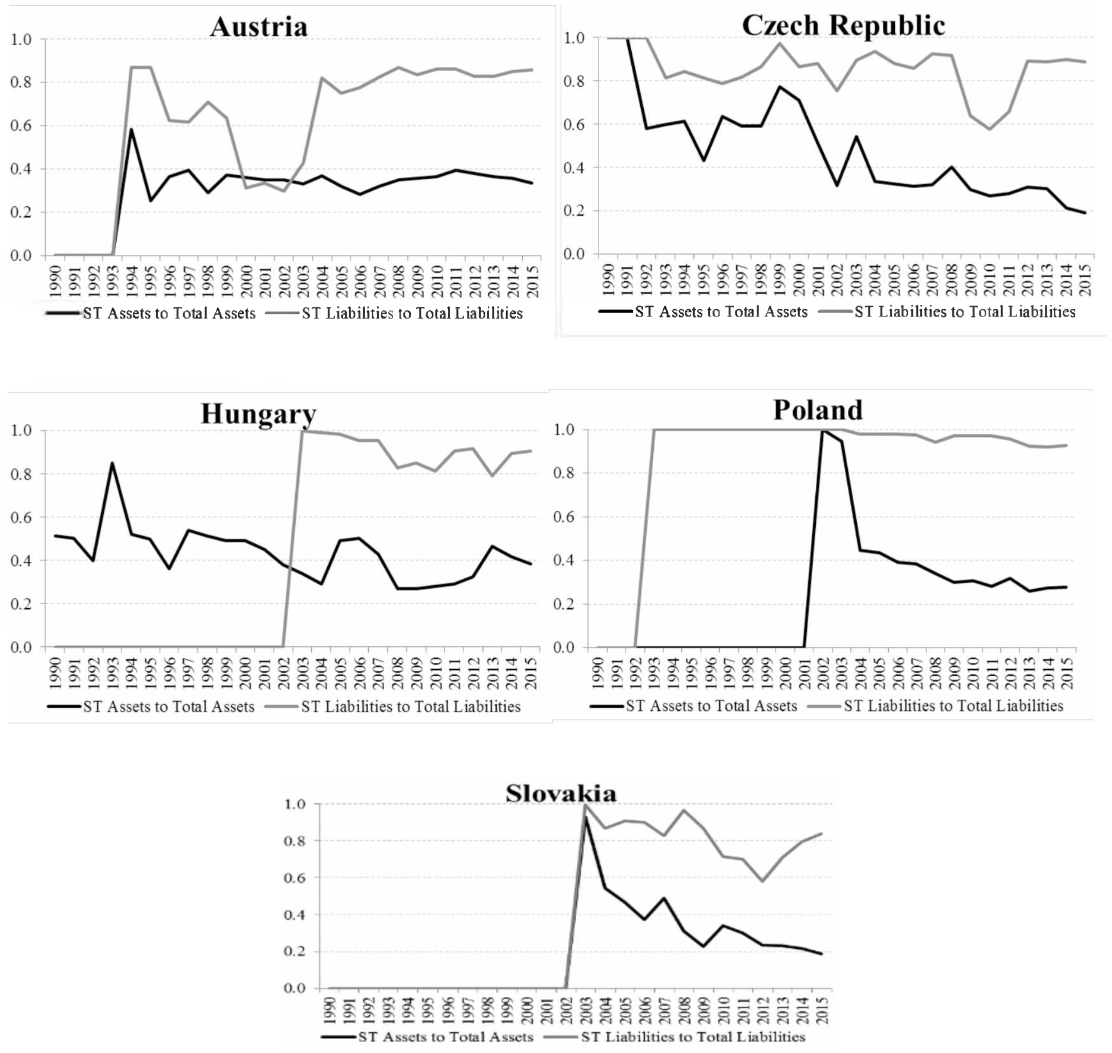
Thirdly, in relation to the maturity structure and the possibility of hedging short-term liabilities (i.e. on-demand liabilities, assuming their legal maturity, not the effective maturity), we look at a relative share of short-term deposits to total deposits and short-term assets to total assets in Figure 5.2. We can see that in all the analysed ACs, the discrepancy is highly visible, as banks have more short-term products on the liability side than on the asset side. This indicates a presence of a repricing gap. However, this conclusion stems from applying legal maturities on demand deposits (NMDs), not their effective maturities. Assuming the effective maturities for NMDs under the caps required by BCBS (2016), we might, in fact, obtain the result that banks are naturally hedged against interest rate risk, as NMDs will be hedged by long-term assets such as mortgages.

Table 5.2: The relative distribution of deposits according to their maturity

		Deposits < 3 months	Deposits 3 – 12 Months	Deposits 1 – 5 Years	Deposits > 5 Years	Liquidity risk (approximated) in Years
CZ	Share sample	69%	14%	12%	5%	3.04
	Share 2015	85%	4%	9%	2%	3.33
AT	Share sample	55%	16%	24%	6%	2.90
	Share 2015	71%	15%	10%	4%	3.04
SK	Share sample	59%	23%	17%	1%	2.69
	Share 2015	61%	23%	16%	0%	2.68
PL	Share sample	86%	11%	3%	1%	3.17
	Share 2015	74%	18%	5%	3%	2.97
HU	Share sample	49%	41%	7%	3%	2.29
	Share 2015	81%	10%	7%	3%	3.19

S*ource: Authors. The share sample is the share of Deposits < 3 months, Deposits 3 – 12 Months, Deposits 1 – 5 years and Deposits > 5 years out of the sum of all deposits across all the observed horizons, while Share 2015 is the figure only for 2015.*

Figure 5.2: Short term assets/liabilities compared to long term assets/liabilities



Source: Authors based on data from the BankScope database

5.2.5 Conclusion

In this paper we discussed the sources of liquidity and the interest rate risk of the liability side of banks in Central Europe (the Czech Republic, Slovakia, Poland, Austria and Hungary). We described how non-maturity deposits are, due to their embedded options, riskier liabilities than maturing deposits. We found that banks in Central Europe share a common liability structure with a major share of their funding in the form of non-maturity deposits, which translates into a high interest rate risk of the banks' liabilities due to the long effective maturities of non-maturity deposits. The new regulatory requirements set by the BCBS related to IRRBB may be challenging for Central European banks, which are banks with a large amount of non-maturity funding. Firstly, sound models will be required by the regulator. Secondly, regulated banks will need to generate a long data history and proceed with a model development if the regulator finds current models as insufficient.

6 The Application of Interest Rate Risk Regulation on the Czech and Slovak Banking Sectors

6.1 Introduction to the article

Published as: Džmuráňová, H. (2020). The Application of Interest Rate Risk Regulation on the Czech and Slovak Banking Sectors. Ekonomický časopis/Journal of Economics 68(3), pp. 211–230.

Abstract

This paper examines the regulation of Interest Rate Risk Management of the Banking Book in the Czech and Slovak banking sectors. We provide modelling of bank balance sheets in terms of regulatory requirements. The contribution of our paper is two-fold. First, we identify the key business drivers of Interest Rate Risk of the Banking Book of the Czech and Slovak banking sectors. Second, when comparing the interest rate risk of the banking book of both banking sectors, we find that major banks in both sectors report a higher interest rate risk from their client liabilities than from client assets. This fact implies that the banks are exposed to the risks inherent in rising interest rates. We find that the interest rate risk exposure of the Czech and Slovak banks is relatively high, and therefore, the potential contagion risk for large foreign owners with subsidiaries in both countries is not negligible.

Keywords: *bank, economic value, embedded option, interest rate risk, market value, regulation*

JEL classification: G21, G10

6.2 The Article: Interest Rate Sensitivity of Non-Maturing Bank Products

6.2.1 Introduction

In many countries, central banks have provided expansive monetary policy and have set basic interest rates to zero, or even negative values, in the last few years. This new situation will continue to affect a market risk management and a profitability of banks, which has drawn the significant research interest of academic researchers (Alessandri and Nelson 2015; Claessens et al. 2017), as well as international organizations and stability regulators (Altavilla, Boucinha and Peydro, 2018; Bikker and Vervliet, 2017; BCBS, 2016;[26] Borio, Gambacorta and Hofmann, 2017; EBA, 2018[27]). While Alessandri and Nelson (2015) and Borio, Gambacorta and Hofmann (2017) show the adverse impact of monetary policy on easing banks' net interest margins, Molyneux et al. (2019), Bikker and Vervliet (2017) and Claessens, Coleman and Donnelly (2017) highlight the negative effects of an expansive monetary policy on a bank´s profitability (margins) in a low-interest rate environment. The fact that the banks' profitability depends on interest rates is directly related to the repricing gap created by the maturity transformation and it has been already mentioned by Ho and Saunders (1981) who found out that bank's margin models need to jointly assume both asset and liabilities and that bank's total margins exhibit dependence on market interest rates

In our paper, we focus on the interest rate risk management in the Czech and Slovak banking sectors and quantify its impact on the bank's profitability. The iterature defines interest rate risk as the risk of a change in a value of an instrument stemming from changes in interest rates and the client behaviour (Mejstřík, Pečená and Teplý, 2015). The regulation separates interest rate risk into the four following

[26] The Basel Comittee on Banking Supervision thereby denoted as BCBS.
[27] The European Banking Authority thereby denoted as EBA.

risks, as defined by Bohn and Elkenbrach-Huizig (2014), EBA (2018) and BCBS (2016). It are i) a repricing risk – a risk that assets and liabilities reprice at different times; ii) a yield curve risk – a risk of unfavourable movements of market interest rates; iii) a basis risk, arising from the usage of different reference rates for products with similar repricing features; and finally (iv) an optionality risk, which is a risk stemming from embedded options hidden in client asset and liability banking book products. Such products include i) nonmaturity deposits without defined liquidity and interest rate cash flows; ii) assets subject to a prepayment risk and, in the case of revolving loans, to roll-over options; iii) term deposits subject to roll-over options and early termination options; and iv) embedded characteristics such as an implicit zero-floor on household demand deposits or flooring of corporate variable rate loans. To analyse interest rate risk, we investigate the structure of a composite of three major Czech and Slovak bank balance sheets. We analyse the balance sheet to the detail of a product. To the best of our knowledge, we are the first to do so, especially in the product-level detail. We have opted for December 2016 and December 2017 as the months in which we will calculate interest rate risk, given that annual reports are also bases for our investigation.

Interest Rate Risk Management in the Banking Book (thereby denoted as "IRRBB") has become a pivotal point for regulators in the recent years due to i) failures in its management during the 2007 – 2009 crisis and ii) the lack of preparedness for the extended low and negative-interest environment that followed. The main regulations introduced are the following: i) the European Banking Authority's (EBA) update of the IRRBB guidelines from 2015 (EBA 2015); ii) the Basel Committee on Banking Supervision's (BCBS) update of IRRBB guidelines from 2016 (BCBS, 2016); and iii) the EBA's (2018) update of EBA (2015) guidelines that harmonized EBA requirements with BCBS (2016), which are binding for banks since 30 June 2019.

IRRBB belongs under Pillar II of the Basel II regulatory framework (within the Internal Capital Adequacy Assessment Process "ICAAP"), in contrast to the Interest Rate Risk in the Trading Book, which belongs under Pillar I. Under Pillar II, banks are supposed to measure, monitor, evaluate and manage interest rate risk within the defined regulatory exposure limits. Both guidelines set up principles of sound interest rate risk management by defining rules for banks' external and internal models, as well as for their supervision.

There are several recent studies dedicated to this topic in the European context. First, with the EBA stress test, EU banks should benefit from increasing market rates (EBA, 2017). Second, Cerrone et al. (2017) found that Italian banks are exposed positively, as well as negatively, to increasing interest rates, and they actively use different hedging strategies simultaneously to manage their interest rate risk. Third, Memmel, Seyman and Teichert (2016) and Chaudron (2016) did not find evidence that a low interest rate environment resulted in significant exposure to interest rate risk in the German and Dutch banking sectors.

The remaining manuscript is structured as follows. In Section 6.2.2, we provide the theoretical background. In Section 6.2.3, we investigate the composite structure of the main three Czech and Slovak bank balance sheets, mainly in a relation to an optionality risk, and we undertake an empirical analysis of the interest rate risk. The last Section 6.2.4 concludes the paper and states final remarks.

6.2.2 Theoretical Background

Both EBA (2018) and BCBS (2016) guidelines set principles of sound interest rate risk management and supervision of Banking Book assets and liabilities subject to risks arising from changes in a client behaviour, a market environment and interest rates. Formally, BCBS (2016) defines IRRBB 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 positions*".

Management of IRRBB in both guidelines comprises two major areas: i) a management of earnings risk and ii) a management of economic value (EV) risk[28]. In this paper, we primarily focus on the latter, which is a long-term view on the interest rate sensitivity of assets and liabilities recorded in the Banking Book. This approach can unlock structural discrepancies in the Banking Book, especially those arising from the maturity and reprising mismatch or embedded options dependent on interest rates and provide the bank risk managers with insight on how to manage such exposures in the future.

The management of the economic value of risk consists of four major areas that correspond to 4 Sections in our article: i) the calculation of an economic value of a bank's balance sheet for every relevant interest rate scenario (6.2.2.1); ii) the definition of interest rate scenarios (6.2.2.2); iii) the treatment of embedded options (6.2.2.3); and iv) the impact of changes in a bank's balance sheet value under different scenarios on the bank's own funds (6.2.3).

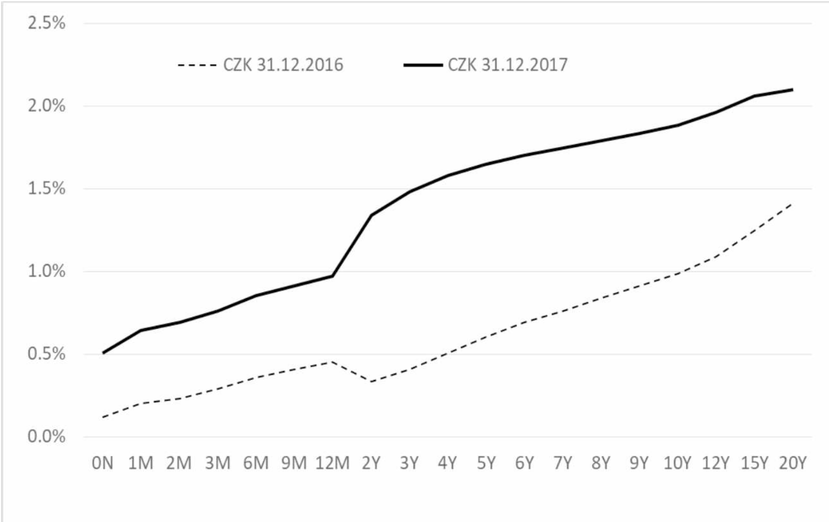
6.2.2.1 The Economic and Market Value of Equity Risk

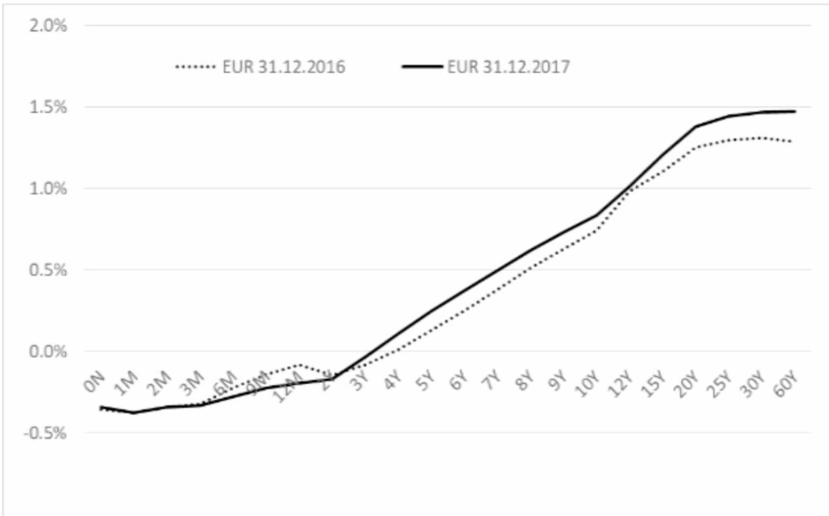
Banks calculate the economic value of bank's balance sheet for specific dates using the end of the period yield curve values (a base scenario) and volumes booked in the balance sheet at that time. In our analysis, we use spot and par Czech-currency and EUR-currency yield curves as of 31 December 2016 and December 2017 consisting of money market rates on the short end and swap rates on the long-end, as shown in Figure 6.1

We use those yield curves to calculate a zero-coupon rate curves, from which we subsequently receive discount factors and forward rates, as described by Choudhry et al. (2001) or Choudhry (2008).

[28] Or management of economic value of equity risk, which compares the amount of economic value risk to banks' outstanding capital.

Figure 6.1: Spot and Par CZK and EUR Yield Curve as of 31 December 2016





Source: Author

The management of interest rate risk assesses changes in the value of an instrument, in our case, a bank's balance sheet, under different interest rate scenarios s. To measure the interest rate risk, we use the economic value of equity (EVOE) measure defined by both the EBA (2018) and BCBS (2016), as well as the market value of equity measure (MVOE).

$$EVOE_s = \sum_{i=1}^{n} \sum_{t_p=1}^{P} CF_{a_{i,s,t_p}} * DF_{s,t_p} + \sum_{i=1}^{n} \sum_{t_p=1}^{P} -CF_{l_{i,s,t_p}} * DF_{s,t_p} \qquad \textbf{Eq. 6.1}$$

$EVOE_s$ is the economic value of equity for a given interest rate scenario s. Values are calculated over the forecast periods $t_p = 1,..,P$ where P stands for a period when the last instrument matures in the portfolio. $CF_{a_{i,s,t_p}}$ are future nominal and interest cash flows from a bank's assets a_i where i = 1, ... n. $CF_{l_{i,s,t_p}}$ are future cash flows of nominal and interest cash flows from bank's liabilities l_i where i = 1, ... n (liabilities receive a negative sign in the calculation, as those are owed by the bank to clients). Assets and liabilities may have different cash flows per different scenarios due to the embedded option, which is why there is added an index s assigned in the equation. Finally, DF_{s,t_p} is a risk-free discount factor calculated from a zero-coupon market rate m_{s,t_p} as requested by the EBA (2018). This market rate depends on a scenario s in a way that m_{s,t_p} for the baseline scenario is the market rates from the spot yield curve and the market rate for the s-scenario is the shocked value of the spot yield curve. The discount factor is derived as:

$$DF_{s,t_p} = \frac{1}{\left(1 + m_{s,t_p}\right)^{t_p}} \qquad \textbf{Eq. 6.2}$$

This discount factor simplifies for maturities under one year as $\frac{1}{1+m_{s,t_p} * t_p}$.

MVOE includes spread mr (a margin) into the discount factor (EBA, 2018), which is added to the zero-coupon rate m_{s,t_p} and is different for each asset and liability Spread is a proxy for other risks, such as credit risk, product costs, etc.

$$EVOE_s = \sum_{i=1}^{n} \sum_{t_p=1}^{P} CF_{a_{i,s,t_p}} * \frac{1}{\left(1 + m_{s,t_p} + mr_{a_i}\right)^{t_p}} + \sum_{i=1}^{n} \sum_{t_p=1}^{P} -CF_{l_{i,s,t_p}} * \frac{1}{\left(1 + m_{s,t_p} + mr_{l_i}\right)^{t_p}} \qquad \textbf{Eq. 6.3}$$

Both guidelines consider EVOE to be a basic measure. BCBS (2016) allows for commercial margins (spreads) in discount factors, but only if those are also included in discounted cash flows. EBA (2018) provides that banks may use specific margins if also used in their internal models. EVOE usage as a basic measure comes from the fact that the spread used in MVOE remains very bank-specific (it comprises charges for credit risk, product costs, etc.). This makes the risk outcomes difficult to compare among banks. Despite these shortcomings, we will investigate the MVOE measure in this paper, as it is a measure of interest rate risk closer to reality given that client asset products are not risk-free.

6.2.2.2 Interest Rate Scenarios

Interest rate scenarios' definition is similar in both the EBA (2018) and BCBS (2016) guidelines through a definition of shocks to the base scenario spot yield curve. EBA (2018) proposed two sets of shocks – two parallel regulatory shocks and 6 additional scenarios. The two parallel regulatory shocks to the current spot yield curve are a parallel shock of a base scenario by 2% up and a parallel shock of a base scenario by 2% down. Banks are supposed to floor negative shocks by linearly increasing the minimum interest rate floor, which starts at –1% for the shortest maturity and linearly increases by 0.05% each year for up to 20 years, to 0%. We derive discount factors and forward rates from shocked curves same as from the base scenario. For each scenario, the economic value of the equity (EVOE) of assets and liabilities calculates as defined in the equation Eq. 6.1. Changes in EVOE in the shock scenario against EVOE in the base scenario are compared relatively with the capital to receive an EVOE risk. The adverse impact on the capital should not lead to a loss higher than 20% of a bank's capital tier 1 + tier 2. We proceed likewise in case of MVOE. Additional 6 scenarios aim to access other shocks than parallel impacts (steepening or flattening of the yield curve, for example). Risk coming out of the worst of the 6 scenarios should not exceed 15% of a tier 1 capital. Our analysis focuses on the two parallel regulatory shocks as 6 scenarios are only a warning limit.

Apart from the predefined regulatory shocks, banks should also define internal scenarios and limits relevant for their market and business based on the past behaviour or extreme events. For example, in the Czech Republic, we can derive such shock from the behaviour of the Czech National Bank (CNB)'s setting of a 2-week repo rate. The Czech National Bank increased the repo rate several times from the August 2017 value 0.05% to the February 2020 value of 2%, with each increase having a magnitude of 0.25%.[29] Due to this, we will apply the +25 bps sector specific shock in our analysis of the Czech Republic (and we apply this shock for Slovakia as well, as in our opinion, the European Central Bank would start increase rates by 0.25% in the future).

6.2.2.3 Managing Optionality Risk

The optionality risk results in cash flows of nominal and interest deviating from the original contract. The reason is that a client exercises his/her option. The management of optionality risk aims to estimate those cash flows. On the asset side, the guidelines mainly require banks to properly monitor and model the interest rate risk arising from the embedded option of the early loan termination. On the liability side, the focus is on non-maturity deposits and the early termination of term deposits.

The early termination (prepayment) of a loan has a potentially significant impact on interest rate risk. The weighted average life is shorter than planned in the contract and consequently, interest rate risk is affected. For example, the early termination of a fixed bullet loan for 5 years at the age of 3 years implies exposure to the interest rate risk 2 years earlier than defined by the contract. This can have a substantial adverse impact on the bank’s profitability in a decreasing interest rate environment.

Since prepayment modelling can have a significant impact on a bank’s interest rate risk measure, both guidelines require proper modelling of this option, and BCBS (2016) sets minimal rules on the dynamics of baseline prepayment ratios that banks determine from historical data. We will use the same shock parameters in our analysis – prepayments are increasing by 20% in +2% shock and decreasing by 20% in –2% shock, 0.25% shock adjustment is by +/– 2.5% only.

[29] Except the first hike in August 2017.

The prepayment embedded options in both Czech and Slovak banking sectors are similar. For the consumer unsecured loans, the fee for prepayment is minimal and clients can prepay at wish for a minimal fee by simply increasing the amount they pay back. In case of housing loans, under many conditions like refixation[30] of the fixed client price or personal events like a divorce, an illness and other, a client can prepay fully without fee. Otherwise, a fee is charged, but it is very low and cannot be considered as a prepayment mitigating factor.[31] In Slovakia, there is a cap on possible fee, but otherwise banks may charge a bit more. On the corporate loans' side, barriers to prepayments are also negligible. Due to this, as clients have prepayment option almost for free (in terms of no or minimal direct fees related to the prepayment event), prepayments can be expected to be quite common in both markets, especially when clients see an opportunity to get a loan for less in another bank.

The analysis of the Czech and Slovak banking sectors' outstanding loans provides evidence that prepayment risk is substantial supporting our expectations mentioned above. Figure 6.2 shows monthly differences in outstanding volumes and new volumes of households loans in the Czech Republic. Evidently, new business seems to be much bigger than the change in the outstanding business. We can derive prepayment for household loans from these data assuming that 0.5% (based on simple annuity) of the total portfolio matures monthly. From such an approximation, we find that prepayment ratio is 1 – 1.5% monthly, which is in line with the data from one Czech bank we have access to. Consumer loans have even higher prepayment rates. We observe that, in the case of Česká spořitelna, CZK 33.5 billion of new volumes of the consumer unsecured lending were generated during

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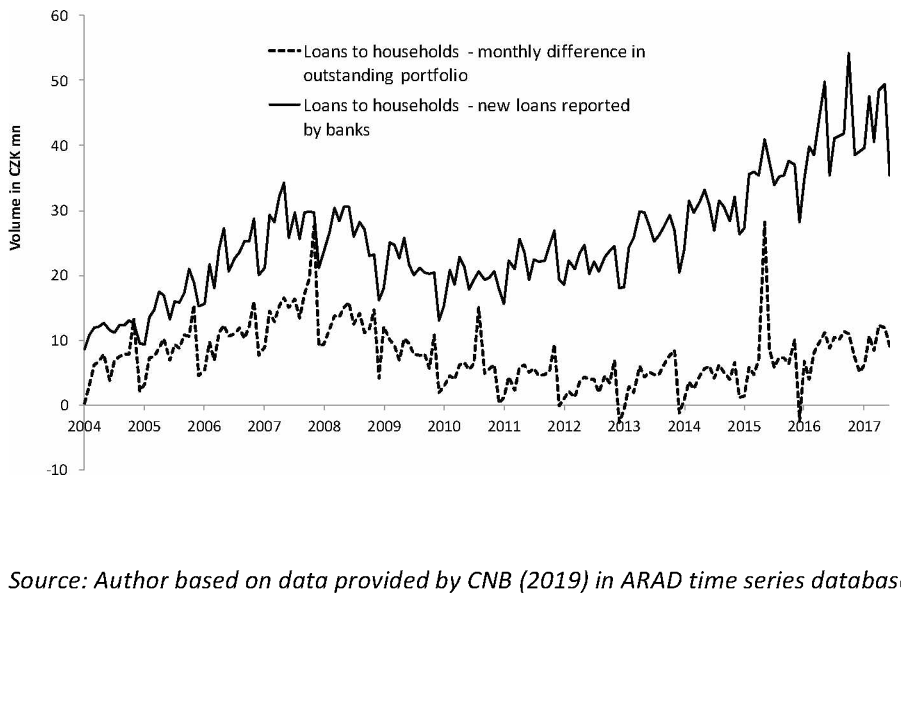
[30] Refixation of the fixed client price: Mortgage loans in both Czech and Slovak banks are usually provided for 20-25 years with periodic repricing periods of usually 3, 5, 7 and 10 years.

[31] This description is fully in accordance with the current consumer credit legislation in the Czech Republic. One has to comment, however, that there are activities within the Czech banking sector in which the Czech National Bank is requested to remove or amend their interpretation/recommendation of a fee definition. The update of this legislation is also awaiting the review by the policy makers. If they would change the wording to a more general definition, it would enable banks to charge larger fees. On top of that, some banks may decide not to follow the current recommendation of the Czech National Bank. We should also stress that this applies to new and the „refixed" loans only. On the other hand, this is a large portion of the current portfolios in banks already.

2016, while the outstanding portfolio reached CZK 64.5 billion. In 2015, same portfolio reached CZK 63.7 billion. This is an annual increase of only CZK 0.8 billion (Česká spořitelna, 2017). The average maturity of consumer loans in the Czech Republic oscillates approximately 7 years. It means that 20% should mature on a yearly basis. As the portfolio practically did not increase within a year, if we subtract estimate for natural amortization from new business equal to CZK 33.5 billion, we get an estimate of prepayments of about CZK 20 billion, i.e. 30% on a yearly basis. This is in line with similar comparison of new and the outstanding volume for consumer loans in the whole sector using the same approach as we used for housing loans above as well as with the data from one Czech bank. The dynamics of prepayments in 2017 are similar. For Slovakia, the situation is alike. Slovakian banks reported EUR 8.1 billion of new loans (mortgage loans and consumer loans), while the outstanding volume increased only by EUR 3.4 billion in 2017 (NBS, 2018). We approximate prepayments from the new business from the NBS (2018) data same as we did for the Czech Republic. We find that 10% – 12% of mortgages and 20% – 30% of consumer loans were prepaid in Slovakia in 2017. This corresponds to the data from one Slovak bank we have access to.

Figure 6.2: New versus Outstanding Loans to Households 2004 – 2017 in The Czech Republic



Source: Author based on data provided by CNB (2019) in ARAD time series database.

Second, we will discuss the IRRBB of nonmaturity deposits (denoted as "NMDs"). The loan-to-deposit ratio in the Czech banking sector amounts to 73%, and NMDs amounted to 77% of total deposits as of 31 December 2016.[32] This indicates a huge structural overhang of client deposits over client assets. Given that, assets and liabilities must be equal; this means that banks must place this liquidity from deposits somewhere else. Practically, there are two options – placing excess liquidity to the CNB facility or a long-term investment into bonds. From this perspective, in volume terms, NMDs must be a major source of interest rate risk for Czech banks. For Slovakia, the loan to deposit ratio is higher, approximately 105% (NBS, 2018). NMDs are bank liability products with two main purposes – transactions and savings. As their name suggests, there is no contractual cash flow calendar for interest and nominal cash flows. Legally, the contractual maturity and repricing period is 1-day. Their realized maturity and repricing period are much longer, however, implying a need to estimate it by the model. BCBS (2016), in its standardized framework, requires the separation of NMDs into the three bundles.

First, deposits are separated into retail and wholesale.[33] Second, retail deposits are separated into transactional deposits (used for transactions) and savings deposits (used for savings, no transactions allowed). Third, stable and non-stable deposits are defined. Stable deposits are likely to remain in a bank under any condition. Non-stable deposits receive 1-day liquidity profile. Fourth, regulation separates stable deposits into core and noncore. Core deposits are unlikely to be repriced, even under significant changes in market interest rates. This is the case of current accounts in the Czech Republic and Slovakia, as banks usually pay 0.01% on this type of deposit regardless of underlying market rates. The bigger the bank, the bigger the core proportion, as many transactions take place between clients of the same bank. In our view, stable transactional deposits in the Czech and Slovak banking sectors should be allocated to core deposits. This translates into a large share of stable funding with a high interest rate risk (Džmuráňová and Teplý, 2015; Hejdová,

[32] Based on the CNB´s ARAD time series database. Year 2017 Figures are very similar.
[33] Deposits from entrepreneurs are treated as retail.

Džmuráňová and Teplý, 2017 and Džmuráňová and Teplý, 2016b). On the other hand, for savings deposits, clients expect a higher rate of return. As we showed in Džmuráňová and Teplý (2016a), a savings deposit pricing in the Czech Republic partially depends on market interest rates, and clients are interest rate sensitive. In our analysis, we assume that the deposit rate on savings accounts maintains a stable spread to market rates: the deposit rate is as a sum of a stable spread plus the difference in the yield curve against the base scenario. Bank reaction to changes in market rates is asymmetric in case of deposit rates. We assume a lag of 12 months in case of rising market interest rates as a bank is reluctant to increase its interest expense. For decreasing rates, we assume immediate impact. The same assumptions we apply also for non-household current accounts.

BCBS (2016) also defines limits on the amount of NMDs allocated to the four groups described earlier. Table 6.1 displays that the maximum allowed average NMDs' maturity under BCBS (2016) is 4.5 years, which is slightly shorter than what European banks report recently (EBA, 2017).

Table 6.1: BCBS (2016) Limits on Core of NMDs under the Standardized Framework

	Maximum allowed proportion of core	Maximum allowed maturity of core (in years)	Maximum allowed average maturity of NMDs (in years)
Retail transactional	90%	10	4.5
Retail savings	70%	9	3.15
Wholesale	50%	8	2

Source: Author based on BCBS (2016).

Notably, a low-rate environment is especially risky for banks in terms of NMDs, as many non-transactional volumes may end up on transactional deposits because other reinvestment opportunities are scarce. Banks must carefully analyse the maturity and repricing characteristics of the core in a low-rate environment. EBA (2017a) points out that banks heavily depend on models calibrated in a low-rate environment, as longer data history is often not available. This implies large model risk. Danielsson et al., (2016) conclude that the model risk itself requires a statistical model.

Last but not least, we will briefly outline the interest rate risk management of term deposits, overdrafts, credit cards and asset roll-overs. First, for term deposits, we define two main embedded options – early termination and roll-over options. At a rollover, a client receives the new price of a product. Henceforth, it is an interest rate risk-neutral embedded option. The same principle applies to the asset rollover. For the early termination of term deposits, banks use similar risk management techniques as for term loans subject to prepayment risk due to it being similar embedded option. In the Czech Republic (after excluding building savings), we observe that only 10% of household and corporate deposits were formed by term deposits as of 1 July 2017. In Slovakia, volumes on term deposits are larger. However, since most term deposits have a maturity under 12 months (NBS, 2018), we will not model the early termination option of term deposits as it cannot affect the interest rate risk significantly.

To household overdrafts and credit cards, we will give similar liquidity and interest rate characteristics as we did to the core of retail transactional accounts. We opted for this because credit cards or overdrafts are, in fact, a mirror of transactional accounts on the banks' asset side.

6.2.3 Interest Rate Risk of the Czech and Slovak Banking Sectors

We analyse three major Czech banks in detail – Česká spořitelna, Česko slovenská obchodní banka (CSOB) and Komerční banka – whose total market shares form approximately 70% of total sector assets as of the end of 2016. Due to the strong tendency of a bank product commoditization in the Czech Republic (Džmuráňová and Teplý, 2016b), all three banks offer very similar products – mortgage loans, consumer loans, credit cards, overdrafts, current accounts, savings accounts and term deposits. All these products are subject to an optionality risk.

For Slovakia, we closely analyse Slovenská spořitelna (2017; 2018), Všeobecná úvěrová banka VUB (2017; 2018) and Tatra banka (2017; 2018). The Slovakian banking sector shows similar types of bank products on the asset side as the Czech banking sector, but the liability side differs. Slovakian banks report more term deposits and fewer savings accounts than the Czech banks. Additionally, Slovakian banks gather funds through mortgage bonds, which is not a common practice in the Czech Republic due to significant over liquidity in the sector.

Table 6.2: Interest Rate Risk Relevant Balance Sheet Items of the Czech and Slovak Analysed Banks as of 31. 12. 2016 (Balance Sheet is not balanced, as other items, such as intangible assets, are not the subject of this analysis)

CZ in CZK bn, SK in EUR bn	Česká spořitelna	CSOB	Komerční banka	Slovenská spořitelna	VUB	Tatra
Assets in analysis	906	937	760	14.7	12.8	11.0
Unsecured loans retail	65	24	23	1.6	1.6	2.0
Secured loans retail	210	257	208	6.1	4.3	2.9
Corporate + Micro loans	236	231	309	2.9	4.1	3.6
Investments + CB placements*	396	425	221	4.1	2.8	2.5
Liabilities in analysis	767	734	759	13.9	12.7	10.7
Current accounts	423	442	496	5.8	5.9	7.7
Savings accounts	138	214	161	2.4	0.2	0.2
Term deposits	5	8	30	2.8	3.3	1.1
Mortgage bonds	0	0	0	1.6	1.7	0.7
Tier + Tier 2	102	70	72	1.3	1.5	1.0

Source: Author based on annual bank's reports. Big difference in assets and liabilities in case of CSOB stems from the fact that CSOB has large volumes in the emitted deposit bills to financial institutions that are not included in this analysis. On the asset side, those are than booked in deposits to CB (Central Bank). These liabilities are booked under cash and cash-equivalent, hence their repricing risk is very low, basically none. Their exclusion has no impact on our analysis. *High asset volumes in case of Česká spořitelna and CSOB are primarily driven by CB placements.

Apart from client assets and liabilities, Czech and Slovak banks pose a large portion of assets into investments and the Central bank placements (i.e., banks' receivables on the Central Bank). Due to this, these assets have a significant inherent influence on IRRBB. We face the problem that neither bank reports the average maturity of their investment portfolio. From the available data, we identified that government bonds form the major part of banks' investments. Table 6.2 and Table 6.3 summarize all balance sheet data.

Table 6.3: Interest Rate Risk Relevant Balance Sheet Items of the Czech and Slovak Analysed Banks as of 31. 12. 2017 (Balance Sheet is not balanced, as other items, such as intangible assets, are not the subject of this analysis)

CZ in CZK bn, SK in EUR bn	Česká spořitelna	CSOB	Komerční banka	Slovenská spořitelna	VUB	Tatra
Assets in analysis	992	1173	897	16.2	13.5	11.4
Unsecured loans retail	66	28	38	1.7	1.6	1.4
Secured loans retail	233	282	219	7.0	5.2	3.5
Corporate + Micro loans	222	237	301	3.4	4.2	3.9
Investments + CB placements*	471	626	341	4.1	2.5	2.6
Liabilities in analysis	825	802	828	14.8	13.7	11.8
Current accounts	562	507	557	6.6	6.4	8.8
Savings accounts	155	215	164	2.8	0.2	0.2
Term deposits	5	12	28	2.6	3.2	1.0
Mortgage bonds	0	0	0	1.5	2.3	0.8
Tier + Tier 2	104	69	79	1.3	1.6	1.0

Source: Author based on annual bank reports. Big difference in assets and liabilities *in case of CSOB stems from the fact that CSOB has large volumes in the emitted deposit bills to financial institutions that are not included in this analysis. On the asset side, those are than booked in deposits to CB. These liabilities are booked under cash and cash-equivalent, hence their repricing risk is very low, basically none. Their exclusion has no impact on our analysis. *High asset volumes in case of Česká spořitelna and CSOB are primarily driven by CB placements.*

Table 6.4 defines the contractual and optionality characteristics of client assets and liabilities in our analysis. This serves as an input from which to derive nominal and interest cash flows for the calculation of EVOE and MVOE as defined in Eq. 6.1, Eq. 6.2 and Eq. 6.3. We apply same characteristics for all banks due to the commoditization tendency in both banking sectors. We discuss specific reasoning how cash flows are derived for products with the contractually undefined maturity and pricing behaviour or prepayment option in Section 6.2.2.3. Client prices for products that reprice before maturity (variable loans, corporate loans, savings accounts) are equal to a sum of an underlying interest rate defined by the interest rate scenario and the margin. We work with the legal floor of the 0% deposit rate on NMDs and we also apply a 0% floor on the underlying market rate in case of the variable rate-linked products. BCBS (2016) defines buckets into which all balance sheet positions are slotted. Entrop et al. (2009) show that cash flow slotting can significantly bias results compared to using more relaxed assumptions that would be closer to the actual product behaviour. Additionally, EBA (2018) does not require such cash flow slotting. Due to this, we do not apply cash flow slotting, as we consider it an unnecessary simplification. All cash flows in our analysis happen on a monthly basis.

Table 6.4: Behavioural and Contractual Characteristics of Client assets and Liabilities

Product	Assumption	Slovakia	Czechia
Household consumer loans	Maturity	7 years	7 years
	Length of fixation period	7 years	7 years
	Type of redemption	annuity	annuity
	Interest rate	10.7%/9.8%	12.2%/10.8%
	Prepayment ratio (monthly)	3%	3%
	Spread	10.8%/10.7%	11.7%/11.4%
Household mortgage loans	Maturity	20 years	20 years
	Length of fixation period	5 years	1 month – 7.5 years*
	Type of redemption	annuity	annuity
	Interest rate	2.5%/2.3%	2.88%/2.6%
	Prepayment ratio (monthly)	1%	1%
	Spread	2.42%/1.97%	1.8-2.4%/2-2.2%
Household overdrafts	Maturity	10 years	10 years
	Length of fixation period	10 years	10 years
	Type of redemption	linear	linear
	Interest rate	15.5%/15.5%	13.6%/12.5%
	Spread	13%/13.1%	14.16%/14%
Household credit cards	Maturity	10 years	10 years
	Length of fixation period	10 years	10 years
	Type of redemption	Linear	Linear
	Interest rate	15.5%/15.5%	21%/19.4%
	Spread	13%/13.1%	20.8%/20.8%
Corporate + micro loans	Maturity	5 years	5 years
	Length of fixation period	1 month	1 month
	Type of redemption	Annuity	Annuity
	Interest rate	2.6%/2.4%	2.54%/2.74%
	Prepayment ratio (monthly)	1%	2%
	Spread	3.2%/3.1%	1.8%/1.75%
Households current accounts	Maturity core/non-core	10 years/1 day	10 years/1 day
	Length of fixation period	fixed to maturity	fixed to maturity
	Type of redemption	linear	linear
	Interest rate	0.01%	0.01%
	Volume core	90%	90%
Households savings accounts	Maturity core/non-core	9 years/1 day	9 years/ 1 day
	Length of fixation period	12 months	12 months
	Type of redemption	Linear	Linear
	Interest rate	0.2%/0.1%	0.2%
	Volume core	70%	70%
Households term deposits	Maturity	1 year	1 year
	Length of fixation period	1 year	1 year
	Type of redemption	Bullet	Bullet
	Interest rate	0.58%	1%/0.6%
	Volume sensitivity	0%	0%
Corporate current accounts	Maturity core/non-core	8 years/1 day	8 years/ 1 day
	Length of fixation period	12 months	12 months
	Type of redemption	linear	linear
	Interest rate	0.01%	0.01%
	Volume core	50%	50%
Investments** and Central bank placements***	Maturity	10 years	10 years
	Length of fixation period	10 year	10 year
	Type of redemption	linear	linear
	Interest rate	3.34%/3%	2.9%/2.6%
Mortgage bonds	Maturity	7 years	
	Length of fixation period	7 year	
	Type of redemption	linear	
	Interest rate	2.16%/1.7%	

** 60% 5-year fixation, 20% 1-month fixation and 20% 7.5-year fixation, based on the Czech National Bank data. ** Banks should manage investments based on the liquidity and the interest rate characteristics of liability that used as a source of money for investments. These are stable cores of NMDs. Due to this; we model investments in our analysis as 10-year bullet deals in the linear replicating portfolio. Concerning yields, we use government bonds' residual maturity basket yields to derive average portfolio yield. *** For the Central Bank placement, we assume that it is a bullet of 14 days and receives repo rate. This implies negligible (for simplicity 0 in our analysis) interest rate risk.*

Source: Author. Two numbers x/y are for year-end 2016 respectively 2017.

To derive the characteristics summarized in Table 6.4, we used the following key sources: i) the Central Bank's data, Internet and Regulation sources are from the freely available resources and source for deposit rates and prepayments' approximations); ii) the knowledge and the expert opinion provided by two banks in the Czech Republic and Slovakia; iii) webpages of analysed banks (the source of information for maturities and deposit rates); iv) regulatory guidelines of BCBS (2016) and EBA (2018) – the baseline setup for separation of NMDs into cash flow buckets and the response of prepayment ratios to different interest rate scenarios and v) a paper by Džmuráňová and Teplý (2016b), in which the authors derived the liquidity profile of term deposits and NMDs in the Czech Republic, and where we also discussed the prepayment option of a client and its impact on a banks' profit.

Table 6.5 shows the results for the interest rate risk in terms of the adverse capital impact. We show impact with and without investments and mortgage bonds to be able to fully separate interest rate risk inherent to the business model of client assets and liabilities.

Table 6.6 shows value changes of client assets versus value changes of client liabilities as of 31 December 2017 (this is a proxy for the maturity mismatch or the repricing gap.

Table 6.7 shows how individual client products contribute to a bank's client assets and liabilities interest rate risk in terms of the economic value risk across all shock scenarios. This results show the product drivers of interest rate risk.

Table 6.5: The Interest Rate Risk – Capital Impact in % with/without Investment Portfolio

	31 December 2016			31 December 2017		
	Impact on capital EVOE	*Impact on capital MVOE*	*Shock with the highest negative capital impact*	*Impact on capital EVOE*	*Impact on capital MVOE*	*Shock with the highest negative capital impact*
Česká spořitelna	−6/−20	−5/−19	−2	−16/−32	−15/−31	−2
CSOB	−11/−27	−10/−26	−2	−25/−43	−24/−41	−2
Komerční banka	−15/−24	−13/−23	−2	−28/36	−26/−35	−2
TOP 3 Czech Republic	−10/−23	−9/−22	−2	−22/−36	−21/−36	−2
Slovenská spořitelna	−8/−16	−7/−15	−2	−12/−21	−11/−20	−2
VUB	−2/−3	−1/−3	−2	−7/−5	−7/−4	−2
Tatra banka	−7/−12	−7/−12	−2	−15/−19	−15/−19	−2
TOP 3 Slovakia	−5/−10	−5/−9	−2	−11/−14	−10/−13	−2

Source: Author's own calculations. The first number is with investments; the second one is without investments. We show thereby only negative impact into capital which is for all banks present for –2% yield curve shock scenario. For positive scenarios, all banks report positive impact on capital.

Table 6.6: The economic Value (effective duration) Mismatch between Client Assets and Client Liabilities as of 31. 12. 2017 and Gain/Loss to Capital

Changes to base scenario economic value, TOP 3 Slovakia, in EUR mn			
Scenario	2%	−2%	0.25%
Client assets	−585	562	−80
Client liabilities	1 799	−1 104	237
Relative mismatch A/L*	−32%	−51%	−34%
Total value change	1 215	−542	157
Changes to base scenario economic value, TOP 3 Czech Republic, in CZK bn			
Scenario	2%	−2%	0.25%
Client assets	−21	46	−3
Client liabilities	121	−138	16
Relative mismatch A/L*	−17%	−34%	−17%
Total value change	100	−91.5	13.3

Source: Author's own calculations. The lower the percent, the higher the mismatch

Table 6.7: The Interest Rate Risk – Bank Products (in %)

	Slovakia		Czechia	
Client assets	*2016*	*2017*	*2016*	*2017*
Unsecured loans retail	31	27	11	12
Secured loans retail	51	55	63	68
Corporate + Micro loans	18	18	26	20
Client liabilities				
Current accounts	86	87	75	76
Savings accounts	10	11	25	24
Term deposits	4	3	0	0

Source: Author's own calculations. The table shows relative importance of the product on an economic value change of client assets or client liabilities across all analysed scenarios. It shows which products have the biggest impact.

First, banks are exposed to the interest rate risk of liabilities, which stems from the fact that assets reprice faster than liabilities, as well as banks having fewer client assets than client liabilities (Table 6.6). Slovakian banks' exposure is to a lesser extent, mainly stemming from a lower amount of savings accounts and a higher amount of term deposits that reprice more quickly than savings accounts. Due to this exposure to liabilities, for all banks, the adverse and relevant regulatory impact on capital comes from decreasing interest rates, as shown in Table 6.5. The positive impact on a capital in the case of increasing rates (+2% scenario) is substantial and is on average +25% of capital for Slovakia and the Czech Republic. In terms of client assets and liabilities only, it amounted, for example, to CZK 100 billion for TOP3 Czech banks as of 31. 12. 2017 (Table 6.6). This stems by the fact that we assume there will not be higher outflows from retail current accounts in case of positive shocks. This assumption results from the usage of regulatory caps as described in Table 6.1, which are already restrictive enough. However, on both markets, there is evident tendency of decrease of term deposits and increase of demand deposits (based on the Central Banks' data). If we would increase the 1-month outflow from household's current accounts from 10% to 25% in the Czech Republic and 15% in Slovakia in case of 2% shock, we would see that benefit of banks from higher interest rates would decrease by 20% in both countries. Our results are in line with the findings of EBA (2017a), as the Czech and Slovakian banks will benefit from increasing market rates, as will around one third of other European banks.

Second, two analysed Czech banks (CSOB and Komerční banka) are not within both regulatory limits set by the EBA (2018) and BCBS (2016) on EVOE, as the maximum detrimental impact into capital goes above –20% in 2017. We also see that the risk almost doubled between 2016 and 2017. The reason for this yearly increase is an application of a floor on a yield curve and its shocked scenarios, as defined by EBA (2018), as well as of a legal floor of 0% on interest rates to ensure that commercial margins would not decrease (banks are not expected to decrease deposit rates below a value of credit risk, for example). The further yield curve goes away from the floor; the possible loss stemming from decreasing interest rates gets bigger. The floor application is also the reason why Slovakian banks are well within the limit given that EUR interest rates are substantially lower than CZK interest rates.

Third, prepayment option affects the interest rate risk exposure largely. The presence of prepayments largely decreases the time to repricing of fixed assets. For consumer loans, we found an average duration of approximately 1 year, which is noticeably lower than the average maturity of a portfolio of 3.5 years. We compared our prepayment ratios with the EBA (2017a), and ours are slightly higher. This we attribute to the fact that the Czech and Slovak economic sectors have larger proportions of long-term fixed mortgage loans than other European countries. The EBA (2017a) points out that impact of the EVOE measure is significantly dependent on the presence of prepayment options, which our analysis confirms. Moreover, the interest rate risk impact of prepayments indicates that assets reprice faster in the case of decreasing market rates as prepayments increase, which also explains why the relative mismatch between economic value changes has a bigger magnitude in negative shocks. This result confirms the findings by Teplý and Bečvaříková (2016), who showed a significant impact of prepayments on banks' interest margins. To provide the complete picture, we approximated the impact on the capital without a prepayment option, as well. The negative impact on capital would decrease by 25% on average, but banks would also gain less benefit from increasing interest rates.

Fourth, banks extensively use investments to close value change mismatches generated by the repricing gap between client assets and liabilities. Excluding the impact of investment portfolios (and Mortgage bonds), the adverse impact on the capital shown would be at least double.

Fifth, in terms of the interest rate risk of individual product types, we will comment briefly on mortgage loans and demand deposits. Based on their balance sheet importance (Table 6.2 and Table 6.3) and the product characteristics summarized in Table 6.4, we would expect that the major interest rate risk of client assets stems from mortgage loans, while the major interest rate risk of client liabilities will be driven by current accounts. Table 6.7 supports this conclusion. The results also show that the Czech banking sector is more exposed to interest rate risk from savings accounts than the Slovak banking sector, which is relevant as it poses higher uncertainty about the interest rate risk of Czech banks' liabilities, as savings accounts are modelled products and each model is subject to model risk.

Finally, we need to highlight that our analysis of the interest rate risk of banks' balance sheets did not take into the account the hedging (derivatives) due to the un-availability of data regarding the structure of those products. We also neglect possible gains from the currency compensation as defined in EBA (2018). Banks are allowed to decrease the negative impact from the major currency with the 50% weight of the positive impact (if any) across same shocks from other currencies. As the TOP3 analysed Czech and Slovak banks are largely retail-business-based, we consider the analysis in terms of major currency only as sufficient. In relation to the hedging topic, EBA (2017a), as well as Cerrone et al. (2017), mention that banks use derivatives to manage their interest rate risk exposures extensively. CSOB and Komerční banka would need to have around CZK 40 billion (CSOB) to CZK 70 billion (Komerční banka) of the fix receiver interest rate swaps with an average duration of 5 years to ensure an EVOE ratio below –20% as of 31. 12. 2017. These amounts are far below the reported volume of derivatives in annual reports. This indicates that neither CSOB nor Komerční banka would in fact be above 20% in their regulatory reporting to the Czech National Bank. Additionally, Table 6.8. summarizes how much

% of the reported derivatives (which are booked as the Banking Book derivatives whenever possible) would have to be to allocated to the 5-year average duration replicating portfolio of fix receiver interest rate swaps in each bank to have 0 interest rate risk, together with the reported amount of the Banking Book derivatives in the Czech Republic and total derivatives in Slovakia each bank had as of a year-end 2017 and as of a year-end 2019. As we can see, necessary volumes to close the balance sheet interest rate risk to 0 are in line or well below the reported volume of derivatives. In case of Slovakia, this is driven by the inclusion of the Trading book derivatives, though, as we are not able to sufficiently separate the Banking book derivatives properly in the provided data from banks. When accessing this analysis, one must also take into the account the fact that the aim of the bank is not to have 0 interest rate risk. Such position would disable a bank to benefit (create profit) from the maturity transformation. This calculation is purely theoretical, and the rational bank will keep its balance sheet's interest rate risk within limits, but not fully closed. Nevertheless, the conclusion that hedging place vital role in the bank´s interest rate risk management is supported in other studies as well, for example, in Alessandri and Nelson (2015) or Flannery (1981).

Table 6.8: The Effect of Derivatives

	ADVERSE SHOCK TO HEDGE	BANK	REPORTED DERIVATIVES 2017/2019 IN CZK BILLIONS FOR CZECH BANKS/EUR BILLIONS FOR SLOVAK BANKS	% DERIVATIVES 2017/2019*
CZECH BANKS	-2%	Česká spořitelna	157/184	106/90
	-2%	ČSOB	755/937	23/19
	-2%	Komerční banka	750/1087	29/20
SLOVAK BANKS	-2%	Slovenská spořitelna	2.332/2.579	71/64
	-2%	VUB	3.886/2.481	29/45
	-2%	Tatra banka	3.325/3.964	47/39

Source: Author. * Calculation for 2019 is approximation as it uses values for interest rate risk from 2017. Based on annual reports Česká spořitelna (2020), CSOB (2021), Komerční banka (2020), Slovenská spořitelna (2020), VUB (2020) and Tatra banka (2020) and disclosure of data under 163/2014 in the Czech Republic (which enables proper separation of Banking Book and Trading Book derivatives).

Even though our results focus mainly on the client view and products perspective, the conclusion in relation to hedging shows that banks can hugely influence their interest rate risk through the derivatives market. Interest rate risk of client asset and loans is given largely to the bank by the market set up and banks can use derivatives to close potential gaps which arise due to this. Given the reported volume of derivatives as shown in Table 6.8., bearing in mind also the huge volume of the Trading book derivatives Czech banks report, we can conclude that banks indeed use the Banking Book derivatives to manage interest rate risk extensively and, additionally, both Czech and Slovak banks are quite active in this area.

Our analysis shows that Slovak and Czech banks’ exposure to the interest rate risk of client assets and liabilities is substantial and cannot be covered solely by investments into risk-free, long-term government bonds. We claim that the baseline interest rate exposure stems from client asset and liabilities, and the rest (i.e., investments and derivatives) are dependent on it. Due to this, our analysis provides a unique view on IRRBB, since we separate client assets’ and liabilities’ risks. Such an analysis has not been presented in any study on either the domestic level or on the international level.[34]

6.2.4 Conclusion

This paper discusses the recent updates of IRRBB by regulators EBA (2018) and BCBS (2016). In accordance with both regulatory guidelines, we calculated the interest rate risk of client assets and liabilities of the Czech and Slovak banking sector, approximated by financial statements of the TOP 3 large banks. Unlike other researchers, who provided high-level analysis, we provide the granular modelling of bank balance sheets and behavioural options embedded in client products (prepayments, non-maturity deposits). We found that both banking sectors are largely exposed to the interest rate risk of client liabilities because of high shares of non-maturity deposits and the fact that those liabilities have higher sensitivity to changes in interest rates than client assets. Client assets reprice more quickly than client liabilities also due to the prepayment option of a client which exposes the bank to the early termination of positions. Consequently, the Czech and Slovak banking sectors would be able to benefit from increasing market rates. This can be related to several studies that estimate effect of bank´s profitability under different interest rate environments, with focus at low or negative interest rates. Even though margin interest rate risk, which is often focus of those studies, is not a part of interest rate risk we investigate in this article[35], Alessandri and Nelson (2015), Borio, Gambacorta and Hofmann (2017), Molyneux et al. (2019), Bikker and Vervliet (2017) and Claessens, Coleman and Donnelly (2017) all find evidence for the adverse effects of low/negative interest rates on bank´s profits (margins), as well as evidence for the opposite in case of increasing interest rates. They thus conclude as well as us, that banks are expected to benefit on a long-term, from higher interest rates.

[34] Apart from studies dedicated solely to value of NMDs such as Bloechlinger (2018), Kalkbrener and Willing (2004) or Strnad (2009).

[35] As margins for on balance sheet positions that mature only are fixed in contracts.

Both the Czech and Slovak banking sectors report similar exposure to interest rate risk, which might be a potential source of contagion for large foreign owners with assets in both countries, as both sectors would respond similarly to alike interest rate developments.

This paper separates Interest Rate Risk of the Banking Book into different types of client products using the aggregated balance sheet data and product behavioural characteristics. We observe interest rate risk of only the client part of the balance sheet, which gives us a unique view of IRRBB because other studies are usually high level oriented. In this respect, our research is unique and provides new insights at the product level, as well as the baseline information about the drivers of interest rate risk in the Czech and Slovak banking sector.

7 Conclusions

This thesis dealt with the implications of the maturity transformation stemming from the embedded optionality and behavioural factors of bank products, clients and banks in the banking system in the Czech Republic. We described the methodologies and theories behind the management of interest rate risk (IRRBB) and liquidity risk of the banking book. We also calculated the interest rate risk and the liquidity risk of banking products in the Czech Republic (and Slovakia). According to our knowledge, we are the first to evaluate, estimate and measure the interest rate risk in the Czech banks according to the IRRBB guidelines. In the conclusion to this thesis, we would like to summarize the main findings and provide an update to our research to reflect the current economic situation and environment.

In the first article, *Duration of Demand Deposits in Theory,* we investigated the methodologies employed by banks to manage the interest rate risk stemming from demand deposits, which are products with undefined timing of cash flows and the non-contractual (bank administrated) pricing. These features make the demand deposits' risk management challenging, and appropriate methods must be used by banks. We discussed the best practice statistical models to fit the dynamics of market interest rates, deposit rates, the volume dynamics of demand deposits and a replicating portfolio method, thus providing a theoretical background to our further analysis and the methods we have used throughout our research.

The reason we started with the interest rate risk management of demand deposits stems from their importance for the analysis and results presented in this thesis. A typical standard commercial bank in the Czech Republic has the following balance sheet structure:

Table 7.1: Typical balance sheet of a commercial bank

Assets	Liabilities
Cash and Balances with CBs	Current accounts – Client deposits
Loans to customers – term loans	Savings accounts – Client deposits
Loans to customers – OVD and CC	Term deposits – Client deposits
Investments	Other liabilities
Other assets	Equity

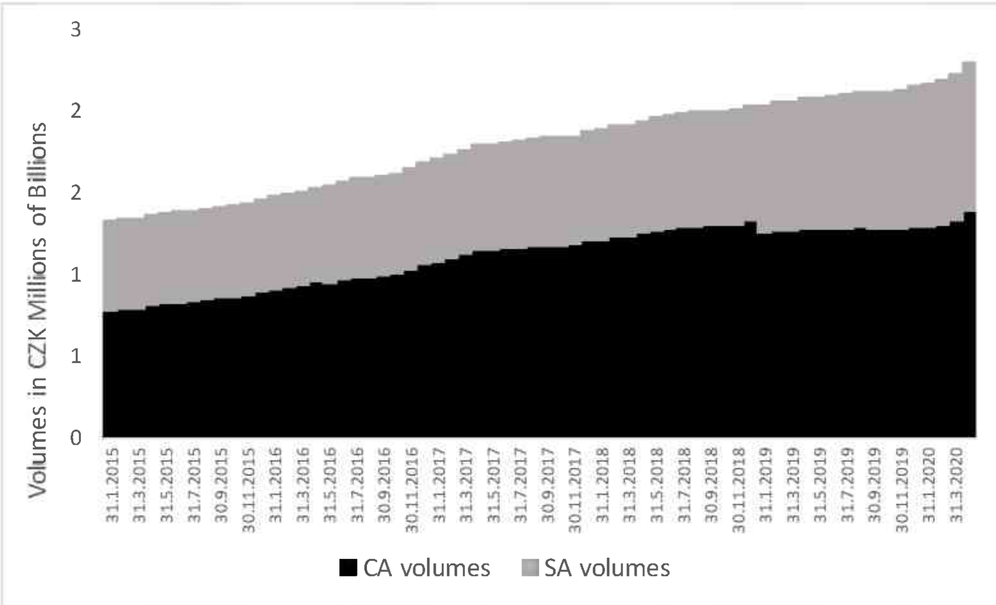
Source: Authors. OVD = overdrafts. CC = credit cards.

According to the Czech National Bank data, demand deposits form 83% of the total deposit base, of which we estimate 64% are current accounts and 19% are savings accounts, as of December 2020[36]. This makes them, in volume terms, a major source of interest rate risk and liquidity risk for Czech banks. We also argued that savings accounts are riskier due to their embedded characteristics. Savings accounts are used for savings, which implies that clients are potentially interest rate sensitive. As a result, we started our practical research with an investigation into the interest rate risk of savings accounts in the Czech Republic in the form of a case study in the second article entitled *Why are Savings Accounts Perceived as Risky Bank Products.* In this case study, we defined three types of banks and we assigned the behaviour to them according to the typical behaviour of Czech banks. We used the models of a market rate, a deposit rate and simple assumption about the volume development to evaluate the exposure to interest rate risk in the form of earnings risk of savings accounts in the Czech banking sector. The outcomes of this case study provided enough evidence in favour of our argumentation/hypothesis that savings accounts pose high interest rate risk. We concluded that, when market interest rates increase, banks that are more dependent on funding from savings accounts will have to increase deposit rates on savings accounts to attain the required level of funding, which in turn could lead, under an extreme scenario, to significant profit squeeze. As it has been some time since the publication of this article, we would like

[36] Please note that numbers shown in Table 1.1. are for the period 2015-2020 while here we refer only to December 2020.

to provide an update on the dynamics of savings accounts in the Czech Republic. Figure 7.1 demonstrates that savings accounts continue to increase and maintain a strong position in the Czech Banking sector.

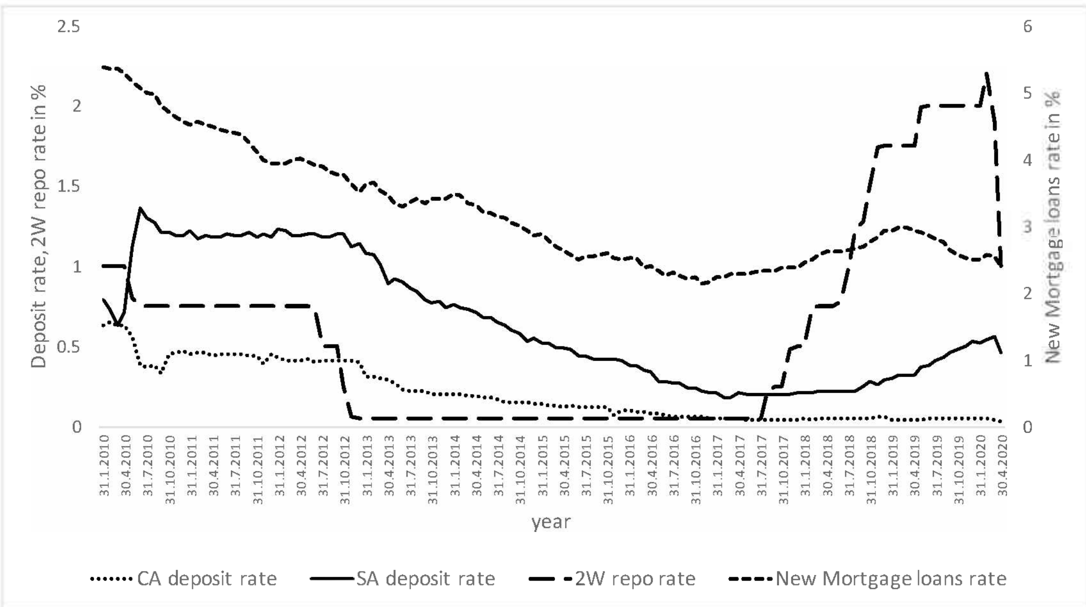
Figure 7.1: Dynamics of savings accounts (SA) and current accounts (CA) in the Czech Republic since 2015



Source: Authors based on data provided by the CNB

More importantly than the volume dynamics, we have had a chance to evaluate the results of our analysis in the real business cycle, as market interest rates did, indeed, increase in the Czech Republic and fell again, due to the Covid-19 pandemic outbreak in the first quarter of 2020. Below we provide Figure 7.2, which documents the dynamics of deposit rates on savings accounts and on current accounts, market interest rates represented by the Czech National Bank's 2-week repo rate, and new mortgage loans prices in the Czech Republic. As we can see, the tempo of the repricing of savings accounts is greater than the tempo of the repricing of current accounts, which confirms the results presented in the second article. Current accounts' deposit rates remain stable and very low, which is to be expected, as current accounts are transactional accounts and, as such, should not exhibit the interest rate sensitivity. Furthermore, banks are slow to reprice mortgage loans due to high competition, but savings accounts' repricing picks up, as small banks are dependent on the funding from such non-stable deposits. Even though we have to bear in mind that the pricing of mortgages and, therefore, the banks' internal profitability (margin) from mortgage loans depends also on the long-term interest rates, we can still see a substantial delay in the response to the market environment, which indicates that the competition plays a substantial role, and that the bank profit margin from mortgage loans cannot be stable. As our article is up to date in terms of the current situation, we can still claim that savings accounts as such pose substantial interest rate risk due to the fact that the sensitivity of the deposit rate to changes in market interest rates is higher than the sensitivity that we observe for other bank products on the liability as well as on the asset side.

Figure 7.2: Deposit rates, mortgage rates and market interest rates in the Czech Republic since 2010

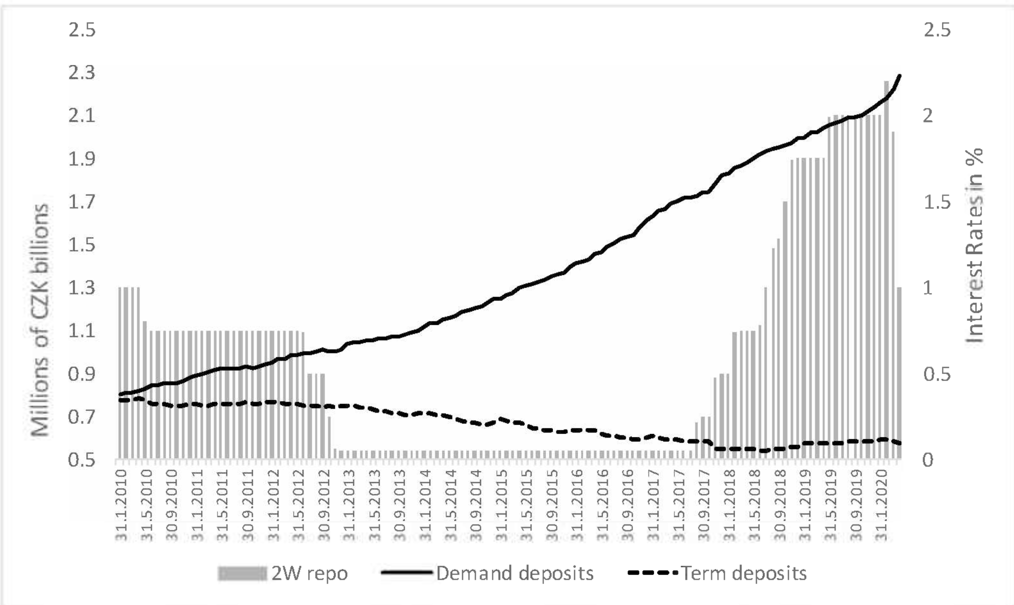


Source: Author based on CNB data (ARAD time series). 2W stands for the 2-week repo rate.

In the third article, *Risk Management of Demand Deposits in a Low Interest Rate Environment,* we continued with our research into deposits and we dived into the topic of the liquidity risk of deposits in the Czech Republic. While the previous two articles were predominantly focused on demand deposits (current accounts and savings accounts), in this article we added an analysis of term deposits. This article estimates the liquidity risk of demand deposits and term deposits in the Czech Republic using the time series analysis and simulations, with special focus on the effects of a prolonged low-rate environment. We published this article in 2016. At that time, market interest rates in the Czech Republic were still very low. We estimated that the effective maturity of aggregate demand deposits in the Czech banking sector is 9 years when limits on the last cash flow having maturity of 10 years are imposed and even much longer without those limits, compared to their legal maximum maturity of overnight. On the banks' level, demand deposits are expected to be more volatile than on the level of the whole banking sector, but for large banks, we can assume similar characteristics as for aggregate demand deposits. This implies that banks can use demand deposits as a stable source of funding, but we also argued that banks need to assess the dynamics of demand deposits carefully. We showed how term deposits decreased substantially in the Czech Republic due to the low-rate environment and the fact that many banks offered relatively high-yield savings accounts. We also argued that once market interest rates start to increase, term deposits will start to provide a relatively good opportunity for clients, and a part of the demand deposits will be moved to term deposits. We mentioned that banks need to have proper models to be able to estimate the proportion of such volatile deposits in order to ensure that a bank is ready for a potential transfer to term deposits from demand deposits.

As in the case of the previous article, given the increase in market interest rates in the Czech Republic in the period 2017 – March 2020 (until the outbreak of the Covid-19 pandemic), we have, once again, a unique opportunity to validate the results of our research. Figure 7.3 shows the dynamics of term deposits and demand deposits in the Czech Republic. As we can see, the decrease in term deposits continued beyond 2016, but it stopped in 2017, when market interest rates started to increase. Term deposits' volume even increased a bit, even though demand deposits continued to increase sharply during this period as well. We can conclude that a low-rate environment indeed leads to outflows from term deposits to demand deposits, as we show in *Risk Management of Demand Deposits in a Low Interest Rate Environment,* and that this decrease stops when market rates increase. We can also see a small increase in term deposits' volume, which would probably have continued if market interest rates had not decreased again due to the Covid-19 pandemic. The observed relationship between term deposits and demand deposits in the Czech Republic supports the conclusions of our article, as well as being in line with the regulatory IRRBB guidelines of the EBA (2019) and BCBS (2018), which explicitly mention that banks need to estimate and model properly the interest rate sensitivity of volumes on demand deposits. We find evidence that this relationship is present in the Czech Republic, and banks need to take it into account in their IRRBB.

Figure 7.3: Demand deposits and Term deposits in the Czech Republic 2010-2020



Source: Authors based on CNB data (ARAD time series). 2W stands for the 2-week repo rate.

Furthermore, there is one more potential factor that could destabilize demand deposits in banks. Even though this goes beyond the analysis presented in this thesis, it should be mentioned as it is an interesting topic for a future research. Recently, the non-banking institution providers like Apple Pay or PayPal aim to enter the market for the clients' transactional banking. If many clients would move their transactional banking to those non-banking institution providers in the future, banks could face certain decrease of their stable source of funding as the stable core of demand deposits is formed by a large portion by transactional deposits. Banks need to closely monitor the client's behaviour to pick up possible signals of this and react on it in advance. The entry of the non-banking institution providers should also be accompanied with the proper policy response. Our recommendation would be that all banking related business should be a subject to the unified regulation. This would ensure proper protection of the stability of the financial system. Even though the current situation of such possible effects on the stable source of funding in banks is not an immediate threat yet, it could potentially have an effect in the future.

In the fourth article, *Liability Risk Management of Central European Banks Under New Regulatory Requirements,* we analysed the structural risk drivers on the liability side of the banks' balance sheets in the CEE region (namely in the Czech Republic, Slovakia, Poland, Austria and Hungary). In those countries, several large banking houses, such as Erste Group Bank or Raiffeisen operate, which poses systemic risk if the sectors exhibit the same balance sheet risk characteristics. As well as analysing the structure of the liability side, we discussed the IRRBB regulation and its implications for the banking sectors in the CEE region. At the time of the publication of this article, this topic was relatively new, and banks were devoting extensive projects to bring themselves into the compliance with the new guidelines. The major finding from this article was that the IRRBB regulation could be challenging for banks, as all banks in the CEE region display a large amount of funding comprised of non-maturity demand deposits, which are a potentially unstable source of funding, as we discussed extensively in this thesis. This also implies that the liability structures across the sector are not diversified, and potential exposure to systemic risk is present.

In the last article, *The Application of Interest Rate Risk Regulation in the Czech and Slovak Banking Sectors,* we concluded both our research and this thesis. This article not only puts together all the research inputs we gathered on the topic of our thesis, but it also provides a comprehensive and detailed overview of the IRRBB regulation-based metrics in the Czech Republic and Slovakia. We used real bank balance sheet data from two consecutive years of three selected major Czech and three selected major Slovak banks, drawn from the freely available resources, to calculate the interest rate risk of each of those banks. To be able to calculate the interest rate risk metrics, we employed the methods for demand deposits and term deposits explained in articles in this thesis, and we also discussed in more detail the implications and the modelling of the early loan termination (a loan prepayment in advance of a scheduled maturity, in part or fully). In both sectors, the advanced models for loan prepayments are needed to estimate properly the duration (interest rate risk) of client loans. We used freely available data as well as the information from two big banks in the sector to create our prepayment models. We employed procedures from the EBA (2018) and BCSB (2016) regulatory guidelines to obtain the Market Value of Equity (MVOE) and Economic Value of Equity (EVOE). Working in terms of regulatory requests enabled us to assess if any banks could be potentially considered to have issues with compliance with the guidelines, given the structure of their client assets, client liabilities, investments and other factors. Apart from that, we assessed whether banks will gain or lose under increasing/decreasing market interest rates. This we estimated as an effect on a bank's capital.

We found out that all major banks in both the Czech Republic and Slovakia are positioned well within the regulatory limits, with minor exceptions. However, we also found evidence that the interest rate risk positioning of the Czech and Slovak banks indicates that the banks will gain when market interest rates increase, as client assets will reprice sooner than client liabilities. Consequently, the converse applies to decreasing market interest rates. The reason why client assets have shorter duration profiles is two-fold. Client assets usually reprice earlier than at maturity, i.e. a 20-year mortgage loan will usually reprice after 3-10 years. Additionally, relatively large prepayments push the average maturity and duration of client loans down. On the other hand, the duration profiles of demand deposits are very long. Even when we take into account the potential interest rate sensitivity of savings accounts (and also if we employ an additional scenario for current accounts) and use the maximum maturity limits as set by the regulations, we discover that client liabilities reprice later than client assets, thus constituting, on the one hand, a relatively stable source of funding, but, on the other hand, representing a sticky price burden in a low or negative interest rate environment.

The finding that Czech banks receive lower net interest income when interest rates decrease is quite an up-to-date topic given the substantial rate cuts made by the Czech National Bank in March-May 2020 due to the Covid-19 pandemic, in which the 2-week repo rate decreased by 2pp in a matter of weeks, accompanied by the money market Pribor rates, as indicated in Figure 7.4. This makes the standard regulatory shock of -2% we employ in our analysis (together with the other prescribed regulatory interest rate shocks) very realistic. Based on our analysis, we would conclude in the summer of 2020 that Czech banks will post high interest rate risk related losses due to the impact of the Covid-19 pandemic on the Czech-currency (CZK) yield curve in the subsequent years until the 2-week repo rate will return to a level of 2% again. Now in April 2021, we have exactly 12 months to look back since the outbreak of the pandemic in the CEE region to evaluate early assumptions of its effect on the Czech banking sector in the relation to IRRBB. We can see one important factor of the pandemic, which directly influenced balance sheets of Czech banks (and in fact of all the CEE banks). It is a substantial increase in demand deposits. It amounted to 17%[37] in 2020, while in previous years, it was 5% in 2018-2019 and around 11%[38] for 2015-2017[39] on a yearly basis. There are numerous reasons for this, starting from a fear of future and ending with a limited opportunity to spend money as the economic activity has been substantially reduced. Still, even in the pandemic year, Czech banks reported good profit for 2020, albeit significantly artificially reduced (by around -50% compared to previous years) due to a preparation for the potential credit risk losses. Credit risk is not, however, the topic of our research. The large increase in demand deposits and

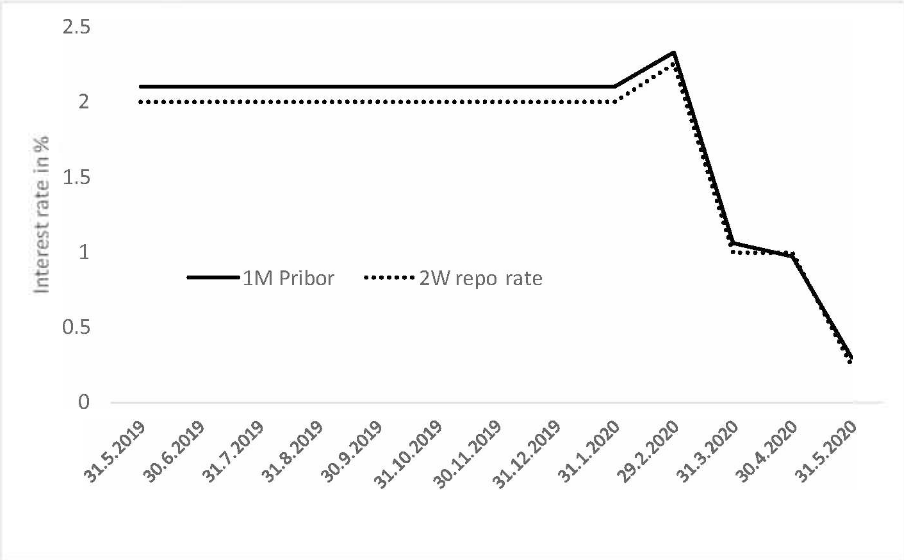
[37] CNB (2021)
[38] Within this period, the increase was driven by the Czech National Bank interventions. To keep the CZK value low and support exports, the Czech Bational Bank flooded the market with the liquidity.
[39] CNB (2021)

effect of the pandemic on interest rate risk, though, is. The decrease in the net interest income was present for all major Czech banks. Banks were able to mitigate it partially through a loan demand (cheaper loans due to the decrease of the CZK yield curve supported the volume growth). The interest income optimization through the timely hedging and investments played the role as well. The main driver of a lower profit in 2020 was credit risk in the Czech banking sector, not interest rate risk. Assuming results shown in the fifth article, the Czech banking sector liabilities reprice slower than the Czech banking sectors assets, which exposes Czech banks adversely to a decrease in interest rates. That is exactly what happened in 2020. Taking this into the account as well as the fact that demand deposits substantially increased (more than loans as loans increased by 7.5%[40] in 2020), we can conclude that the interest rate risk gap of Czech banks probably opened even more as a result of the Covid-19 pandemic.

We have evaluated briefly only year 2020. The impacts of the Covid-19 pandemic on the banking sector will not be negligible and will not be only a topic of the year 2020 due to unfortunately slow vaccination strategies in the CEE region in the beginning of 2021. There are not only potential the credit risk and interest rate risk related losses we mentioned above, but there is also a threat of a lower loan production due to the economic downturn. It will be possible to assess the long-term interest rate risk related losses caused by the Covid-19 pandemic only after the publication of this thesis. According to the findings of our analysis, we estimate that banks across the sector could face on average a decrease in their net profit amounting to 30% (cumulative estimate) of their capital during at least the next few years if rates remain low. We stress that this estimate is the loss stemming from the interest rate risk only.

[40] CNB (2021)

Figure 7.4: The CZK short-term rate dynamics May 2019 - May 2020



Source: Author based on the CNB data. 2W stands for the 2-week repo rate.

As a concluding remark, we would like to compare major results of our research to the several recent studies that deal with relatively similar topics. The European banking sector bears many similarities, as evidence suggests, but there are heterogeneous factors influencing different banks in different countries. For example, in the Czech Republic and Slovakia, the household housing loans are usually fixed rate instruments, while in Austria or Germany, large portion of household loans has until recently been the floating rate based. Due to those differences, we can only roughly relate our research to other studies as the different set up of banking products influences IRRBB enormously. On the other hand, there are also similarities. In the Czech Republic, savings accounts are associated with relatively high deposit rates and hence quite high interest rate risk for banks, as we extensively discuss in our research, which is similar to Belgium (Maes and Timmermans, 2005). There is a common consensus in the academic research done on European banks that prolonged period of a low-rate environment brings challenges to both internal as well as the regulatory IRRBB models. Same as us, many studies mention that yield curve as well as behavioural models need to be frequently revisited during a low-rate environment and limitations need to be properly understood and included in the risk management and the bank's steering activities through the proper function of ALCO meetings (Gnan and Beer, 2015; EBA 2018). The special focus needs to be paid to the interest rate sensitivity of behavioural factors. Similar as us, several studies aim to estimate overall exposure of the banking sector to changes in interest rates. We find out that Czech and Slovak banks will benefit from increasing market interest rates. Alike conclusion for European banks is presented in the EBA (2017a) survey and Hoffmann et al. (2018). Chaudron et. al. (2018). Alessandri and Nelson (2015), Flannery (1981) as well as Hoffmann et. al. (2018) show that banks actively hedge their interest rate risk positions to achieve the targeted amount of risk, which we mention as well in the relation to the relatively large interest rate risk results of client assets and client liabilities we receive in our study. Additionally, Alessandri and Nelson (2015), Borio, Gambacorta and Hofmann (2017), Molyneux et al. (2019), Bikker and Vervliet (2017), Claessens, Coleman and Donnelly (2017), Boungou (2019) and Demirgüç-Kunt and Huizinga (1999) show compression in the banks' margins in a low-rate environment or decreasing interest rates or the fact that banks are expected to benefit from increasing interest rates. The margin compression in the low or negative interest rate environment is often closely related to the legal interest rate floors on deposits, which is an additional factor that can decrease banks' profitability stemming from the Covid-19 pandemic related effects into interest rates. On the other hand, Chaudron et. al. (2018) and Tan (2019) show that the net interest rate margins remain relatively stable (on Dutch banks), also due to the compensating volume effects. Finally, Deloitte (2019) mention increasing importance of ALM activities in banks and a need for the usage of not only the regulatory IRRBB methods for steering. This is not only due to the enhanced regulatory supervision, but also as it is a proper tool to ensure the banks' profitability.

Concerning further research opportunities, we see a proper direction in the more micro-level focused research. In our last paper, we developed the regulatory based IRRBB model, which we applied on banks and calculated their interest rate risk using the regulatory approach. Our aim was to see the performance of Czech and Slovak banks based on the regulatory set up, which enabled us to compare banks with each other. In further studies, we would like to go more in the direction of a micro study of IRRBB of selected banks by using customized models and tailored interest rate scenarios that would enable us to calculate the interest rate risk of the banking book that could be used to create hedging models. For this, the bank’s internal data would be a necessary milestone.

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9 Appendix

This thesis comprises five articles that were published between 2013 and 2020 and which deal theoretically as well as empirically with an interest rate risk and a liquidity risk of a banking book, with primary focus at the Czech banking sector. The final thesis includes some changes, mainly in the first article, when compared to the original versions of articles that were published. Those changes are a result of the opponents' feedback. Final thesis also includes separate Introduction and Conclusion chapters, in which we summarize the whole thesis and bring major findings up to the date.

The Appendix comprises the last Section of the thesis and it summarizes all changes which were done as a result of the advisor's and opponents' pre-defense feedback, as well as our response to the feedback and valuable ideas that were included in all reports. It also serves to document how the thesis articles changed compared to their original published versions.

Before we get to the detail of each report, we would like to kindly thank to our advisor and all three opponents for their review and valuable feedback to our research. The independent review of the research always brings valuable discussions, improvements and new areas that can be investigated. All those three areas we have accessed in our review of the thesis. We start the report of changes with the feedback from the advisor and then we continue with the opponents' reports. The feedback to the opponent's reports is structured alphabetically.

9.1 Advisor's pre-defense report by Doc. Ing. Zdeněk Tůma CSc.

Advisor

"a) The thesis consists of five papers where the unifying link is the focus on interest and liquidity risks in banks´ balance sheets. There are two major factors arising in a couple of previous years, namely savings accounts and the option of loan prepayment. These issues are extremely topical, and they are not covered by the literature too much. The contribution of the author is original in this respect and also the fact that Hana works in this field helps to her deep understanding of these issues. Moreover, she is the first – as far as I know – who analysed the interest risk in the Czech banking sector arising from the new guidelines on the management of interest rate risk.

b) As I mentioned there is not much specialized literature in this area yet, but Hana covers the available literature; it is accompanied by her knowledge of the regulatory framework including the very recent development."

Author

We have added added several additional literature references in the revised thesis version

Advisor

"c) The thesis is defendable at the IES and complies with the requirements at this institute. The successful defense is conditional on responses to opponents´ comments & questions.

d) All papers from the thesis have been published. I could imagine that paper(s) could be published in a higher-rated international journal but it is the fact that Hana´s research was focused on the Czech (and Slovak) banks (with the exception of one paper that covers CEE) so that the journals in the CEE area were more appropriate. Another aspect is that the situation regarding these parameters (saving accounts, prepayment options) differ substantially across individual countries (e.g.

floating interest rates for mortgages in some countries only) and it complicates any quantitative comparison. This could be a challenge for further research."

Author

What we would like to add in this respect is that as a result of a low-rate environment in the European currency area, new mortgage loans in Austria, for example, are now also largely fixed for longer periods, similarly or even longer than in the Czech Republic or Slovakia. This could enable interesting comparative study in the future.

Advisor

"e) Papers focused on saving accounts conclude that SA are risky products that can have a serious impact on the liquidity and capital of banks. Since the publication of the article the money market has gone through the whole cycle: interest rates fell to zero levels, jumped up to decrease again a couple of months ago.

Did concerns expressed in these papers materialize, were there liquidity and/or capital problems observable in the Czech banking sector?"

Author

This is a very good question and similar one was raised by Prof. Viktor Kotlán Ph.D. in his opponent's report. We answered it as follows:

The answer to this question is yes and no. The analysis shown in the second article is valid as well as its results are valid under the situation at that time. This implies that this analysis is valid for any banking business created in the dependence on a high cost and unstable funds under the special situation of a prolonged and very low interest rates. There are many factors that could have taken place after our analysis till the moment of market rates' increase in 2017, though. First, small banks, whose balance sheet was predominantly populated by savings accounts, could have increased their core of current accounts. This would make them less exposed to the interest rate risk of savings accounts. Second, they might have invested into riskier assets, mitigating thus the effect of savings accounts' costs. This would help them with booking higher profits on the short run. As the increase in CZK yields was cut short with the Covid-19 pandemic, they would have manage the period of increasing interest rates in the Czech Republic between 2017 - beginning March 2020 easily as savings accounts would also not be repriced as much and assets would provide enough high return. Third, with the increased balance sheet size, more fee income could have been generated. All those factors could help to mitigate losses indicated by our analysis. Let us now try to evaluate those factors on the bank which has been used as a typical example of a small bank in the second article – Air Bank:

i. The relative share of current accounts to savings accounts in Air Bank's balance sheet was 27% as od 12/2019 (Air Bank, 2020). This implies that the bank indeed gained more stable funding as in our article, we reported less than 10% share of current accounts as of 12/2013. Still, it is significantly less amount of the stable source of funding in a form of current accounts then in the well-established banks.
ii. On the asset side, we can see that large portion is not invested into the traditionally credit-risk safer retail and corporate lending like housing, consumer or investment loans. Based on The Annual Report 2019 (Air Bank, 2020), 46.4% of assets are loans to clients, but almost half of this is a loan to daughter companies. Traditional loans to households and corporates in fact amount only to 21.6% of total assets. On top of that, the credit risk losses imposed as a result of the Covid-19 pandemic could easily deteriorate income from this usually credit-safer client lending. Moreover, 33% of assets is retained in cash and around 15% is placed mostly to the Czech government bonds. Based on this structure, the amount of the traditional client loans which creates a basis of the maturity transformation is not yet build in Air Bank, even after more than 7 years of its existence. An excess liquidity is placed either in cash, which is a short-term and unstable instrument from the interest earnings perspective as it is fully subject to volatility of short-term market interest rates (assuming most of cash is placed at Central Bank)

or into loans to some daughter companies. This opens the bank to potential losses from risky assets.

iii. The fee income has indeed increased consistently with the increase in the bank's size, but adding the fee costs, it is almost negligible on the net basis (Air Bank, 2020).

All things considered, given how the Covid-19 pandemic cut the interest rates' increase in the Czech Republic short, and considering at least some increase in current accounts and the standard lending, it makes sense that Air Bank did not immediately observed effects of interest rate risk of savings accounts within the period 2017 – March 2020. However, their high dependence on the unstable funding on the liability side and the structure of the asset side still pose a risk and concerns. From this perspective, we still see results of our analysis to be valid.

Advisor

"Is it the regulation of SA really the appropriate response (caps etc.)? Supervisors rely much more on checking/verifying internal models today; if it is not sufficient, should we really move to a direct regulation?"

Author

The banking sector is a substantially regulated industry. To question if all its aspects and risks need to be regulated is an approach we agree with. Proper internal models and supervision as a substitute to one rule fits all regulation schemas would be a more appropriate approach under a condition this supervision is done in a timely manner and all market participants are subject to it to a same extent and regularity. This would require yearly detailed external audits by a supervisor. When this would become a standard, then we would agree that the supervision would be a more appropriate solution than the direct regulation.

Advisor

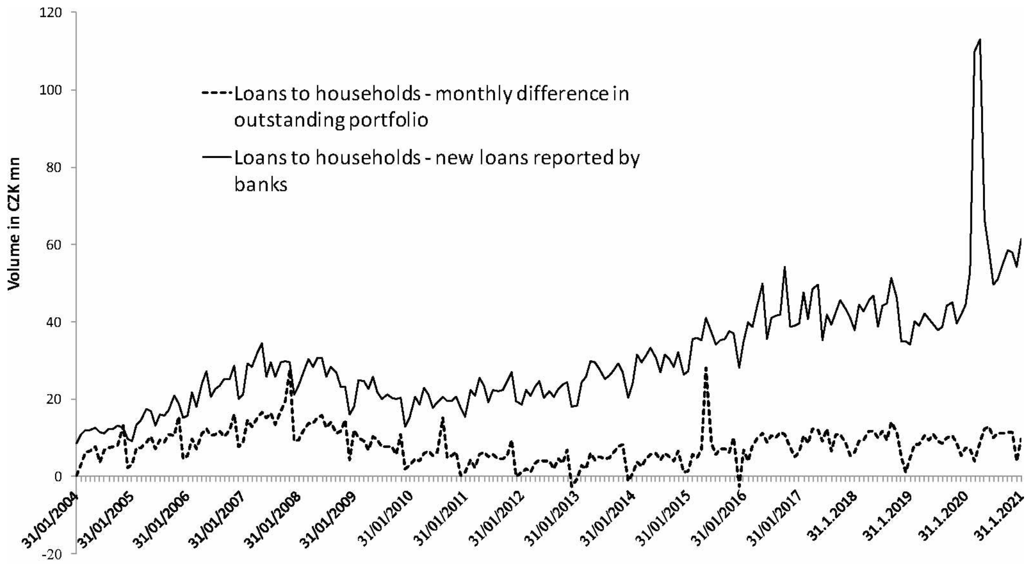
"The paper "The Application of Interest Rate Risk Regulation on the Czech and Slovak Banking Sectors" (Chapter 6) was published recently but the analysis is based on 2016-2017 data. In table 6.4, it is stated that the prepayment (monthly) ratio is 1%. Is not it significantly higher today (in the Czech Republic)? Could the current situation change your conclusion that „major banks report a higher interest rate risk from their client liabilities than from client assets"?"

Author

There is an unfortunate usual lag between the published research and the current economic environment, stemming from the delayed data availability as well as from the lengthy publication process. We track the dynamics of prepayments in the Czech Republic regularly. In the period 2017-2019 prepayments developed in line with numbers used in our analysis. Year 2020 brought several changes. First, there was a sudden drop in market interest rates stemming from the Covid-19 pandemic. This action by itself triggers banks to reprice down new mortgage loans, which can be expected to lead to higher prepayments. On the other hand, this was a result of the pandemic, so we could also expect that many people may not have available funds to prepay. What we would in fact expect would be decrease of prepayments in 2020. This could increase interest rate risk of assets, but given the huge inflows of demand deposits Czech banks experienced in 2020 (17% demand deposit yearly increase versus 7.5% of loans), we would not expect it would be feasible that interest rate risk of assets would increase more than interest rate risk of liabilities, given the difference in the interest rate risk profile of assets and liabilities was substantial already before.

We have evaluated our analysis of prepayments from loans to households in the Czech Republic shown in Figure 6.2 using additional data for 2018-2020 (CNB, 2021). Figure 9.1 shows the updated Figure 6.2. As we can see, prepayments in 2018-2019 were in line with estimates used in the paper as the gap size is similar, but year 2020 developed interestingly. First, we can hardly see much evidence for the prepayment decrease, which we would expect as a result of the pandemic. Rather there is an apparent increase in the gap in 2020. (The apparent large peak is present for April and May 2020 data and we think it must be a data quality problem, so it should not be considered.) This increase in the gap is interesting factor that would require further analysis when more data will be available also for year 2021. There seems to be some evidence for the increase in prepayments from households loans in the Czech Republic. As mentioned above, the most obvious factor influencing this would be a drop in market interest rates. This would in fact, together with the increased demand deposits we mentioned above, open Czech banks to interest rate risk even more. We added comments on the impact of the Covid-19 pandemics on IRRBB of Czech banks in Section 7.

Figure 9.1: Loans to households in the Czech Republic, the prepayment gap approximation 2004-1/2021



Source: Author based on CNB (2021)

Advisor

"f) I recommend the thesis for defense without substantial changes presuming Hana will respond appropriately to my aforementioned questions & comments as well as to comments of opponents."

9.2 Opponent’s pre-defense report by Prof. Viktor Kotlán Ph.D.

Opponent

“The author approaches the thesis via a compilation of five published articles circling around interest and liquidity risk of mainly Czech banking sector. The ordering of the articles respects their publication date but also makes sense from a story-building perspective. I would say the historical perspective is also showing the gradual growth of the author’s insight into the subject over time.

While the articles likely went through some sort of review process, their quality differs. The first piece is rather a summary of available theory, not adding much author’s know-how. The second extends the first one by simple empirical analysis and rises hopes for what comes next. The two following pieces leave these expectations only partially satisfied as the depth of the provided analysis stays rather flat offering basic statistical analysis without much deployment of more sophisticated econometric tools. However, fortunately the last article is a real pearl as it performs unique ALM modelling techniques on a sample of 3+3 CZ/SK banks. The final part written most recently is aiming to comment all the articles from the perspective of today’s economic reality.”

Author

The articles have indeed been concluded during 2013-2020 and the further research always brought new insight into the analysed area. Based on the opponents’ reports, following updates were done to rise the quality of the published material:

- The first article includes newly the specific model applications and the inclusion of the know-how from the research development that took place after the publication of this article. Particularly, following Sections were updated: 2.2.3.2, 2.2.3.3 and 2.2.3.4.

- In the second article, we added more empirical evidence for the models that were defined and used in Sections 3.2.5 and 3.2.6. This empirical evidence and the model calibration derails are provided in Section 3.2.9.
- In the articles three and four, we included more details regarding the analysis as well as numerous improvements in the description of methods that were used. Updates were done in Sections 4.2.3.2 and 5.2.3.
- The last article remained largely as it was except the inclusion of the analysis in the relation to the derivatives, which is described at the end of the response to this report. It is indeed the most recent article where years of research are meeting its conclusion point in terms of the art and the practise behind the interest rate risk management of banking products.

Opponent

"All the papers are well researched and provided references are in line with best practice.

The overall contribution of the author rests in summarizing the underlying theoretical bases and putting it in use in empirical analysis. Especially the last contribution is noteworthy in this respect. This approach is only logical taking into account the author is a top international expert in the field of ALM and daily practitioner. I would expect theoretical advancements to be put forth rather by academics and empirical work to be presented by practitioners. With my limited comparison possibilities, I would say the level of contribution overall meets the requirements of a doctoral thesis.

The research outcomes might actually form a valuable analysis for policy makers – central banks and international supervisory bodies such as EBA or ECB. The thesis offers even some explicit policy advice (e.g. article 2).

I recommend the thesis for defense without substantial changes.

Within the defense process, I would welcome author's view on the following:

1) *Given the high dependence of CEE banking sector on cheap and stable funding from demand deposits, how large a challenge for their P&L as well as IRRBB is posed by non-banking institutions payments services (Apple pay etc)? In what ways could banks prepare for this?*
2) *The author mentions savings accounts are risky financing source and even says that „We doubt that business models of some banks in the Czech Republic, which report savings accounts as a primary source of their funding, are sustainable and viable in the long-term horizon." Given the survival of banks drawing on saving accounts even in period of dramatic rise in CNB repo rate till 2020, is this predicament still in place?*
3) *The last paper slightly touches the topic of hedging instruments for IRRBB and their importance. I would say a deeper look into the positions of Czech banks in derivative instruments would be proper counter-weight to the time spent on discussion of long duration properties of the non-maturity deposits."*

Author

We would now like to refer to the addressed questions.

1. This is a very good question that goes beyond potential effects on the stability of demand deposits. There are rising concerns (Authors' own knowledge) regarding the entry of the third-party providers in the commercial banking sector. The commercial banking sector is traditionally viewed as an economy building vehicle which serves as an intermediary in the effective allocation of funds from subjects with excess of funds (savers) to those that need funding (a person buying a flat or a company investing into the new line of fashion). These are basic society needs that has so far been fulfilled for years by commercial banks. Apart from that, the commercial banking sector also serves to provide day to day transactional banking, which has always been a source of the stable funding for banks. The non-banking institution providers aim to, in the first stage, enter the area of the transactional banking. This could lead to a potential effect on the

stability of demand deposits, especially if people would decide to hold larger outstanding balances with the providers like PayPal, for example. In the second stage, their aim would be also to enter the area of the allocation of funds, which could in turn affect amount of loans banks would be able to place.

Before we get to the potential effects it could have on IRRBB and banks, we would like to express our opinion that any banking related activity (transactions provisioning, lending, borrowing) should be a subject to the same regulatory requirements as banks are. This would result in the proper separation of the banking business and let's say, a phone and a laptop business (Apple). This we consider as a proper policy approach to this topic. It would provide the protection for the economy. The reason why banks are regulated is to protect the stability of the financial system.

Second, when it comes to banks and dangers coming from the non-regulated entry of the non-banking institution providers and possible effects on the banks' profit and IRRBB. In our opinion, given increasing cost trends due to the regulation and decreasing margin from the maturity transformation due to a low-rate environment and the competition, the commercial banking sector in CEE will need to go in the direction of a consolidation. The bigger banks will have to acquire smaller ones as it will be the only way how to increase the profit in the long-term. The CEE region is populated by many small and medium sized banks and in our opinion, this is not a sustainable set up in a long-term. In our opinion, this is also a proper reaction to the non-banking institution providers as this will, by definition, increase the stable core of current accounts and thus ensure higher resilience against the non-banking institution providers. This in turn implies stable interest rate risk and liquidity risk of demand deposits. Another potential solution would be a proper retention process, but this could prove difficult in the environment where customers can solve immediately all online. Finally, banks need to properly monitor the stability of their core of current accounts to be able to react in a timely manner if there would be signals many depositors leave their transactional business to the non-banking institution providers.

We have decided to add this information to the thesis as well. Adjustments in the form of additional text were done in Sections 4.2.4 and 7.

2. The answer to this question is yes and no. The analysis shown in the second article is valid as well as its results are valid under the situation at that time. This implies that this analysis is valid for any banking business created in the dependence on a high cost and unstable funds under the special situation of a prolonged and very low interest rates. There are many factors that could have taken place after our analysis till the moment of market rates' increase in 2017, though. First, small banks, whose balance sheet was predominantly populated by savings accounts, could have increased their core of current accounts. This would make them less exposed to the interest rate risk of savings accounts. Second, they might have invested into riskier assets, mitigating thus the effect of savings accounts' costs. This would help them with booking higher profits on the short run. As the increase in CZK yields was cut short with the Covid-19 pandemic, they would have manage the period of increasing interest rates in the Czech Republic between 2017 - beginning March 2020 easily as savings accounts would also not be repriced as much and assets would provide enough high return. Third, with the increased balance sheet size, more fee income could have been generated. All those factors could help to mitigate losses indicated by our analysis. Let us now try to evaluate those factors on the bank which has been used as a typical example of a small bank in the second article – Air Bank:

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ii. On the asset side, we can see that large portion is not invested into the traditionally credit-risk safer retail and corporate lending like housing, consumer or investment loans. Based on The Annual Report 2019 (Air Bank, 2020), 46.4% of assets are loans to clients, but almost half of this is a loan to daughter companies. Traditional loans to households and corporates in fact amount only to 21.6% of total assets. On top of that, the credit risk losses imposed as a result of the Covid-19 pandemic could easily deteriorate income from this usually credit-safer client lending. Moreover, 33% of assets is retained in cash and around 15% is placed mostly to the Czech government bonds. Based on this structure, the amount of the traditional client loans which creates a basis of the maturity transformation is not yet build in Air Bank, even after more than 7 years of its existence. An excess liquidity is placed either in cash, which is a short-term and unstable instrument from the interest earnings perspective as it is fully subject to volatility of short-term market interest rates (assuming most of cash is placed at Central Bank) or into loans to some daughter companies. This opens the bank to potential losses from risky assets.

iii. The fee income has indeed increased consistently with the increase in the bank's size, but adding the fee costs, it is almost negligible on the net basis (Air Bank, 2020).

All things considered, given how the Covid-19 pandemic cut the interest rates' increase in the Czech Republic short, and considering at least some increase in current accounts and the standard lending, it makes sense that Air Bank did not immediately observed effects of interest rate risk of savings accounts within the period 2017 – March 2020. However, their high dependence on the unstable funding on the liability side and the structure of the asset side still pose a risk and concerns. From this perspective, we still see results of our analysis to be valid.

3. To access this topic is a challenging task as there is a limited possibility to know what duration profile banks have on their derivatives, given that the data that is available does not include this information. In Section 6.2.3 we have already made brief estimates for the effect of this in the original version for banks that got above the regulatory threshold of the 20% maximum loss stemming from the adverse interest rate shock. We claimed that in the practice banks extensively use derivatives to further decrease and adjust the interest rate risk of the total balance to the desired levels. We have now revisited this short comment in the article and provided more analysis and its potential effects into IRRBB, assuming that banks aim to hedge the liability position – i.e. assuming that a bank is entering a fix receiver position. Section 6.2.3 includes this information.

9.3 Opponent's pre-defense report by Prof. David Tripe Ph.D.

Opponent

"This thesis is interesting because it addresses an issue which has not received a great deal of attention in prior research - retail bank interest rate risk and its potential effect on bank net interest income. It identifies the problem that many of banks' liabilities are in effect on demand, giving liability holders the option (often for free) of being able to call their funds whenever they wish to. In many jurisdictions there is a corresponding put option for borrowers, at least for some classes of loans, and note that there is some discussion of this as prepayment risk in Chapter 6 and 7 of the thesis. It would have been good to have seen more detail on the conditions applying to these prepayment options on both sides of the balance sheet."

Author

Thank you for this comment, it was indeed missing in the original version. There are two major embedded prepayment options booked on the Balance Sheets of Czech and Slovak banks. On the asset side, it is an embedded option of a client to prepay partially or fully a loan in advance of its scheduled maturity. There are many underlying conditions to this option which slightly differ in relation to the product. There are 3 major conditions, in general:

1. In case of the unsecured consumer loans, a client can prepay practically without a fee or respectively, for a minor fee, in full or partially, whenever wished. Usually, even though some banks and other lending providers limit this to a certain extent by requiring a previous notification, a client can simply send out the amount he/she wishes to prepay to the account where he/she deposits standard repayments of interest and nominal as given by the contract. If the prepayment is only partial, a client can decide to continue paying as scheduled. This ultimately results in a loan ending earlier than planned. Alternatively, he/she can consolidate a loan and create a new cash flow schedule. Both those cases are extensively demanded by clients. From the bank's perspective, the second case – the so-called loan consolidation,

can fully be seen as the closure of the previous contract and the new contract opening. Many banks follow this approach also in their internal systems, an internal pricing and the internal interest rate risk management.[41]

2. In case of the secured housing loans to households, historically, there were more barriers to prepay. This has changed with the relatively recent update in the customer credit legislation in the Czech Republic. In Slovakia, this update took place even earlier. In respect to details, we focus at the Czech Republic. The set up in Slovakia is similar, though. Currently, under special conditions like a divorce, an illness and other, a client can prepay all the outstanding loan at a wish and a bank is not able to charge any prepayment fee. Also, every year, a client can prepay 20% of the original balance and last but not least, whenever the fixed deposit rate changes, a client can prepay fully for free too. The latter case happens at the so called "refix" period. Housing loans in the Czech Republic are usually provided for 20 years, but their pricing mechanism can be defined as a long-term variable-fixed product. Price adjustments to the current market conditions happen usually each 3, 5, 7 and recently also 10 years. In Slovakia, those "refix" periods are a bit shorter. Except those cases listed above, a prepayment is a subject to a very small fee, which is defined as a reasonable cost and regulated by the law. Historically, this fee was substantial, and clients could prepay freely only during the "refix" time. This has mitigated prepayments between "refix" sufficiently. This is not the case anymore on the Czech market, which has resulted in increase in prepayments during all lifetime of a loan. This has increased the embedded option risk of the secured housing loans both in Czech Republic and Slovakia. For the full precision, we should add that only new and the "refixed" loans are subject to the new rules in the Czech Republic- But this already comprises more than a half of all mortgage loans in 2021.

[41] And inherently also in the internal liquidity risk management. One has to note here, on the other hand, that for the liquidity risk management, prepayments are of a low importance as they in fact decrease liquidity risk.

3. The third case are prepayments from corporate loans. In this case, especially in case of large corporate clients, this is usually individually based. Generally, a prepayment is allowed and often is for free as it is treated individually within a client – bank relationship.

We have added the description of conditions behind prepayments to the thesis as it was indeed missing for readers who are not in the detail acquainted with the Czech and Slovak banking markets' specifics. This information was added to Section 6.2.2.3.

On the liability side, there is the early termination of a term deposit. As term deposits are a minor product in both markets, we do not dedicate special chapter to their analysis. There is a small fee related to the early termination of term deposit, but clients usually do not close those in advance as they deposit there a liquidity surplus they do not expect to need within the given fixed term. Due to this, we assume 0% early termination in our analysis.

Opponent

"Relative to this point, it would also have been useful to have had some clarification provided on what distinguishes a savings accounts from current accounts in the Czech Republic. Are some restrictions generally applied to withdrawals from savings accounts, or can they just be regarded as higher-interest-bearing current accounts?"

Author

We have added the description of differences between current and savings accounts in the second article in Section 3.2.2.1. In the Czech banking system, savings accounts are very close to current accounts in definition of how quickly a client can receive funds – on demand. There are some conditions in case a client withdraws the balances form savings account, then the deposit rate is diminished. There are no significant limits on the money transfers from savings accounts like it is in case of term deposits (until a term deposit matures, there is a fee for a premature withdrawal plus often there can also be a notice period). Except that a client cannot usually do transactions from savings accounts. Savings accounts can, in majority of cases, be used only to deposit money or send it back to the main transactional (current) account.

Opponent

"A more extensive description of the Czech banking sector and its operation, beyond the points noted in Chapter 7 of the thesis, would be helpful. This might be part of the introduction, where it would assist readers who do not have a detailed knowledge of the Czech system to contextualise the material that follows. This is a particular issue with the liability structure of Czech banks, where we are given detail on the breakdown of deposits only on page 114 in Chapter 7, and in part in tables 6.2 and 6.3. Data such as that provided in Figures 2.1 and 7., while showing the growth in savings deposits, is of limited value as we don't know what proportion these deposits comprise relative to total funding. In a similar way, Figure 7.3 is of limited value as the data series shown begins only in 2010, while the data reported in table 3.1 is for 2013."

Author

Thank you very much for pointing this out. The information is indeed scattered thorough the thesis, since its form is a compilation of articles. We have added the description of the main characteristics of the Czech banking sector into the Introduction in Section 1. The different timing in presented figures and tables stems from the different timing of the publication of articles. To account for this, we have added basic characteristics of the Czech banking sector's assets and liabilities to the Introduction in the Section 1 in Table 1.1.

Opponent

"In the context of the discussion of high interest savings accounts (page 36), it might be useful to comment on the role of interest expense as a substitute for the expense of running a branch network, as per Humphrey (1990).

This illustrates the relative sparseness of the references cited. It would be not unreasonable to expect that a wider range of material on interest rate risk should have been reviewed, such as the strand of material that follows from Ho & Saunders continuing through to Molyneux, Reghezza & Xie (2019). The discussion of interest rate stickiness would also have been assisted by reference to Mester & Saunders (1995) and related work."

Author

Thank you, all the mentioned sources are very interesting. Concerning sources that investigate margin risks and bank's profitability, mainly those that refer the interest rate risk of margins, we have to proceed with caution. One needs to take into the account that the interest rate risk discussed in our analysis must be distinguished from the pure margin risk, which is a risk on top of changes in interest rates. It is a risk that that a client price changes not only due to changes in interest rates, but also due to changes in the spread charged on top of interest rates. For example, in Section 6, we assume stable margins (spreads) on top of interest rates. This is a consequence of the fact that volumes that banks have on the balance sheet for the given as of date have fixed margins in all contracts. Hence the present value related calculations like we do in Section 6 are the pure interest rate risk measure (risks stemming from changes in market interest rates) and the margin risk is not considered as it is not present (as margins are fixed in contracts). When we conclude that banks gain for increasing market rates in Section 6, this conclusion assumes stable margins. This positive relationship between banks' profitability and interest rates, found in the most of the sources that investigate it, is partially on the top of the interest rate risk discussed in Section 6 as a margin oriented studies also inherently include margin risk. This additional margin risk rises as a part of earnings risk. In the earnings risk measure, we can assume a flat or a dynamic balance sheet (EBA, 2018). For the flat balance sheet, volumes are kept flat, and maturing instruments are reinvested into same products under new interest rate environment and under new margins. For the dynamic balance sheet, there can be increase/decrease in volumes. Margin risk enters the earnings´ risk through new margins. It is an additional factor. Ho and Saunders (1981) and Molyneux et al (2019) analysis is more on the side of earnings risk. Having all this in mind, we can compare our results in Section 6 to sources that show that banks have positive relationship between increasing interest rates and margins. Additionally, two sources mentioned in Molyneux et al (2019), namely Flannery (1981) and Demirgüç-Kunt and Huizinga (1999) are of interest as well. All the mentioned sources were added to the thesis.

Mester and Saunders (1995) reference was added to our discussion why deposit rates are exhibiting delayed response. The paper itself provides evidence for the prime rate changes and concludes that upward responses are quicker as banks' aim to benefit more quickly form a higher loan interest rates. The exact opposite behaviour applies to deposit rates.

Finally, in the relation to the branch network. There is a common trend in the Czech banking sector[42] of the decrease of the size of the branch network as it is a cost efficient. We mention this in the second article, specifically referring there to the new banks that entered the market without the branch network. Humphrey (1990) mentions that some banks may find it more efficient to have branches due to other costs that would arise when servicing customers (travelling costs, for example), while other banks may prefer to have fewer branches or none even. Given the current situation, in which clients can manage practically all online, one would conclude, based on Humphrey (1990), that there are no such servicing costs anymore. Henceforth, there is no reason for any bank to have branch network. And this is exactly the reason for the trend in which the banking industry goes. But there is a counter factor. Some clients will always prefer to come to the branch, some signatures and activities will always, or at least for the foreseeable future, be needed to be done in person. This means that a certain portion of the branch network will be present. In the relation to small banks with almost no branch network, we agree that the part of the embedded costs of running the banking

[42] Or to be fully precise, in the whole banking industry in the CEE region

business could in such a case be transferred to clients in a form of a higher deposit rate. This was not considered in the description in the second article, which we amended.

Opponent

"The five articles that comprise the main part of the thesis have all been published in refereed journals or in proceedings. This provides an affirmation of their quality, at least from a Czech perspective, even though the respective outlets may not rank especially highly in international terms.

The time period over which they have been published, however, is quite lengthy, during which a number of changes have occurred. The economic environment when the papers were being written differed from earlier periods in terms of the level of interest rates and the mix of banks competing in the Czech market, while the Covid 19 pandemic has changed things again. Some attempt has been made to address some of these issues in the conclusion section (Chapter 7), although with 6 months having elapsed between the start of the pandemic and the thesis being submitted for examination, I would have expected to have seen at least an acknowledgment that the pandemic might change things further."

Author

We have indeed aimed to summarize and bring presented results up to date in Conclusion in Section 7, where we also briefly mentioned the Covid-19 pandemic. At the moment when we were writing Section 7 (the summer of 2020), it was too early to comment in the detail on the possible changes the Czech banking sector might face aside from the obvious concerns related to credit risk at that moment. Now in April 2021, we have exactly 12 months to look back since the outbreak of the pandemic in the CEE region to evaluate early assumptions of its effect on the Czech banking sector in relation to IRRBB. We can see one important factor of the pandemic, which directly influenced the balance sheet of Czech banks (and in fact of all CEE banks). It is the substantial increase in demand deposits. It amounted to

17%[43] in 2020, while in previous years, it was 5% in 2018-2019 and around 11% for 2015-2017[44] on a yearly basis. There are numerous reasons for this, starting from a fear of future and ending with a limited opportunity to spend money as the economic activity has been substantially reduced. Additionally, we updated our estimate of prepayments from households' loans in the Czech Republic we did in Section 6.2.2.3 and to our surprise, there seems to be even evidence for increase in prepayments in 2020, which we would not expect in the pandemic year. Still, even in the pandemic year, Czech banks reported good profit for 2020, albeit significantly artificially reduced (by around -50% compared to previous years) due to a preparation for potential credit risk losses. Credit risk is not, however, the topic of our research. The large increase in demand deposits and effect of the pandemic on interest rate risk, though, is. The decrease in net interest income was present for all major Czech banks, but banks were able to mitigate it partially through loan demand as well as probably through optimization of the net interest income with timely hedging and investments. The main driver of the lower profit in 2020 was credit risk in the Czech banking sector, not interest rate risk. Assuming results shown in the fifth article, the Czech banking sector's liabilities reprice later than Czech banking sector's assets, which exposes Czech banks adversely to further decrease in interest rates. That is exactly what happened in 2020. Taking this into the account as well as the fact that demand deposits substantially increased (more than loans as loans increased by 7.5%[45] in 2020), we can conclude that the interest rate risk gap of Czech banks probably opened even more as a result of the Covid-19 pandemic. We have added this information to Section 7. Larger prepayments would even support this conclusion further, but regarding that, we would like to point out that one has to wait a bit and analyse the situation in 2021 as well, before applying this information.

[43] CNB (2021)
[44] CNB (2021)
[45] CNB (2021)

Opponent

"Another consequence of the thesis having been written as separate essays over a period of time is that there is a lack of consistency in notation. This is a particular problem with Chapter 2 of the thesis. If I look at Equation 2.1, I do not find a definition for b or t (although I can guess that t is time). In Equation 2.2, m has become market rate (Is it still the benchmark as it was in 2.1?). By the time we get to Equation 2.4, m has become the margin, yet the preceding text suggests that the intention is to measure duration. Equation 3.2 appears to be a more accurate rendering of Equation 2.1, although there is again an inconsistency in notation. These issues and the (non-exhaustive list of) typographical issues recorded below have contributed to making the thesis sometimes hard to understand."

Author

All equations were reviewed and harmonized thorough the whole thesis. Thank you.

Opponent

Minor issues:

- *Abstract, line 12: "reprise" should be "reprice".*
- *Page 34, line 5: "later" should be "latter".*
- *Equation 3.1, page 39: I think that some of the notation is meant to be in subscripts.*
- *Page 44, line is presumably meant to be 2 -week (rather than a reference to a Weiner process).*
- *Table 3.2: the source described as "company bonds" is presumably meant to be "corporate bonds".*
- *Equation 4.1: as this is written, it appears to be a sum of maturities, rather than an average of maturities.*
- *I find Figure 5.1 less than straightforward. Are we being shown the results for 3 different and incompatible data series? If so, the results for the Czech Republic and Slovakia are so inconsistent to be of little use. Would it be better to omit the data for the first year?*
- *In Table 5.2, are the single year figures for 2015 or 2017?*

- *In Figure 5.2, are we looking at short term liabilities or all liabilities?"*

Author

- Corrected to: `reprice`, thank you.
- Corrected to `latter`, thank you.
- The original equation 3.1. has been removed from Section 3 as the description in Section 2 was revised and more details were added. The original equation 3.1. can now be found as a part of the optimization procedure description in Section 2.2.3.4, but it has been changed substantially.
- Yes, 2W was used as a short-cut for 2-week. To avoid misunderstandings, it was changed in the text to 2-week. Thank you.
- Yes, this term has been aligned in the whole thesis to corporate bonds.
- The description as well as equations were harmonized. Thank you.
- Figure 5.1 shows how much non-maturity (demand deposits) make in total liabilities under the different levels of the consolidation of the mother and the daughter companies. If we would have only a bank that would have 20 million NMD (non-maturity deposits) and 25 million liabilities in total, then there would be only single line with the value of 80%. On average, we can see that banks in the Czech Republic have almost 50% of total liabilities comprised by NMDs. Banks in Slovakia show results slightly above 50%. This is quite comparable and correct representation of the importance of NMDs in total banks' liabilities in the both analysed markets. There is indeed some volatility in first years, which is driven by the data quality, but it is not affecting each country, hence the data was not excluded.
- Table 5.2 shows results for (i) Share sample – which is a share across a horizon from 1990 to 2015 and (ii) Share 2015, which is a share only in 2015. Share 2017 was a typo, it was meant to be Share 2015. Thank you. Table 5.2 was corrected.
- In Figure 5.2 we show the share of the short-term asset to all assets (black line) and a share of the short-term liabilities to all liabilities (grey-line). The

aim is to see if there is a structural difference in the short-term versus the medium and the long-term fixed products on both sides of the balance sheet. We find evidence for this in all analysed countries. We can see that countries generally have longer-fixation on asset side than on the liability side as they have more long-term assets as their share is larger (we assume condition asset = liabilities). But this is because we used legal maturities for demand deposits (NMDs) in this analysis. We adjusted the description in the preceding paragraph to the figure as it was vague. Thank you for pointing this out.

Opponent

- *"There is an original contribution.*
- *The thesis is based on relevant references, although it would be improved by the utilization of more references.*
- *The thesis should be defendable, subject to some amendments, which should include more description of the Czech banking environment, some tidying-up of notation, and some additional references.*
- *Results from the thesis have already been published in respected economic journals.*
- *Suggested improvements should follow from my comments on the thesis*
- *I recommend the thesis for defense after the revisions indicated in my comments.*

References:

- *Ho, T.S.Y. & Saunders, A. (1981). The Determinants of Bank Interest Margins: Theory and Empirical evidence. Journal of Financial and Quantitative Analysis.*
- *Humphrey, D. B. (1990, September/October). Why do estimates of bank scale economies differ? Economic Review (Federal Reserve Bank of Richmond).*

- *Mester, L. J. & Saunders, A. (1995). When does the prime rate change? Journal of Banking and Finance.*

- *Molyneux, P.; Reghezza, A. & Xie, R. (2019). Bank margins and profits in a world of negative rates. Journal of Banking and Finance. 107. Article 105613."*

9.4 Opponent's pre-defense report by Prof. Jiří Witzany Ph.D.

Opponent

"The thesis deals mainly with a seemingly simple, but in fact quite challenging problem of non-maturity (demand) deposit modelling in terms of their interest rate and liquidity risks. It is closely related to the new regulatory documents on interest rate management of the banking book (IRRBB) issued by EBA and BCBS.

The first article, according to the introduction, aims to provide a theoretical description and a detailed explanation of an intriguing procedure known as non-maturity deposit portfolio replication. I have seen this procedure implemented by some banks and noticed a number of inconsistencies and implementation issues. Therefore, I was looking forward to find a good description of this procedure in the article. However, I must say, the presented description does not meet my expectations. It describes the procedure very vaguely and refers the reader to related literature to figure out details."

Author

The original aim of the first article was to provide a brief summary of methods and the literature, which is why we referred the reader to details in other papers. The revised version of the article now includes more information regarding the possible application of the mentioned models. There are several adjustments thorough the text. Models shown in Section 2.2.3 were redone and include now the specific model applications. Particularly Section 2.2.3.4 was redone and includes the detailed description of the replicating portfolio method together with two applications.

Opponent

"In addition, the mathematical formulations are quite lousy. For example, what is the meaning of the deposit rate model equation $d=f(d,m)$ or volume dynamics

equation $V=f(V,m,d,x)$, does it mean that the deposit rate or volume is the fixed point of the equation, or does it indicate some kind of VAR model. "

Author

Thank you very much for this feedback. Equations were reviewed and redone. We have changed the general representation of possible models to the specific possible applications to provide more details and bring more information to the reader. Adjustments in the text include several changes in Section 2.2.3.2 and Section 2.2.3.3., where we added text and did the formula adjustment.

Opponent

"The replication portfolio optimization Eq. 2.4 is formulated with the goal of min(σm) or max(m), where m is the margin from the reinvestment of demand deposit. If m is treated a random variable in the standard deviation (of m) minimization approach, then m cannot be maximized in the second approach. What is meant here is probably the expectation, $E[m]$…"

Author

We have added more clarification regarding the replicating portfolio procedure – whole Section 2.2.3.4 is now longer and includes our example and possible application of the procedure. Indeed, we must work with the expected margin, which has not been clarified in the original version of the article, thank you for pointing this out.

Opponent

"Regarding the replication procedure, i.e. simulation of the variable m, the devil is hidden in the details, and the details are not too much described here. It seems that the author assumes a new reinvestment of the full volume at any point of time according to the weights (since short positions are not allowed). But this is not practically possible, the replication portfolio must be dynamically rebalanced in line with the stochastic volume development, which means that sometimes (when NMD volume significantly drops) short positions (financing) might be needed."

Author

One must distinguish between the dynamic and the static replication procedure. We would like to stress that margin itself is not simulated, but variables that enter it, are, but only in the dynamic replication. In the static replication procedure, margin is a given outcome of the replicating portfolio yield and the deposit rate expense. No simulations enter the static replication. The expected margin is evaluated over all possible iterations/set ups of the replicating portfolio and the one that maximizes Sharpe ratio, as we show in the reworked and enlarged Section 2.2.3.4, is selected. In the dynamic replication, possible paths of the development of volumes and the deposit rate expense determine the constraints for the maturity of the replicating portfolio and simulations of market rate determine the possible yields, but over each simulated path of constraints and yields, same procedure as for the static replication is applied.

Furthermore, regarding the portfolio rebalancing. This is a very good comment. In fact, it touches the issue that replicating portfolio approach is not exactly reflecting banks' investment strategies. One should set up constraints of the replication procedure having this in mind. The procedure must distinguish liquidity and interest rate risk properly. We can cease the assumption of the short selling assuming we always have enough funds of demand deposits that are reinvested linearly. This inherently assumes that each zero-coupon bond (and money market instrument) is linearly reinvested in time and funds for the reinvestment are always available. This must be ensured by the proper and robust model for the demand deposit volume, that derives the average maturity of demand deposits in a way that possible outflows are already covered in this estimate and the average maturity of demand deposits is not expected to be lower. In other words, only the volume that is expected to stay at given maturities, is replicated and the procedure does not expect higher outflows as the maturity estimate is already conservative enough.

Opponent

"Overall, my recommendation is that the author provides a full and mathematically sound description of the replication procedure which is technically the most difficult but also the most important part of the thesis. "

Author

The whole Section 2.2.3.4. has been largely adjusted to provide the idea behind the static replication we discuss in this article. We added two application of the method to show the idea behind the approach. Thank you very much for this overall feedback to this Section.

Opponent

"The second article with an empirical study focusing on saving deposits provides more details on the market rate, client rate, and deposit volume models used in the replication procedure. It is surprising that the deposit volumes are supposed just to grow with the accrued deposit rate without any other volatility which lies in the centre of NMD modelling."

Author

This is, indeed, simplification, albeit similar one as used in the regulatory approach. The article was missing reasoning behind this. We need to take into the account that banks place deposits into assets and, as the balance sheet increases, so does the capital of the bank. As our analysis in this article aims to show the relative effect of the over-priced savings accounts on a capital of a bank, not to model volume dynamics in the traditional sense as done for the interest rate risk and the liquidity risk management within IRRBB, we see this simplification as sufficient for our purposes. Furthermore, in this article, our aim is to calculate a net interest income of a bank. Our analysis is similar to the earnings risk estimation, which forms a part of the IRRBB regulation EBA (2018). The IRRBB regulation defines two types of balance sheet over which banks are supposed to estimate their earnings risk. The static balance sheet assumes flat development of volumes. The dynamic balance sheet assumes dynamc growth as given by models or by the internal business projections. Our analysis is more in line with the static balance sheet. We have added short text regarding this to the original article in Section 3.2.5.

Opponent

"In addition, the replication procedure is not implemented in the optimization sense. The author simply sets a replication strategy (weights of investments to instruments with different maturities) and calculates the cumulative net interest income for three types of banks and several predefined portfolios."

Author

Thank you for this comment. Yes, the replication procedure was taken as an inspiration and was described methodologically, but it is not implemented. A modelling of demand deposits and resulting maturity and duration estimates are not a focus of this study. The focus is to see if high-interest rates offered on savings accounts at the time of a low-rate environment are reasonable from the risk management point of view. In this sense, we rather focus on earnings risk. Banks employ diverse approaches to model demand deposits, but in the end their reinvestment strategy is diversified into major asset classes as we employed in our analysis. We agree that the description of the replicating procedure was misleading, and it was in fact a duplicity in terms of the whole thesis. This part was taken out from the second article due to this reason. Section 3.2.3 was updated.

Opponent

"The results also depend on the predefined client rate adjustment mechanism which just seems to be expertly setup. This is an interesting study but it cannot be used to draw general conclusion regarding the interest risk of the saving deposits. There is no empirical evidence for the presented repricing mechanism and to show that its parameters are realistic. "

Author

We observed several years of development of deposit rates and we created the deposit pricing behaviour of banks based on that. This was not in the detail shown in the original paper due to the space limits, but we included it now in the revised version in the thesis. We added the whole Section 3.2.9., which is dedicated to the empirical evidence which drives the underlying pricing mechanism in the study.

Opponent

"It is also not clear whether the replication weights correspond to the real approaches of the banks. In fact, if the deposit pricing policy was given, the replication portfolio should be constructed to fit the policy. Or vice versa, if the replication strategy was primarily given, then the saving deposit pricing policy should reflect the returns of the strategy. Defining ex ante the pricing policy and the replication strategy not surprisingly leads to evidence of a misalignment between the two, and it is not methodology correct to draw general conclusions on savings account risk based on this set up."

Author

The approach we took in this study was to: (i) assume banks aim to keep similar spread between the deposit rate and the market interest rate in the simulation period as during the observed period – this is the pricing model (pricing mechanism) and (ii) assume the reinvestment of deposits is done into the simplified classes of assets with weights that represent the average Czech bank asset strategy – thus corresponding to the real strategy of banks. In the study, the pricing of savings accounts is given by the interest rate scenario assuming spreads and the deposit rate adjustments as derived in Section 3.2.9.2. Volumes were only increasing by the capitalization and consistently placed into the reinvestment portfolio, as well as all maturing cash flows (as mentioned earlier, this is very close to the static balance sheet assumption). Assets were generating the interest based on the interest rate scenario too. The whole model is in fact the simplified view on the net interest income calculation of a bank, in which on the liability side, we assume savings accounts and capital and on the asset side, we assume usual asset classes Czech banks have on their balance sheets. The difference in interest income from assets and interest expense form savings accounts defines the banks' margin. In the case of the adverse scenarios, in which a bank has to reprice savings accounts up to keep volumes, the repricing mechanism may lead to capital losses. This us due to the fact that assets generated during a low-rate environment reprice later than savings accounts in banks that have aggressive pricing strategy of savings accounts.

It would be true that the replicating portfolio should reflect the pricing strategy in the case we would like to fully hedge the interest rate risk of demand deposits. But banks aim to profit from the open position to interest rate risk and hence the real reinvestment portfolio in fact will hardly ever match purely the interest rate risk of deposits.

Again, due to the space constraints, the published article lacked the detailed description of this, and we improved this in the final version provided in the thesis. Adjustments include additional details in Table 3.2. and several revisions/additions thorough the text regarding the logic behind the set-up of the reinvestment portfolio.

Opponent

"A minor remark is that the estimated coefficients of the market rate model should be properly reported including the estimation errors and more details on the estimation procedure."

Author

This was included in the revised version in Section 3.2.9.1.

Opponent

"The goal of the third article is to analyse liquidity characteristics of the Czech banking system retail deposits, namely the average maturity of term deposits and the effective duration of demand deposits. The calculation of the average duration should straightforward, however the simple Eq. 4.1 is incorrectly stated. The effective duration of demand deposits is using an ARIMA model fit to the time series of demand deposits in the system. The model then allows to estimate deposit outflows on a confidence level and considering the regulatory limit of 10 years."

Author

We would like to clarify that the article estimates the average maturity of demand deposits, not their duration (in terms of a measure of interest rate risk). To estimate a duration, we would also need a model for the pricing behaviour, which is not done in this article. Only the average maturity is derived in this article. Eq. 4.1 refers to term deposits, not demand deposits. Average maturity of term deposits is the weighted average maturity of all outstanding term deposits. m_i was the weighted average maturity of each term deposit. We adjusted equation accordingly to be harmonized with the remainder of the thesis.

Opponent

"My first, less important, remark, is that the results of the ARIMA fit coefficients should be properly reported (are not reported at all) and the effective duration should be more precisely set in mathematically terms (the verbal description is quite murky)."

Author

Table 4.2 includes descriptive statistics of the series and we have additionally provided model outcomes with all the relevant statistics. Furthermore, the verbal description in Section 4.2.3.2 has been improved with the mathematical description behind the derivation of the average maturity from simulated volumes. The misleading equation was entirely removed and only the final model equation is provided within the text.

Opponent

"The second remark is that the resulting effective duration estimate (9.3) cannot be extended to individual banks (the result is used in the subsequent papers by the authors on the level of individual banks). The stability of demand deposits in the banking system is much larger than the stability of demand deposits for an individual bank, since any payment between transactional accounts does not change the system NMD balance, but it does change the balance with a substantial probability in case of an individual bank (no bank has a market share above 50%)."

Author

As mentioned above, the analysis derives the weighted average maturity also in case of demand deposits. Ambiguous naming in Conclusion (Section 7) has been adjusted to refer only to the maturity. However, we would like to provide the answer as this is very good comment, which would in fact apply to both maturity as well as duration. When demand deposits are analysed on the aggregate level, we indeed disregard potential volatility on the bank's level within the single product level. Thus, applying the results presented in the article on the single bank level may indeed not be fully correct, especially in case of small institutions that do not exhibit large core of current accounts. On the other hand, the article aims to show potential risk factors in the relationship between demand deposits and term deposits. For such analysis, the aggregate data is valid source, in our opinion. The inputs regarding average maturity are not used in the later analysis in full, but only as a reference to the stability of demand deposits. The subsequent analysis presented in Section 6 uses assumption summarized in Table 6.1 to define average maturities of demand deposits.

Opponent

"The fourth paper looks at the structure of short-term versus long-term assets and liabilities of CME banks and discusses the common interest rate and liquidity risk issues in the context of the IRRBB regulation. There are again some with incorrectly stated mathematical formulas, namely Eq. 5.1 and 5.2., but otherwise the results of the analysis are interesting."

Author

Equation Eq. 5.1 was adjusted, thank you. Equation Eq. 5.2. included small typo V_{i1} in place of V_i, and incorrect definition of the baseline scenario, it should not be flat rates, but forward rates. Otherwise it shows the proper form how to derive the effective duration, which is exactly the interest rate risk (the risk of value changes due to different interest rates, it can be both a gain as well as a loss).

Opponent

"The last paper performs a detailed analysis of the interest rate risk of top 3 Czech and top 3 Slovak banks. It is based on a set of assumptions regarding duration individual products on the asset and liability side including the controversial estimate of the long effective duration (9-10 years) of the demand deposits. The study takes optionality, in particular loan prepayments into account. The conclusions confirm the generally known fact that banks are exposed to the interest rate risk with a negative of impact of decreasing interest rates. This sensitivity results might be overestimated due to the high efficient duration of demand deposits estimate (as discussed above) that enters the model."

Author

The paper uses estimates for maturity of demand deposits as given by the Table 6.1. which implies that average maturity of demand deposits spans from 4.15 (retail transactional deposits) years to 2 years (corporate transactional accounts). We use findings regarding the stability of demand deposits from the fourth paper only as an input for the evidence of the stability of demand deposits. We than employ limits given by the regulation and summarized in the Table 6.1. Durations are than always strictly lower than average maturities.

Opponent

"Overall, in spite of the critical remarks, the thesis provides a good overview of the interest rate and liquidity risk modelling of a banking book. The author presents an extensive review of literature and her own contributions to the theoretical methodology and empirical results. There is also an apparent improvement of quality of the five articles published in 2015-2020. However, the thesis requires certain substantial improvements, mainly in precise formulations and descriptions of the mathematical models employed, proper reporting of estimation results, and in some cases a more realistic setting or discussion of the model assumptions. The results of the paper have been already partially published in impacted academic journals, and the thesis, after revisions, could be defended at my home institution. To

conclude, in my opinion, the thesis can be defended after revisions indicated in my comments."