Aalto University
School of Economics

Estimating the Value and Interest Rate Risk of Demand Deposits in Concentrated Markets

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Lauri Tynys
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Aalto University School of Economics **ABSTRACT**

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Lauri Tynys

ESTIMATING THE VALUE AND INTEREST RATE RISK OF DEMAND DEPOSITS IN CONCENTRATED MARKETS

PURPOSE OF THE STUDY

The purpose of this study is to determine the value and interest rate risk of funds deposited in demand deposit accounts under imperfect competition among banks. The value of a demand deposit is divided into two components, which are rent and liability. The former is defined as the profit bank receives from accepting demand deposits (by paying rates below the short-term market interest rate) and the latter as the nominal value of deposits minus the rent. The interest rate risk of demand deposits is measured by their sensitivity to shocks in the short-term market interest rate. The analysis in this thesis is carried out from the viewpoint of a case bank, which is a Finnish commercial bank, and the Finnish banking sector as a whole.

DATA AND METHODOLOGY

Historical data is needed in this thesis in order to estimate the demand functions for deposits and the processes of the variables. Most of the data series span from January 2006 to December 2010, totaling 60 monthly observations. The data was obtained from three sources: the case bank's databases, Bank of Finland, and Statistics Finland. Monte Carlo simulation is used in generating the value and interest rate risk estimates. A majority of the variables are modeled as AR(2)-processes, whereas the short-term market interest rate is modeled using a one-factor stochastic Cox-Ingersoll-Ross model. Moreover, various assumptions concerning deposit balance dynamics are taken into account in the analysis of case bank, whereas the analysis of the whole banking sector is carried out only under AR(2) forecasted balances.

RESULTS

The results indicate that several variables measuring macroeconomic environment and market concentration play an important role in determining the demand function for demand deposits. Also, it is found that both the case bank and the Finnish banking sector as a whole exercise market power, as both of them are able to generate significant positive rents from accepting demand deposits. However, the magnitude of these rents varies a lot depending on the assumed deposit balance dynamics. The largest rent estimates are obtained assuming that future deposit balances evolve according to AR(2) forecasts, whereas under constant and decaying balances the rents are substantially lower. Finally, I find the interest rate risk of demand deposits to be significant, as their valuations are sensitive to short-term market rate shocks under all deposit balance dynamics covered.

KEYWORDS

Bank liability management, market concentration, demand deposits, interest rate risk

Aalto-yliopiston kauppakorkeakoulu **TIIVISTELMÄ**

Pro gradu -tutkielma 19. tammikuuta 2012

Lauri Tynys

AVISTATALLETUSTEN ARVON JA KORKORISKIN MÄÄRITTÄMINEN KESKITTYNEILLÄ MARKKINOILLA

TUTKIMUKSEN TAVOITTEET

Tämän tutkimuksen tavoitteena on määrittää sekä case-pankin että suomalaisen pankkisektorin avistatalletusten arvo sekä niihin liittyvä korkoriski epätäydellisen kilpailun vallitessa markkinoilla. Talletuksen arvon määrittämisessä on otettava huomioon kummatkin siihen vaikuttavat komponentit, jotka ovat talletuspreemio ja vastuuarvo. Näistä ensimmäinen on pankin saama voitto, jonka se ansaitsee ottamalla avistatalletuksia vastaan ja maksamalla näille talletuksille korkoa, joka on lyhyttä markkinakorkoa alhaisempi. Talletuksen vastuuarvo saadaan puolestaan vähentämällä talletuspreemio talletuksen sen hetkisestä nimellisarvosta. Korkoriskiä mitataan tässä tutkimuksessa talletusten arvon herkkyydellä markkinakoron äkillisiin muutoksiin.

AINEISTO JA MENETELMÄT

Tutkimuksessa käytetään historiallista dataa talletusten kysyntäfunktioiden sekä muuttujien prosessien määrittämisessä. Suurin osa aikasarjoista koostuu kuukausittaisista havainnoista (60 kpl) aikaväliltä tammikuu 2006-joulukuu 2010. Aineisto on kerätty kolmesta lähteestä; case-pankilta, Suomen Pankista ja Tilastokeskukselta. Talletusten arvo- ja korkoriskiestimaattien määrittämisessä hyödynnetään Monte Carlo -simulaatiota. Suurinta osaa muuttujista kuvataan AR(2)-prosessien avulla, poikkeuksena kuitenkin lyhyt markkinakorko, jota mallinnetaan stokastisella Cox-Ingersoll-Ross-mallilla. Case-pankin analyysissa otetaan huomioon useita vaihtoehtoisia talletuskannan kehityksen skenaarioita, kun taas koko pankkisektorin tarkastelussa talletusten oletetaan kasvavan AR(2)-ennusteen mukaisesti.

TULOKSET

Tulokseni osoittavat, että useat makrotaloudelliset sekä pankkisektorin keskittyneisyyttä mittaavat muuttujat ovat merkittäviä avistatalletusten kysynnän määrittäjiä. Tulokseni tarjoavat evidenssiä myös siitä, että sekä case-pankki että suomalainen pankkisektori kokonaisuudessaan käyttävät markkinavoimaa, sillä kummankin avistatalletuskannan arvosta talletuspreemio muodostaa merkittävän osan. Talletuspreemion suuruus riippuu kuitenkin oletetusta talletuskannan kehityksestä. Suurimmat talletuspreemiot saavutetaan talletuskannan kehittyessä AR(2)-ennusteen mukaisesti, kun taas tasaisen ja pienenevän talletuskannan oletuksella ne ovat huomattavasti pienempiä. Tulokseni osoittavat myös, että avistatalletusten korkoriski on merkittävä, sillä niiden arvostukset ovat herkkiä lyhyen markkinakoron äkillisille muutoksille riippumatta oletetusta talletuskannan kehityksestä.

AVAINSANAT

Pankkien vastuiden hallinta, markkinan keskittyneisyys, avistatalletukset, korkoriski

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1. INTRODUCTION

The basic function of deposit banks is to create maturity mismatch between its assets and liabilities by obtaining funding from the side of public having excess funds and using these funds to grant loans to the side in deficit. If it is assumed that banks are able to invest their cash at the market interest rate, they make profits from both deposits and loans by paying rates below the market rate to depositors and charging rates above the market rate from the borrowers. Banks have two main sources of short-term funding available, which are deposits and money market securities, such as certificates of deposit. Deposits can be further divided into two main categories, which are term deposits and demand deposits. Under a term deposit contract the depositor agrees to keep the money in the bank for a predetermined time, but demand deposits can be withdrawn by the depositor at any time with no cost.

Funds deposited in demand deposit accounts, or DDAs, contain some distinctive characteristics from a bank’s point of view. While depositors consider them as extremely liquid investments, banks face challenges in measuring their sufficiency, value, and exposure to different risks. These challenges arise because the contractual maturity of DDAs is zero, but in practice their balances remain more or less stable in banks’ balance sheets over time, causing their practical maturities to be substantially in excess of zero. Since these deposits do not have market prices available either, the standard practice has been to value them simply at their nominal values in banks’ balance sheets.

DDAs play an important role in the overall funding of Finnish banks, as the DDA market in Finland totalled approximately 70 billion euros in the end of 2010, representing some 15 % of the banks’ total liabilities. The banking sector in Finland is also characterized by a high degree of concentration, which increases the possibility that banks exercise market power. Bank market power within the DDA market can be inferred from the rents banks obtain from accepting these deposits. The deposit rent is defined as the spread between the short-term market rate and the deposit rate set by the bank multiplied by the nominal value of deposits in the bank’s balance sheet, whereas deposits’ liability value is obtained by subtracting the rent from the nominal value of deposits. The greater (smaller) these rents are, the more (less) banks exercise market power in the DDA market. Naturally, the presence of bank market power and deposit rents has to be taken into consideration in the valuation and risk measurement of DDAs.

1.1. Objective and Contribution of the Thesis

The objective of this thesis is to measure the value and interest rate risk of DDAs while taking into account several macroeconomic considerations and imperfect competition among banks as well. An additional aim is to clarify which factors determine the public's demand for DDAs and, thus, have to be taken into account in the valuation and risk management procedures. Also, the effects of assumed deposit balance dynamics on DDA valuation and interest rate risk estimates is covered, as several different scenarios for future evolvement of DDA levels are studied. The base case scenario in previous papers has been to assume that deposit balances remain constant over time, but this thesis, on the other hand, focuses on the effects of decaying and growing balances as well. The analysis in this thesis is carried out for a Finnish case bank and, to some extent, the Finnish banking sector as a whole. The case bank studied here is a relatively young commercial bank, which has been growing faster than the sector during the recent years. This historical difference in the pace of growth leads to the last objective of this thesis, which is to examine how the expected future deposit balance growth rate affects the value and interest rate risk estimates of DDAs.

The general theoretical framework of banks' profit maximization used in this thesis is similar as in Hutchison and Pennacchi (1996) and the methodology used to obtain the DDA value and interest rate risk estimates is Monte Carlo simulation. Interest rate risk of these deposits is measured by the sensitivity of their value to term structure slope shocks in the market interest rate. The short-term market rate, which is considered as the only source of risk in the valuation procedure, is modeled as a one-factor stochastic Cox-Ingersoll-Ross process and the other variables are modeled as autoregressive AR(2) processes. Moreover, Ordinary Least Squares (OLS) regression is used in estimating the DDA demand functions.

Two research hypotheses are tested in this thesis. The first one of these, denoted by H_1, concerns the banks' ability to generate profits from DDAs, whereas the second hypothesis (H_2) focuses on the interest rate sensitivity of DDAs. The two hypotheses are defined as follows:

> H_1: *Banks exercise market power and thus earn positive rents from their DDAs.*
>
> H_2: *DDA rates do not perfectly adjust to interest rate shocks, thus causing a positive term structure slope shock to increase the value of DDA rents.*

Both of these research hypotheses stem from theories of market concentration, and to be more precise, from structure-performance hypothesis and efficient structure hypothesis. The basic logic of both of them is that prices are less favorable to consumers in more concentrated markets.[1] The statistical test used to test H_1 and H_2 is a one-sided *z*-test.

This thesis provides several contributions, both from academic and practical perspective. First, most of the previous papers studying deposit rents and interest rate risk concentrate on the U.S. banking sector, whereas only little attention is paid to the European banks. This is an important gap to fill, since the role of banks is more crucial in the bank-centered European economies compared to the market-centered U.S. economy. This thesis is, at least to the best of my knowledge, the first paper concentrating on Finnish environment.

The second contribution to existing research is that this thesis provides additional insights to the role of deposit balance dynamics in the valuation and risk measurement of DDAs. This is done by studying three alternative scenarios of deposit balance dynamics, which are growing deposits, constant deposits, and decaying deposits. The third academic contribution of this thesis is the additional focus put on macroeconomic and banking sector competition aspects. Previous papers mainly assume that deposit demand is affected only by the market interest rate and the deposit interest rate set by the bank, but this thesis includes macroeconomic and market concentration factors as determinants of deposit demand as well.

From the case bank's point of view, this thesis provides practical contributions. First, the bank receives an assessment of its DDA risk position. The valuation and risk measurement of DDAs is somewhat challenging and time-consuming, but altogether essential in order to fully understand the characteristics of these deposits. Second, this thesis is aimed to serve as a guideline for further refinements in the case bank's liability management procedures. This is an issue of first-order importance, since the risk management practices of banks worldwide are being reconsidered after the recent banking crisis and banks need to have a solid understanding about the risks they are exposed to in order to adapt to the new regulatory environment.

[1] See, e.g. Berger and Hannan (1989) and Goldberg and Rai (1996) for further information on structure-performance hypothesis and efficient structure hypothesis. Also, Chapter 2.1. of this thesis covers the principles of the concepts.

1.2. Results

The results indicate that strong evidence supporting both H_1 and H_2 is found, as all the rent and interest rate risk estimates under different deposit balance dynamics are significant at the 1 % level. I find that the mean rent for the case bank equals 19.66 % under constant deposits, 61.70 % under growing deposits, and 1.55-8.10 % under decaying deposits, depending on the decay rate. For the banking sector only the case of growing deposits is covered, under which the mean rent equals 32.90 %. The interest rate risk estimates under +100 bps (+200 bps) shock, i.e. the change in the value of rent due to a given market rate shock, for the case bank range between 4.07 % and 52.10 % (8.18-98.37 %), depending on the assumed DDA balance dynamics. For the banking sector and under growing deposit balances the estimate obtained is 6.28 % for +100 bps shock and 12.67 % for a +200 bps shock.

The results obtained in this thesis are somewhat well in line with previous research. My results on the magnitude of DDA rents are similar to the results by O'Brien (2000), as I find that under constant deposit balances the average rent for the case bank equals 19.66 % and the results of O'Brien indicate a rent of 21.10 % under the same assumptions. However, the magnitude of these rent estimates are somewhat different in Hutchison and Pennacchi (1996) and Dewachter et al. (2006), as the former finds the average rent to be lower and the latter finds it to be substantially greater. Despite the differences in the magnitude of rent estimates, the conclusion in previous research and in this thesis is the same, i.e. deposit rents constitute a significant part of the deposit value, causing the liability value of deposits to be lower than their nominal value. Moreover, the results considering the interest rate risk of deposits are similar in this thesis compared to previous research, as I find that a positive term structure slope shock increases (decreases) the value of DDA rent (liability).

1.3. Structure of the Thesis

This thesis proceeds in the following manner. In Chapter 2, I present a review of the previous literature related to banking sector concentration, deposit valuation, and measuring the risk characteristics of deposits. After that, the methodology used in this thesis is thoroughly described in Chapter 3, followed by an introduction to data and variables in Chapter 4. Finally, in Chapter 5, I present the results obtained in this thesis and discuss their implications from several viewpoints. Chapter 6 concludes.

2. PREVIOUS LITERATURE

In this chapter I discuss the previous research related to this thesis. First, the research focusing on market concentration in banking sector and competition between banks is covered. Second, I introduce the relevant papers from the area of valuing deposit rents and liabilities. Third, the literature related to modeling market interest rates is covered. After that, the focus will be on studies concentrating on interest rate risk of deposits. Finally, in the last section, I present an overview of the studies focusing on deposit balance dynamics and the factors affecting deposit demand. An important concept related to balance dynamics, bank runs, is also covered in the last section.

2.1. Market Concentration in Banking Sector

Market competition and concentration have been popular subjects among academics for decades. In his seminal paper, Demsetz (1973) points out that a majority of prior empirical research focused on identifying monopolies within a given industry, and these papers had a desire to be policy-relevant. He also states that studying market concentration can provide other fruitful topics for research as well. Demsetz identifies two fundamental sources of market concentration, namely the superior ability of few firms to produce and market their products and the superiority of an industry structure in which there are only a few firms. The former of these sources of concentration can be viewed as an endogenous factor, whereas the latter has a more exogenous nature.

Berger et al. (2004) provide a comprehensive review on the studies focusing specially on banking sector concentration and competition. Their paper stems from the fact that the consolidation of banks around the globe in recent years has intensified the public policy discussions on the influences of market concentration. As they compare old and new research in that area, they conclude that while the older research focuses on market concentration and bank performance, the emphasis of the newer research is on credit availability and financial stability - topics of first-order importance.

Examples of recent studies on bank competition and market concentration are provided in, e.g., Kano et al. (2006), Hays et al. (2009), and Fernández et al. (2010). Kano et al. focus on the credit availability issue mentioned in Berger et al. (2004) as they investigate the benefits from bank-borrower relationships for a sample of Japanese small- and medium-sized enterprises. They hypothesize that these benefits vary due to three factors identified in the theoretical literature: verifiability of information, bank size and complexity, and banking sector competition. They find that their sample firms benefit most from bank-borrower relationships when they do not have audited financial statements (i.e. their company information is less transparent) and when they borrow from small banks in less competitive markets. Hays et al., on the other hand, focus on the banks' viewpoint. They examine the impact of market concentration on the yield on assets and the cost of funds for American commercial banks and find that market concentration has no significant impact on them. Finally, Fernández et al. relate banking sector concentration to economic growth and financial stability, as they analyze how the effect of concentration on economic growth varies across countries depending on bank regulation, supervision, and institutions. They find that banking sector concentration has a negative effect on economic growth and that tighter restrictions on bank activities reduce this effect.

Traditional structure-performance and subsequent efficient structure hypotheses constitute two essential concepts concerning banking sector concentration. The assumption under the former is that non-competitive pricing behavior explains the positive correlation between market concentration and profitability, whereas the latter assumes that it is explained by the greater efficiency of firms with dominant market shares (Berger and Hannan, 1989). Under both structure-performance hypothesis and efficient structure hypothesis, prices are less favorable to consumers in more concentrated markets. However, Berger and Hannan state that they differ in terms of the structural model behind the phenomenon. Structure-performance hypothesis assumes that concentration is exogenous resulting in noncompetitive behavior, whereas the efficient structure hypothesis takes firm-specific efficiencies as exogenous and these efficiencies result in both more concentrated markets and noncompetitive prices. Both of these hypotheses are tested in Goldberg and Rai (1996) in the context of European banks. Their results support the efficient structure hypothesis for banks located in countries with low market concentration, whereas no significant evidence is found to support the structure-performance hypothesis.

Another relevant research area from the viewpoint of this thesis is the banks' deposit interest rate setting behavior in the presence of imperfect competition among banks. This question is in the heart of the study by Neumark and Sharpe (1992) as they examine the asymmetric deposit interest rate adjustments to changes in market interest rates. They find that banks in concentrated markets are slower to raise deposit interest rates in response to rising market interest rates, but faster to reduce them in response to declining market interest rates. Thus, banks with market power profit from market interest rate movements in both directions. Neumark and Sharpe conclude that since deposit interest rates are inversely related to the price charged by banks for deposits, their results suggest that downward price rigidity and upward price flexibility are consequences of market concentration. Martín-Oliver (2008) extends the deposit interest rate analysis by studying the competition among Spanish banks in terms of three output components, namely loans, deposits, and commissions. He recognizes the imperfect competition within banking sector as well, but also states that the competition in loan and deposit markets has increased during the period from 1989 to 2003.

In a somewhat recent paper, Vajanne (2009) tests for the existence of bank market power in euro area countries by employing data on demand deposit interest rates and corresponding market interest rates. Her results suggest that despite country specific differences, there exists a general pattern of banks exercising market power within the euro area and the reactions of deposit interest rates to market interest rate movements are clearly asymmetric, i.e. flexible when market rates are decreasing and rigid when they are increasing. Finally, Kahn et al. (1999) introduce a slightly different kind of consequence stemming from bank market power. They argue that retail deposit interest rates cluster around integers and fractions, and propose a theory based on the "limited recall" of retail depositors to explain this. Their theory suggests that deposit interest rates are sticky at their integer levels and the propensity for integer rates increases with the level of market interest rates and deposit market concentration. They also argue that when banks set non-integer rates, they are more likely to be just above, rather than just below, integers. Moreover, they find strong empirical support for the theory's implications.

2.2. Deposit Rents

As discussed in the previous section, the banking sector is typically concentrated which leads banks to exercise market power. One sign of this market power that the literature suggests is the rents banks receive from accepting deposits. In the presence of market power, banks set their deposit interest rates below the short-term market interest rate and thus receive positive net cash flows from accepting deposits. Hutchison and Pennacchi (1996) state that the value banks obtain from deposit rents equals the present value of all stochastic cash flows they receive in all futures dates, and this value is a part of the banks' "going concern value" or "charter value". In their paper, Hutchison and Pennacchi estimate Negotiable Order of Withdrawal (NOW) and Money Market Deposit (MMDA) account rents for more than 200 U.S. commercial banks. Instead of measuring deposit rents as plain dollar values, they present them as present values of all future rents per initial deposit balance. There is some divergence between banks in their results, but the median rents per deposit equal 6.55 % for NOW accounts and 7.88 % for MMDAs. Moreover, for simplicity reasons Hutchison and Pennacchi assume that the only source of risk in the valuation of rents is the movements in short term market interest rate, which is assumed to fluctuate according to a Vasicek model. These changes in short-term market interest rate cause the banks' current profitability of deposits to vary in time and hence the deposit rents can be viewed as stochastic from a single bank's point of view.

Jarrow and van Deventer (1998) contribute to the literature by extending the analysis by Hutchison and Pennacchi (1996) by valuing credit card loans in addition to demand deposits. Whereas Hutchison and Pennacchi use an equilibrium-based approach, the model of Jarrow and van Deventer is based on arbitrage-free pricing methodology. Moreover, they employ a "market segmentation" argument to justify differences between market interest rates and the rates paid (charged) on demand deposits (credit card loans). According to the argument only banks, not individual investors can accept demand deposits and grant credit card loans, but both of them can trade in frictionless and competitive Treasury security markets.

An important aspect in valuing deposit rents, which is the asymmetric adjustment of deposit rates to market rate changes, is taken into account in O'Brien (2000). Similarly as in Jarrow and van Deventer (1998), O'Brien uses an arbitrage-free pricing method that models deposit rents as interest rate contingent claims. He also states that widely used autoregressive models may be suitable for forecasting near-term deposit rents, but they are less suitable for longer-term rent forecasts. Whereas Hutchison and Pennacchi (1996) present an analytical solution for estimating rents, O'Brien uses numerical methods for this purpose, i.e. Monte Carlo simulation over a 30-year horizon. Assuming fixed deposit balances, he finds that (i) under asymmetric adjustment of deposit rates to changes in the market rate the median rent per deposit across all 74 sample banks equals 21.10 % for NOW accounts and 12.20 % for MMDAs and (ii) under symmetric adjustment, the median is 15.30 % for NOWs and 10.90 % for MMDAs. Since partial adjustment of deposit rates with relation to changes in market rate is likely to occur when banks exercise market power, one can conclude from the results of

O’Brien that the profitability of deposits is negatively related to the level of competition in the market.

The work by both Hutchison and Pennacchi (1996) and O’Brien (2000) use data on U.S. banks, but the issue is of great interest in the bank-centered European economies as well. Dewachter et al. (2006) strive to fill this gap by examining the rents for a sample of Belgian banks’ retail savings deposits accounts. They extend the previous analyses by studying deposit rents and liability values under different deposit withdrawal or decay rates and servicing costs. Their results indicate that (i) for a base case (servicing cost equals 0 % and withdrawal rate 15 %) the average deposit rent equals 22.60 % and (ii) for varying decay rates and servicing costs it ranges from 4.40 % to 47.80 %, where the greatest value is obtained with constant deposits (i.e. zero decay rate) and zero servicing costs. They find that deposit rents constitute and economically and statistically significant component of savings deposits, even though their valuations are sensitive to assumptions about servicing costs and outstanding balances’ decay rates. Furthermore, they argue that deposit liability values depreciate significantly when market rates increase and, thus, offset some of the value losses on the asset side.

2.3. Interest Rate Models

Models for short-term interest rates can be roughly divided into two categories: one-factor and multi-factor models. The assumption under the former is that there is only one stochastic factor driving the process, i.e. there is only one source of risk, whereas the models in the latter category contain multiple risk sources. The literature related to valuing deposits and estimating their risk typically assumes that the interest rates evolve according to the one-factor models, and, thus, this section concentrates on three most widely used models in that category. These are the Vasicek model (1977), Cox-Ingersoll-Ross model (1985), and Hull-White model (1990).

Vasicek (1977) was the first to introduce an interest rate model incorporating mean reversion, which means that the process strives towards its long-term mean. This is a very essential assumption in modeling interest rates, since it is not reasonable to assume that they could rise or descend indefinitely. Vasicek model has two components, which can be viewed as “drift” and “shock” components. Both of these components contain two elements: the drift component is determined by (i) the speed of mean reversion and (ii) the spread between the long term mean level of the process and the current interest rate. The shock component, on the other hand, is determined by (i) volatility of the process and (ii) a Wiener process that is intended to model the sole source of market risk. However, as pointed out in Hull and White (1990), there is a fundamental disadvantage in the Vasicek model, which is that the short-term interest rate being modeled can become negative. Obviously, this is not likely to occur with actual interest rates.

The problem of Vasicek model's negative interest rates is taken into account in the model by Cox, Ingersoll, and Ross (1985). Essentially the model is very similar to the Vasicek model, as they both are mean reverting, continuous time first-order autoregressive processes. However, the key difference lies in modeling the shock component of the process. Whereas the Vasicek model assumes that the magnitude of shocks does not depend on the current level of the state variable, i.e. short-term interest rate, the Cox-Ingersoll-Ross model does make this assumption. To put it differently, the volatility of the Cox-Ingersoll-Ross process is conditional on the current level of the state variable. In practice, when the interest rate is close to zero, the magnitude of the shock is small, causing the smallest possible value for the state variable to be zero. If the interest rate becomes zero, the next shock has a zero effect and the drift component of the model causes the interest rate to rise.

Hull and White (1990) further develop the two aforementioned models. Depending on whether the shock component of the model is assumed to be conditional on the state variable or not, the Hull-White model can be considered as an extension of either Vasicek or Cox-Ingersoll-Ross model. The main difference between Hull-White model and the previous two models is the increased time-dependence included in the process. To be more precise, Hull and White add a time-dependent drift term to the process for the short rate, and allow the speed of mean reversion and volatility to be functions of time. Moreover, Hull and White highlight the practical attractiveness of the extended Vasicek model because of its easy analytic tractability. They also compare the performance of the extended Vasicek model with the one-factor Cox-Ingersoll-Ross model and with two different two-factor models by testing whether the option prices given by their model are similar to those given by other models. By fitting all the models to the same initial term structure of interest rates, the same term structure of interest rate volatilities and the same data on the expected future instantaneous standard deviation of the short rate, their results suggest that the differences between the option prices produced by the models are small.

2.4. Interest Rate Risk of Deposits

Banks generating maturity transformation between their short-term liabilities and long-term assets face several risks. These risks are well summarized by Kalkbrener and Willing (2004), as they divide them to credit risk, interest rate risk, and liquidity risk. In this section, I will focus on the literature covering the interest rate risk of demand deposits. As pointed out by Jarrow and van Deventer (1992), understanding the risk characteristics of these deposits play a major role in successful liability management of deposit banks.

Studies focusing on risk management of non-maturing liabilities, such as demand deposits, are of great practical importance. However, a number of authors agree on the fact that theoretical research on the subject has proceeded somewhat slowly (see, e.g., Jarrow and van Deventer, 1998; O'Brien, 2000; and Kalkbrener and Willing, 2004). A widely used method in quantifying the interest rate risk associated with deposits is the duration measure introduced by Cox et al. (1979).[2] This measure is used by Hutchison and Pennacchi (1996), and they state that the current profitability of deposits varies with market rate movements due to imperfect competition in the deposit market, and a proper measure of deposit duration must incorporate these changes in profit stream values. The results of Hutchison and Pennacchi indicate that the median duration for NOW accounts is 6.69 years and for MMDAs 0.37 years. Keeping in mind that zero duration occurs only when the retail deposit market is fully competitive, it can be inferred that the NOW accounts face a less competitive environment than MMDAs.

An equivalent concept of duration is used also by O'Brien (2000), who points out that the Cox et al. (1979) concept of duration can be viewed as the maturity of a zero-coupon bond with the same interest rate elasticity as the deposit value. He presents his duration results under symmetric and asymmetric adjustment of deposit rates to market rate changes and shows also how a given market rate shock affects the estimates. The results indicate that under fixed deposit balances and asymmetric adjustment, the duration for NOW accounts ranges from -0.70 to 1.28 years, depending on the interest rate shock assumed. The shocks

[2] The measure is not the same as Macaulay duration, since it is not based on permanent market rate shocks and parallel shifts in the yield curve. For more information on the subject see Cox et al. (1979). Moreover, Hutchison and Pennacchi (1996) state that theories of term structure of interest rates, which provide the basis for interest rate risk measures such as Macaulay duration, assume that security prices are determined in perfectly competitive markets. They also argue that this competitive market paradigm is less defensible for many financial instruments, e.g. demand deposits.

concerned are from -300 to +300 bps with 50 bps intervals, where the smallest duration is assigned to the largest negative and the greatest duration to the largest positive shock. Under symmetric adjustment, the duration estimates range from 0.14 to 0.19 years. The MMDA durations range from -0.17 to 0.64 years under asymmetric adjustment and from 0.13 to 0.17 under symmetric adjustment. Comparing to the results of Hutchison and Pennacchi (1996), these NOW account and MMDA duration estimates are fairly small. O'Brien also covers the hedging of deposit interest rate risk and states that the interest rate risk of deposit values will be hedged if the bank's assets have the same durations as that for the deposit liabilities for a given market rate shock. However, O'Brien also emphasizes that those short-term assets hedging changes in deposit values will not hedge cash flow uncertainty associated with deposits.

In addition to duration, O'Brien (2000) uses another measure for interest rate risk, which is the deposit value's interest rate sensitivity. This measure is defined as the percentage change in the deposit liability value due to a given market rate shock. It is reasonable to calculate interest rate sensitivity measures for the deposit rents as well, as they can reveal important information about the dynamics of rent forecasts in the presence of stochastic interest rates. Again, O'Brien reports his results considering multiple scenarios for deposit balance dynamics, deposit rate adjustments, and interest rate shocks. He finds that under fixed deposits, asymmetric deposit rate adjustment, and positive market rate shocks the median interest rate sensitivity of NOW accounts ranges between -0.97 and -0.82 percentage points, depending on the interest rate shock assumed (from +50 to +300 bps with 50 bps intervals) so that the smallest value is affiliated with the largest shock. The respective range for MMDAs is from -0.56 to -0.42 percentage points. Other things being equal but under symmetric adjustment, the interest rate sensitivity for NOW accounts (MMDAs) ranges from -0.18 to -0.16 (from -0.16 to -0.15) percentage points. As these results indicate, the interest rate risk of deposits depends heavily on the assumption of deposit rate adjustment to market rate shocks. Also, because the range of the results is wider in the case of asymmetric adjustment, it can be concluded that interest rate risk increases with bank market power.

Dewachter et al. (2006) use a similar sensitivity measure for interest rate risk as O'Brien (2000). They present their results for different servicing cost-decay rate combinations and find that the average interest rate sensitivity for Belgian banks' savings deposits ranges from -3.77 % to -3.18 %. For a base case (servicing cost 0 % and decay rate 15 %), the bank-specific interest rate elasticity ranges from -3.95 % to -3.54 %, whereas the average for the sample is -3.77 %. These results should be interpreted so that deposit liability (rent) values depreciate (appreciate) when market rates increase. Dewachter et al. also point out that the precise hedging characteristics depend on the decay rate assumptions and to a large extent on the nature of the assumed interest rate shock, but in general the changes in deposit liability values are likely to offset some of the value losses on the asset side.

Understanding the characteristics of demand deposits' interest rate risk is also essential for bank regulators and supervisors. Dewachter et al. (2006) analyze the treatment of demand deposits under the International Financial Reporting Standards (IFRS 39 Financial Instruments: Recognition and Measurement) and state that the practice of assuming equality between fair and nominal value of demand deposits can be problematic. This relationship is quite controversial, because it is inconsistent with banks' actual risk management practices and implies that demand deposits' fair values are completely insensitive to interest rate changes.

Entrop et al. (2009) study the robustness of the standardized framework proposed by the Basel Committee on Banking Supervision (2004) to quantify the interest rate risk of banks. The committee suggests calculating the interest rate risk on the basis of time bands, which show the outstanding amount of interest rate sensitive assets and liabilities broken down by their remaining time to maturity or re-pricing period. The suggested treatment for demand deposits is that these positions should be slotted into the time bands according to the guidance of national supervisors, but so that their assumed economic maturity does not exceed 5 years. Next, a measure for interest rate risk is calculated using modified durations assigned to each time band (assuming a yield of 5 %). Entrop et al. generalize this framework and study how the estimated level of interest rate risk changes if the assumptions of the standardized framework are violated. Their results indicate that interest rate risk estimates under the framework are very sensitive to its assumptions and therefore they should be treated with caution when used for supervisory and risk management purposes.

2.5. Deposit Balance Dynamics

It is essential to accurately understand the deposit balance dynamics in order to reliably estimate the value and interest rate risk of demand deposits. Often changes in DDA balances can be seen as stochastic from the bank's point of view and, according to Jarrow and van

Deventer (1998), this stochastic growth is a major confounding factor in the valuation of deposits. A standard assumption in the research focusing on valuation of deposit rents and estimating their interest rate risk is that deposit balances remain constant through time (Hutchison and Pennacchi, 1996; and O'Brien, 2000). This makes interpretation of the results straightforward, but may be an oversimplifying assumption on the other hand. Dewachter et al. (2006) tackle this problem by presenting their results for a range of plausible, constant, annual deposit balance decay rates. Furthermore, they state that the valuation of both current and expected future deposits is a more challenging exercise, because it is difficult to forecast the future demand for deposits.

Many factors play a role in determining the dynamics of deposit balances and several issues have to be taken into account when estimating their future fluctuations. In practice, the key issue is to identify the variables that significantly affect the demand for deposits. Even though the focus in Hutchison and Pennacchi (1996) is in measuring deposit rents and interest rate risk under constant deposit balances, their analysis does cover the estimation of retail deposit demand function. Their model defines the quantity of retail deposits demanded as a function of short-term market rate, deposit interest rate set by the bank, and a set of other variables that reflect the local market conditions. However, for analytical simplicity they leave the variables measuring local market conditions out of their analysis. O'Brien (2000) extends the analysis by Hutchison and Pennacchi by taking into account other factors in determining the demand for demand deposits. He models bank deposit balances by autoregressive processes that are assumed to satisfy a household desired balances equation such as used in money demand equations. In addition to a lagged balance variable, his autoregressive model contains one variable for the spread between market rate and deposit rate and another to measure the bank's income. O'Brien points out that using this autoregressive demand function for deposits, the predicted deposit growth is high, which greatly increases longer-term rents.

The deposit demand specification presented in O'Brien (2000) is not based on any theoretical model and Nyström (2008) makes an attempt to overcome this challenge by developing a framework under which deposit volumes are modeled in a theoretically sound way. His framework focuses on the behavior of depositors and the model for deposit demand takes into account the market rate, the deposit rates, and several customer processes. These processes are (i) the total volume deposited in a transactions account, (ii) the total volume deposited in a savings account, and (iii) how a customer divides the volume deposited in savings accounts into different accounts. The last of these processes addresses the question of internal migrations of savings accounts' volumes.

Another important issue to consider in determining dynamics for deposit balances is macroeconomic risk. This issue is examined in Levy-Yeyati et al. (2010). They argue that depositors seem responsive to macroeconomic risk in a broader sense than that often considered by the literature and during crises it becomes more important determinant of deposit demand than traditional bank-specific characteristics. Also, differences in deposit withdrawals across banks can be explained by their different exposures to macroeconomic factors. Levy-Yeyati et al. use two variables to describe macroeconomic risk, one variable for country risk and one for exchange rate risk.[3] However, they also highlight that during favorable times, macroeconomic factors are mostly insignificant in explaining depositor behavior.

Bank runs are a particular case of interest in examining the dynamics of deposits balances. A bank run takes place when all depositors panic and withdraw their deposits simultaneously, including even those who would prefer to leave their deposits in the bank if they were not concerned about the bank failing (Diamond and Dybvig, 1983). Chari and Jagannathan (1988) agree that this kind of contagion effect, where general public's observations of large withdrawals from the banking system result in even larger withdrawals of deposits, can be viewed as a trigger for bank runs. However, their model also presents two alternative reasons for deposit withdrawals. First, they argue that withdrawals occur when some of the depositors get adverse information about the prospects of the bank. In this case, also the uninformed depositors may observe this and thus have an incentive to liquidate their deposits. Second, Chari and Jagannathan state that some individuals need to withdraw their deposits for other than information-based reasons, for example if they are simply in need for liquidity. Thus, if by chance a large group of such depositors withdraw their deposits simultaneously, then the uninformed depositors will be misled causing an increasing probability of a bank run. Carmona (2007) argues in same vein and also points out that bank runs occur because both banks and depositors are illiquid.

[3] Levy-Yeyati et al. (2010) use data from Argentina and Uruguay. They measure country risk by the spread on Argentine and Uruguayan sovereign bonds over comparable U.S. bonds. Exchange rate risk is measured by the 12-month forward exchange rate relative to the spot exchange rate for Argentina. For Uruguay, they use the spread of the average interest rate on peso time deposits relative to the rate on similar U.S. dollar deposits.

Another plausible reason for bank runs is presented in Goldstein and Pauzner (2005), as they argue that the maturity mismatch between a bank's assets and liabilities may expose it to the possibility of panic-based bank runs. They point out that even though the seminal, equilibrium-based, model by Diamond and Dybvig (1983) shows that the demand deposit contracts the banks offer expose them to bank runs, it is not able to provide tools to predict which equilibrium occurs and how likely each of them is. Goldstein and Pauzner address this issue by developing a modified version of the Diamond-Dybvig model, in which the fundamentals of economy determine the probability of a bank run. They find that the probability depends on the contract offered by the bank, i.e. banks become more vulnerable to runs when they offer more risk sharing.[4]

An essential concept related to bank runs is asset fire sales, which means that a bank must liquidate some of its illiquid assets at a loss. A part of the deposits taken by a bank has to be kept in a very liquid form, since withdrawals of demand deposits are stochastic from a bank's point of view, which indicates that they cannot be forecasted accurately. As stated in Franck and Krausz (2007), it is possible that at a given point in time, the bank's liquid reserves do not cover the depositors' desired withdrawals and under such circumstances asset fire sales are likely to take place. Furthermore, a distressed bank may be forced to liquidate all of its assets even if not all depositors withdraw, because the assets are sold at discounted prices (Diamond and Dybvig, 1983). Another feature of the asset fire sale process is that it is self-reinforcing, as pointed out by French et al. (2010). They state that if a bank is forced to sell its assets at fire sale prices, other banks may have to revalue their assets at these temporarily low market values as well. In other words, one distressed bank can cause problems to many others and, thus, reduce the financial system's capacity to bear risk and make loans.

[4] Risk sharing is basically a transfer of wealth from patient agents to impatient agents. Impatient agents can consume only in period 1 , whereas patient agents can consume either in period 1 or period 2 (the model assumes three periods: 0, 1, and 2). (Goldstein and Pauzner, 2005)

3. METHODOLOGY

This chapter discusses the methodological issues related to this thesis. There are three important papers that form the basis for the methodology used here: Hutchison and Pennacchi (1996), O'Brien (2000), and Dewachter et al. (2006). The issues discussed in this chapter include the general theoretical model, Monte Carlo simulation, autoregressive processes, and stochastic processes. All the aforementioned jointly constitute the methodological foundation of this thesis.

3.1. The General Model

The basis of the methodology used in this thesis is the equilibrium-based model of bank's profit maximization introduced in Hutchison and Pennacchi (1996). This model is founded on the assumption that banks operating in DDA markets face imperfect competition, and thus exercise market power. The market power of banks can be inferred from the fact that they are able to set their deposit rates below market rates so that their profits are maximized. Banks are assumed to know the deposit demand function they face, since otherwise they would not be able to set the deposit rate at the profit maximizing level. Under the model, the demand function for demand deposits is given by

$$D(t) = D(r(t), r_d(t), x(t)), \tag{1}$$

where $D(t)$ is the quantity of deposits demanded, $r(t)$ is the short term market rate, $r_d(t)$ is the deposit interest rate set by the bank, and $x(t)$ is a vector of other variables affecting the demand for deposits at date t. Due to analytical simplicity, Hutchison and Pennacchi leave $x(t)$ out of their analysis. However, the assumption in this thesis is that several variables concerning market concentration and macroeconomic conditions play a role in determining the demand function for deposits. Moreover, there is a multicollinearity problem associated with the demand function when both the market rate and the deposit rate are included in the same equation and demand function is estimated using OLS regression. Therefore, instead of using the two interest rates independently, I follow the work of O'Brien (2000) and use the spread between them ($r(t)$ - $r_d(t)$) in my analysis. Hence, by using the spread Equation (1) can be expressed as follows:

$$D(t) = D[(r(t) - r_d(t)), x(t)]. \tag{2}$$

The next step in the model is to define the optimization problem a bank faces under the assumption that the demand function for deposits is given by Equation (2). If it is further assumed that the bank can invest its deposits at the market rate, $r(t)$, then at each time point the bank sets $r_d(t)$ as the value that maximizes the following equation:

$$\max_{r_d(t)} [(r(t) - r_d(t)) - c(t)]D(t), \tag{3}$$

where $c(t)$ denotes the noninterest cost of accepting demand deposits. These noninterest costs are typically payment intermediation fees, the role of which has dramatically declined since the adaption of internet-based payment services. Because of this marginal role of $c(t)$, it is assumed to be zero throughout the analysis. The solution, i.e. the profit maximizing spread between market rate and deposit rate, to Equation (3) is given by

$$(r(t) - r_d(t))^* = -c(t) - D/(\partial D/\partial(r - r_d)). \tag{4}$$

If the DDA market is fully competitive, i.e. $\partial D / \partial(r - r_d) = \infty$, the optimal spread would be zero and, thus, the optimal deposit rate would equal the market rate. In the presence of bank market power the demand for DDAs is not perfectly elastic and therefore the spread between the market rate and the deposit rate will be positive, indicating that the deposit rate is set below the market rate.

After the profit maximizing spread between the market rate and deposit rate has been determined, the next step is to calculate the cash flows a bank receives from its deposits at some given time point. These cash flows represent the bank's monthly DDA rents expressed in monetary terms. Given that the bank is able to invest its proceeds at the short-term market interest rate, $r(t)$, this monthly rent is denoted by $f(r(t),x(t))$ and given by

$$f(r(t), x(t)) = [(r(t) - r_d(t))^* - c(t)]D(t), \tag{5}$$

where $(r(t) - r_d(t))^*$ is the optimal spread between market rate and deposit rate set by the bank.

The next step in my analysis is to estimate the future monthly values for $f(r(t),x(t))$ (i.e. monthly rents) using Monte Carlo simulation and a 40-year simulation horizon. After that, the present value of future monthly rents (P_0) is calculated using the corresponding simulated value of short-term market rate as a discount rate with each observation. The final DDA rent estimates examined in this thesis are expressed as percentages of initial deposit balance, and this estimate is obtained by dividing the present value of future monthly rents by the DDA balance at t = 0 (P_0/D_0). Finally, after the rent estimates are obtained, DDA liability values (L_0/D_0) are calculated simply by subtracting the rent estimate from the nominal value of DDAs.

After the rent and liability values are estimated for decaying, constant, and growing deposit balances, the associated interest rate risk is quantified. Interest rate risk of DDAs is measured by the sensitivity of rent and liability estimates to changes in the short-term market rate. To be more precise, +100 and +200 bps shocks are artificially placed to the first simulated observation for the market rate and the resulting changes in the rent and liability estimates are calculated. These changes in rent ($\Delta P_0/D_0$) and liability ($\Delta L_0/D_0$) estimates, measured as percentages, serve as DDAs' interest rate risk estimates.

3.2. Dynamics of Macroeconomic Variables and Deposit Balances

The dynamics of the macroeconomic variables, market concentration variables, and growing deposit balances are modeled as autoregressive processes, as is also done in, e.g., O'Brien (2000). In this section, I present the principles of autoregressive models following the manner of representation in Brooks (2008). As stated by him, an autoregressive model is one where the current value of a variable, y, depends upon only the values that the variable took in previous periods plus an error term. In general, an autoregressive process of order p is denoted as AR(p) and expressed as

$$y_t = \mu + \sum_{i=1}^{p} \phi_i y_{t-i} + u_t, \tag{6}$$

where μ is a constant and u_t is a white noise error term. Autoregressive models can be further expanded to autoregressive moving average models, denoted by ARMA(p,q), where p is the order of autoregressive and q the order of moving average part of the model. An ARMA(p,q) model is expressed as follows:

$$y_t = \mu + \sum_{i=1}^{p} \phi_i y_{t-i} + \sum_{i=1}^{q} \theta_i u_{t-i} + u_t. \tag{7}$$

In the equation presented, the autoregressive part is similar to that presented in Equation (6). The latter part, i.e. the moving average part, of the equation takes into account the development of the white noise term so that the current value of y_t depends also on the previous values of that term. So, under an ARMA(p,q) process, which is a combination of AR(p) and MA(q) processes, the current value of y_t depends on (i) a constant, (ii) the previous values of y, (iii) the previous values of white noise term, and (iv) the current value of the white noise term.

Stationarity of a series is a desired property when modeling a variable as an autoregressive process. If a non-stationary series is modeled with such a process, it has to be differenced one or more times before the model construction. A non-stationary series (y) is said to be integrated of order d, denoted as $y_t \sim \mathrm{I}(d)$, if it has to be differenced d times before achieving stationarity. An ARIMA(p,d,q) model, where *I* stands for *integrated*, takes into account the problems associated with non-stationary time series. Moreover, it is also relevant to point out that an ARMA(p,q) model for a series differenced d times is equivalent to an ARIMA(p,d,q) model on the original data. For further information concerning ARIMA modeling of non-stationary series, see Chapters 5 and 7 of Brooks (2008).

Most of the variables' historical data series studied in this thesis are characterized by non-stationarity, which suggests that they should be modeled as ARIMA processes. To be more precise, these variables are modeled as ARIMA(2,1,0) processes, which is the same as an AR(2) process for a series that is differenced once. Following Equation (6), an AR(2) process for a variable y is given by

$$y_t = \mu + \phi_1 y_{t-1} + \phi_2 y_{t-2} + u_t. \tag{8}$$

In order the keep the analysis clear, I use the same process for every variable rather than building different ARIMA models for each of them. Moreover, after the autoregressive models are estimated in a sound manner, they can be used for forecasting purposes as well, as is done in this thesis.

3.3. Dynamics of the Short-Term Market Rate

As discussed in the literature review, there are several different models for estimating the dynamics of a short-term market rate. These can be divided into one-factor and multi-factor models, and traditionally the former class of models has been more popular in the research concerning deposit valuation and risk management. In particular, one-factor models are used in Hutchison and Pennacchi (1996) and O'Brien (2000), where the former uses Vasicek and the latter Cox-Ingersoll-Ross model. A multi-factor approach is used in Dewachter et al. (2006), as they propose a multi-factor joint yield curve deposit rate model, in which bank deposit rates depend on both term structure and a deposit spread factor.

According to established practice in the literature I use a one-factor model to estimate the dynamics of the short-term market rate. More specifically, the Cox-Ingersoll-Ross model is used for that purpose. The main disadvantage of the seminal Vasicek model is that the interest rate process can obtain negative values, but this problem is taken into account in the Cox-Ingersoll-Ross model so that the shock term of the model is conditional on the preceding level of the variable. In practice, it means that the closer the variable's level is to zero, the less significant the subsequent shock effect is. If the variable achieves the value of zero, the next shock has no effect on the process, and the drift term of the process forces the next observation to be above zero. A discrete time version of the Cox-Ingersoll-Ross model is given by the following equation:

$$r_t = r_{t-1} + \kappa(\theta - r_{t-1})\Delta t + \sigma\sqrt{r_{t-1}}\sqrt{\Delta t}\, z_t, \tag{9}$$

where r is the short-term interest rate, $\kappa(\theta - r_{t-1})$ is the drift factor that ensures the mean reversion of the process towards its long-term mean θ, σ is the volatility of interest rate changes that is conditional on the square root of the variable's preceding value, and z_t is a normally distributed and stochastic Wiener process. In this thesis, I use monthly data and the volatility estimates are, thus, also monthly. This means that Δt equals 1, and the model becomes more straightforward.

Moreover, when the positive interest rate shocks are generated to the process, they are assumed to occur at the first simulated observation, i.e. the first month of the simulation horizon. This means that that at $t = 1$ Equation (9) is modified as follows:

$$r_1 = r_0 + \kappa(\theta - r_0)\Delta t + \sigma\sqrt{r_0}\sqrt{\Delta t}\, z_1 + S_1, \tag{10}$$

where S_1 denotes a +100 or +200 bps shock. Naturally, there are no shocks generated to subsequent observations, i.e. S_t equals zero for $t > 1$. Because of the mean-reverting nature of a Cox-Ingersoll-Ross process these artificially generated shocks will not last infinitely, which means that they will gradually die out during the following observations. The time it takes for the shock to vanish depends on the starting level of the process (r_0), the volatility of the interest rate (σ), and the drift factor. Only temporary (yield curve slope) shocks are considered in this thesis, but Equation (10) could be easily modified to take into account permanent (yield curve level) shocks as well, by assuming that S_t remains at the level of either +100 or +200 bps for $t = \{1, \ldots, N\}$, where N is the last observation considered.

4. DATA AND VARIABLES

This chapter presents the data and variables used in this thesis. The range for historical data needed varies, but in most cases it is from January 2006 to December 2010, totaling 60 monthly observations. There are four categories to which the data are divided, which are (i) interest rates, (ii) demand deposit balances, (iii) macroeconomic data, and (iv) market concentration data. Next, I will first briefly introduce the data and variables according to this division, and in the end of this chapter some relevant summary statistics of all the variables are presented.

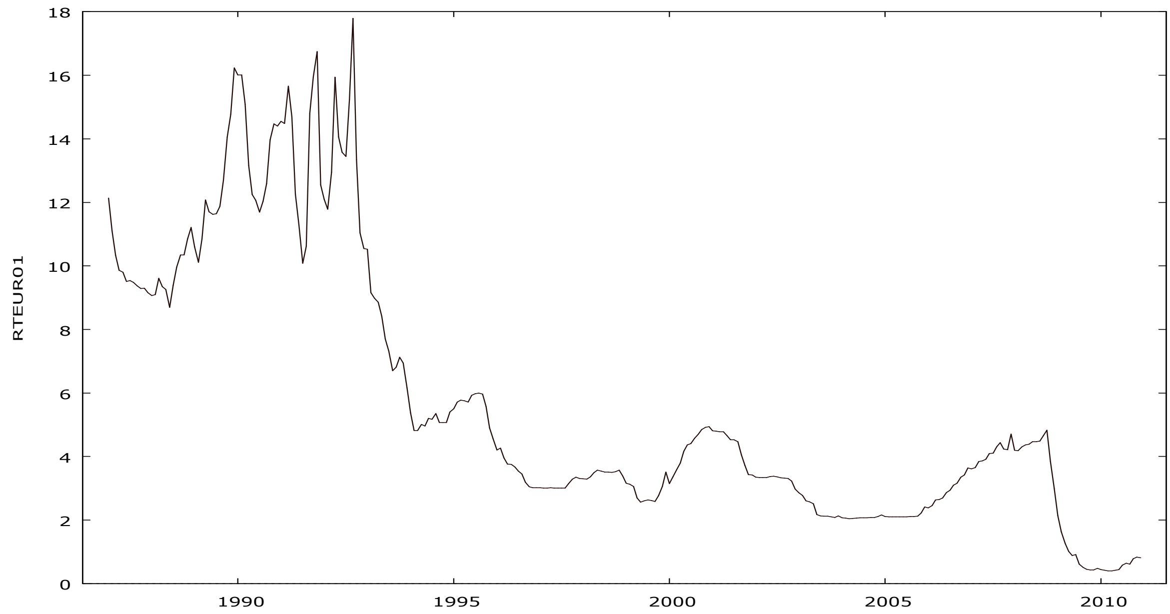
4.1. Interest Rates

There are three key series of interest rate data needed in the analysis. These are the short-term market interest rate, case bank's DDA rate, and the average DDA rate in the Finnish banking sector. Next, the interest rate data is described and the exact variables are presented after that.

A one month Euribor is used as a short-term market rate here, and its historical data, ranging from January 1987 to December 2010, was obtained from the database of Bank of Finland. These monthly observations are average monthly rates within a given month. It is also worth noticing that due to the introduction of Euribor rates in the beginning of 1999, the dataset actually consists of two interest rates, namely one month Helibor (January 1987-December 1998) and one month Euribor (January 1999-December 2010). As will be discussed later in this thesis, a long series of historical data was needed for the market rate, because of the parameter estimation process of the Cox-Ingersoll-Ross model. The variable constructed based on this data, RTEUR01, consists of observations between January 2006 and December 2010. The complete series of one month Helibor/Euribor observations is presented in Figure 1.

Figure 1: Historical development of one month Helibor/Euribor interest rate

This figure presents the historical development of one month Helibor/Euribor interest rate. The data from January 1987 to December 1998 is for Helibor rate and from January 1999 to December 2010 for Euribor rate. Date (month/year) is presented in the X-axis and the interest rate in percentages in Y-axis.



The data for case bank specific DDA interest rates spans from January 2006 to December 2010 and it was kindly provided by the case bank. Obtaining single monthly deposit rate observations was not as straightforward as in the case of market rate and, hence, some refinement of the data was needed. Challenges arise because the changes in deposit rates are largely discrete, which means that they are not constantly revised with respect to changes in the market rate[5] and there are several different types of demand deposit accounts provided by the case bank. In order to overcome this challenge, I use the average monthly rates based on the individual rates of all different DDAs.[6] Moreover, there are two variables constructed based on the case bank's DDA rate data, which are RDT and RSPREAD. The former of these

[5] Often the deposit rate remains constant for a somewhat long period and then it is suddenly revised upwards or downwards. For example, the deposit rate can remain at, say, 2.00 % between dates t and $t + n$, and then increase to 2.20 % at date $t + n + 1$.

[6] To further illustrate how each single monthly deposit rate observation is obtained, the following representation may prove to be useful. Consider that there are N different types of demand deposit accounts denoted by 1, 2, …, N, and the interest rates paid for each of these account types are denoted by X_1, X_2, …, X_N, respectively. The first step is to obtain the average monthly deposit rates for each of these account types. This is simply done by summing all the daily observations of deposit rates within a given month, and then dividing it by the number of observations. These account type specific average deposit rates are denoted by μ_1, μ_2, …, μ_N. The final step in obtaining the average deposit rate for each month is to sum all the μ_i's and divide this sum by N.

consists simply of average monthly deposit rate observations, whereas the latter is defined as RTEUR01 minus RDT.

The last of the interest rate data series needed is for the average DDA rate within the whole Finnish banking sector. This data also ranges from January 2006 to December 2010 and it was obtained from the Bank of Finland’s database. However, the deposit rate data was only available separately for deposits made by households and corporate customers and, thus, in order to construct a single series of deposit rate observations the average of the household and corporate rates was calculated. This series of average rates is then used to construct the sector’s DDA rate variable, MFIRDT. Moreover, a spread variable defined as RTEUR01 minus MFIRDT is also constructed and denoted by MFIRSPREAD.

Figures 2 and 3 present the historical development of these variables introduced. Figure 2 shows the graph concerning the interest rate variables, i.e. RTEUR01, RDT, and MFIRDT, whereas Figure 3 presents the resulting historical fluctuations in spread variables, i.e. RSPREAD and MFIRSPREAD.

Figure 2: Historical development of interest rate variables

This figure presents the historical development of the interest rate variables used in this thesis. These variables are one month Euribor rate (RTEUR01), case bank's demand deposit rate (RDT), and the average demand deposit rate within the whole Finnish banking sector (MFIRDT). Date (month/year) is presented in the X-axis and the interest rate in percentages in Y-axis.

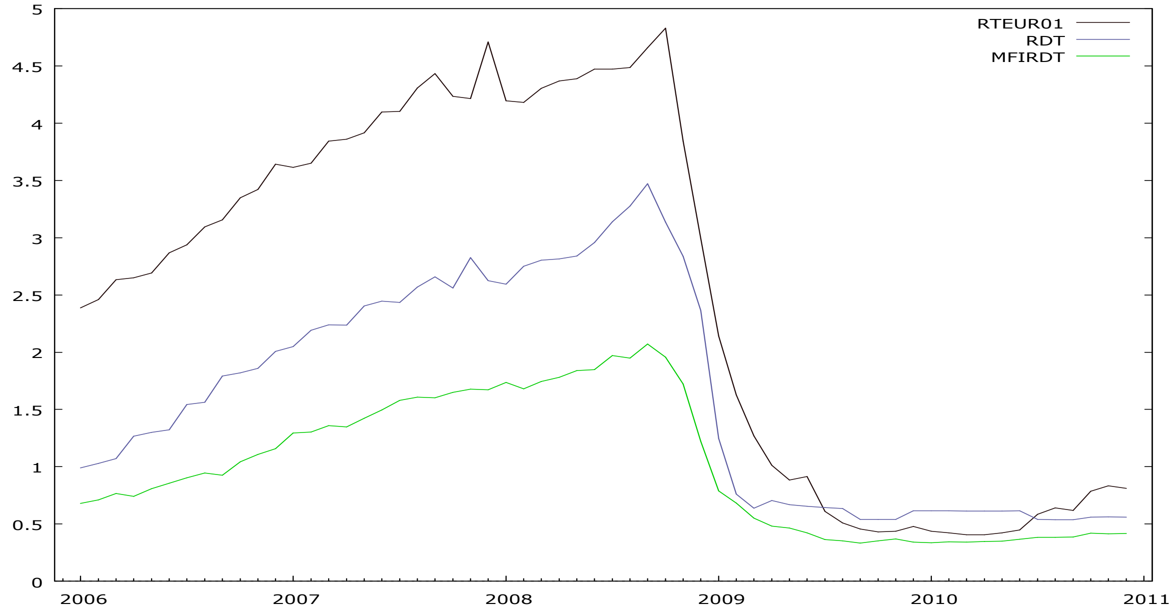
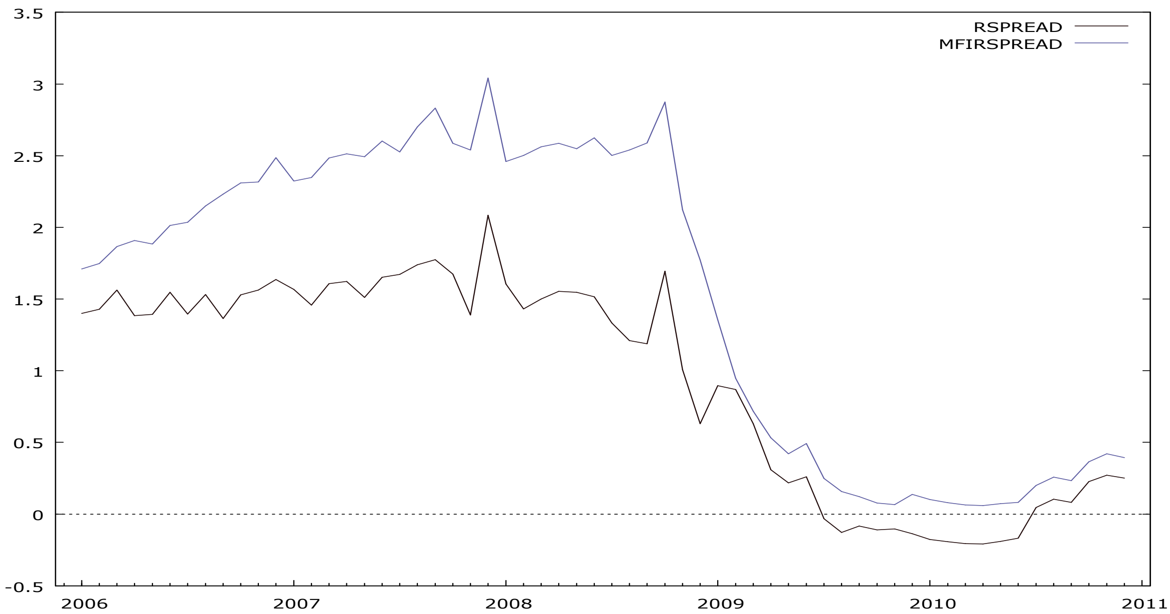


Figure 3: Historical development of interest rate spread variables

This figure presents the historical development of the interest rate spread variables used in this thesis. These variables are the spread between (i) short-term market rate and the case bank's demand deposit rate (RSPREAD) and (ii) short-term market rate and the average demand deposit rate within the Finnish banking sector (MFIRSPREAD). Date (month/year) is presented in the X-axis and the interest rate spread in percentage points in Y-axis.



4.2. Deposit Balances

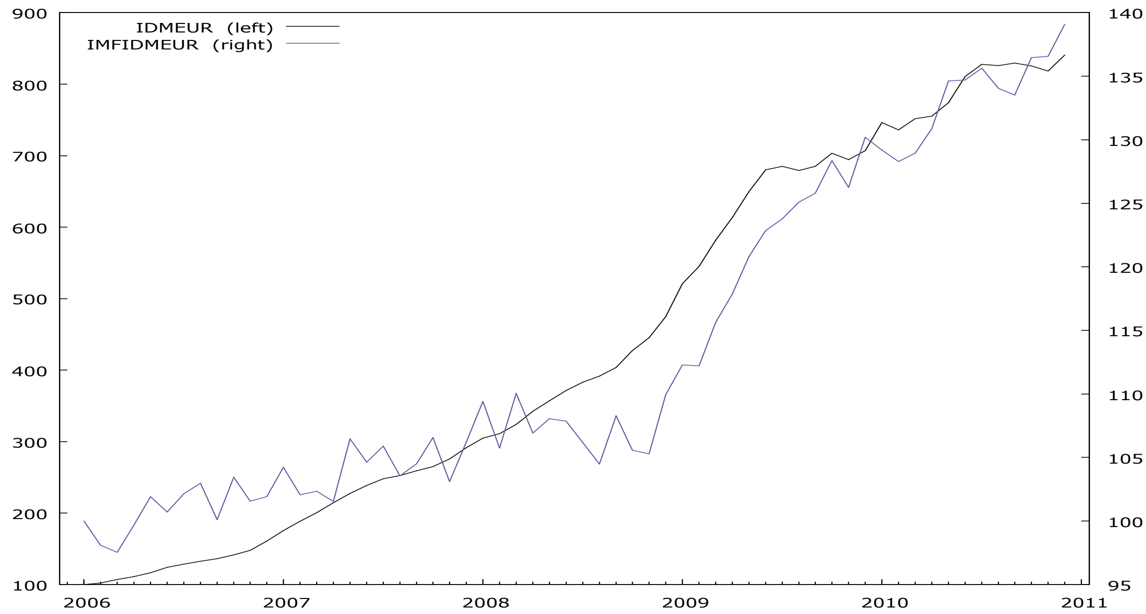
The deposit balance data needed in this thesis consists of monthly DDA balance observations for both the case bank and the whole Finnish banking sector. Both of these historical time series consist of 60 monthly observations between January 2006 and December 2010. Case bank kindly shared its deposit balance data and the sector's aggregate balances were obtained from the database of Bank of Finland. Moreover, since there are several classes of DDAs provided by the case bank, some additional calculations were needed in order to obtain single monthly observations to construct the series. However, this was a straightforward task as it was simply done by summing the individual accounts' average monthly balances. The aggregate balances within the banking sector were readily available as such, thus no further calculations were needed with respect to that data.

A central characteristic of the deposit accounts included in the data is that they should not have any withdrawal constraints. This means, that the depositor is able to withdraw his or her deposits quickly and with no cost at any point in time. In many cases, DDAs can also have bank card contracts attached to them, allowing the depositor to charge the account without ever actually withdrawing the money. Keeping these desired characteristics of demand deposits in mind, there is mainly one class of deposits left out from this analysis, which are term deposits. According to a term deposit contract, the depositor agrees to keep the deposit in the account for a predetermined time. Some contracts may allow an early withdrawal, but there is usually a significant fee charged in that case. In return for these withdrawal constraints, term deposits receive higher interest rates than DDAs.

Two variables were constructed based on the deposit balance data, namely DMEUR and MFIDMEUR. The former is the DDA balance in the case bank, whereas the latter is the aggregate balance in all Finnish banks. The observations in both these variables are expressed in millions of euros. Because the case bank's share of the total DDAs in the sector is fairly small (the mean between January 2006 and December 2010 being 0.83 %), it is reasonable to compare their relative developments during the sample period. Figure 4 shows the historical development of DMEUR and MFIDMEUR so that their indexed levels are presented. For both variables, the balance level of January 2006 is defined as 100. These relative balances are denoted as IDMEUR and IMFIDMEUR, *I* standing for *indexed*.

Figure 4: Relative historical development of deposit balance variables

This figure presents the relative historical development of the two deposit balance variables used in this thesis. These variables are the aggregate demand deposit balances (i) in the case bank (DMEUR) and (ii) in all Finnish banks (MFIDMEUR). Their relative development is presented by their indexed levels, IDMEUR and IMFIDMEUR, where *I* stands for *indexed*. The first observation (January 2006) is used as a base observation, thus assigned a value of 100. Date (month/year) is presented in the X-axis and the indexed deposit balance levels on the two Y-axes.



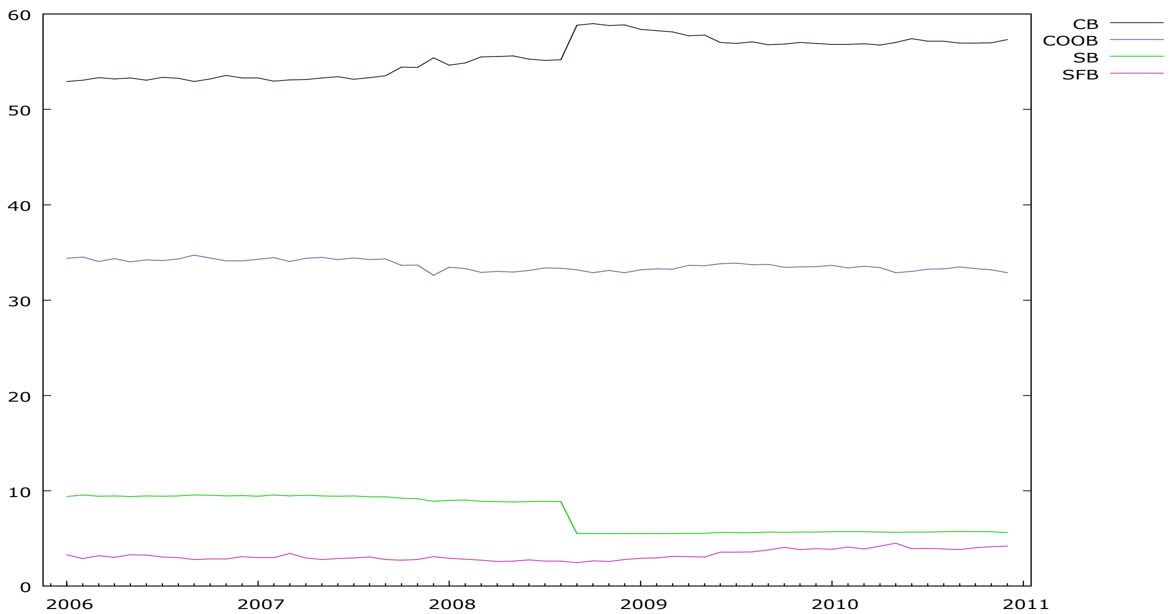
4.3. Macroeconomic Risk and Market Concentration

There are three types of macroeconomic data used in this thesis. These are data on (i) unemployment rate, (ii) economic output, and (iii) consumer prices. The unemployment rate takes into account Finnish citizens in the age group of 15-74 and is defined as the proportion of unemployed job applicants to the whole population. This data was obtained from Bank of Finland’s database. An index that measures the cycles in output levels is used to describe the overall economic condition in Finland. This can also be viewed as a proxy for population’s income, and the advantage of the output cycle index over data on income levels is that there is monthly data available on the output cycle index, whereas the income data is provided on a quarterly basis. The data for economic output cycle index was obtained from the database of Statistics Finland. Consumer prices, which can be considered to reflect inflation rate, are presented by the Finnish consumer price index. The index describes the price development of goods and services purchased by Finnish households. It is calculated so that the prices of different products are first weighted with their respective consumption shares and then these weighted prices are summed. The consumer price index data was obtained from Statistics Finland as well. All these three aforementioned macroeconomic data series span from January 2006 to December 2010.

Market concentration data consists of DDA market shares of different types of Finnish banks.[7] The market share of a given bank type is given as the amount of DDAs in banks of this particular type relative to all DDAs in all Finnish banks. This market share data was obtained from Bank of Finland and it spans from January 2006 to December 2010. This bank type specific DDA market share data is presented in Figure 5.

Figure 5: Deposit market shares by bank type

This figure presents the bank type specific market shares in the Finnish demand deposit market. Market share is defined as the total demand deposit balance in banks of a given type divided by the total balance of demand deposits in all Finnish banks. CB, COOB, SB, and SFB stand for commercial banks, co-operative banks, savings banks, and subsidiaries of foreign banks, respectively. Date (month/year) is presented in the X-axis and market shares as percentages in the Y-axis.



Four variables are constructed based on the macroeconomic and market concentration data. These are the unemployment rate (UNEMP), an index describing the cycles in economic output (OUTPUT), consumer price index (CPI), and Herfindahl-Hirschman index (HHI).

[7] These bank types are co-operative banks, savings banks, commercial banks, and subsidiaries of foreign banks.

Moreover, a dummy variable for low competition in the banking sector (LCD) is constructed as well. UNEMP, OUTPUT, and CPI are constructed simply by using their historical data as such, which means that UNEMP is presented in percentages, and OUTPUT and CPI in form of index values. The base year in the OUTPUT series is 2000 and in the CPI series 2005, i.e. these observations are assigned a value of 100. The construction of HHI, however, needed some additional calculations. It was obtained by summing the squared market shares of the four bank types. So, the possible range of values for the HHI spans from 2,500 to 10,000.[8] Moreover, the low competition dummy variable, LCD, obtains a value of 1 (0) if the observed level of HHI is greater (less) than the sample median HHI. The procedure for constructing HHI and, further, LCD follows the work of Kano et al. (2006).

The historical development of the variables UNEMP, OUTPUT, CPI, and HHI is presented in Figure 6. As shown in the figure, the historical development of HHI has a clear upward trend. Therefore, roughly speaking the first half of LCD observations are assigned a value of zero, whereas the latter half receives a value of one. This is also shown in Figure 7.

[8] In the case when all the bank types have equal 25 % market shares (i.e. the market concentration is as low as possible) the value for HHI is given by $25^2 + 25^2 + 25^2 + 25^2 = 2{,}500$. If, on the other hand, the situation is such that one bank type dominates the market and has a 100 % market share whereas the others have a share of 0 %, HHI is given by $0^2 + 0^2 + 0^2 + 100^2 = 10{,}000$. Naturally, this kind of situation would indicate the highest possible market concentration.

Figure 6: Historical development of macroeconomic and market concentration variables

This figure presents the historical development of the macroeconomic and market concentration variables used in this thesis. These variables are the Finnish unemployment rate (UNEMP), an index describing the cycles in the economic output of Finland (OUTPUT), Finnish consumer price index (CPI), and the Herfindahl-Hirschman index measuring the banking sector concentration in Finland (HHI). In all graphs, date (month/year) is presented in the X-axis. In the graph for UNEMP, the unemployment rate in percentages is presented in Y-axis, whereas the index values are presented in Y-axis in the graphs for OUTPUT, CPI, and HHI. The base year for the OUTPUT series is 2000 and for CPI series 2005. HHI series has no base year, and the possible values it can receive range from 2,500 to 10,000. The larger (smaller) the value of HHI is, the more (less) concentrated the demand deposit market is.

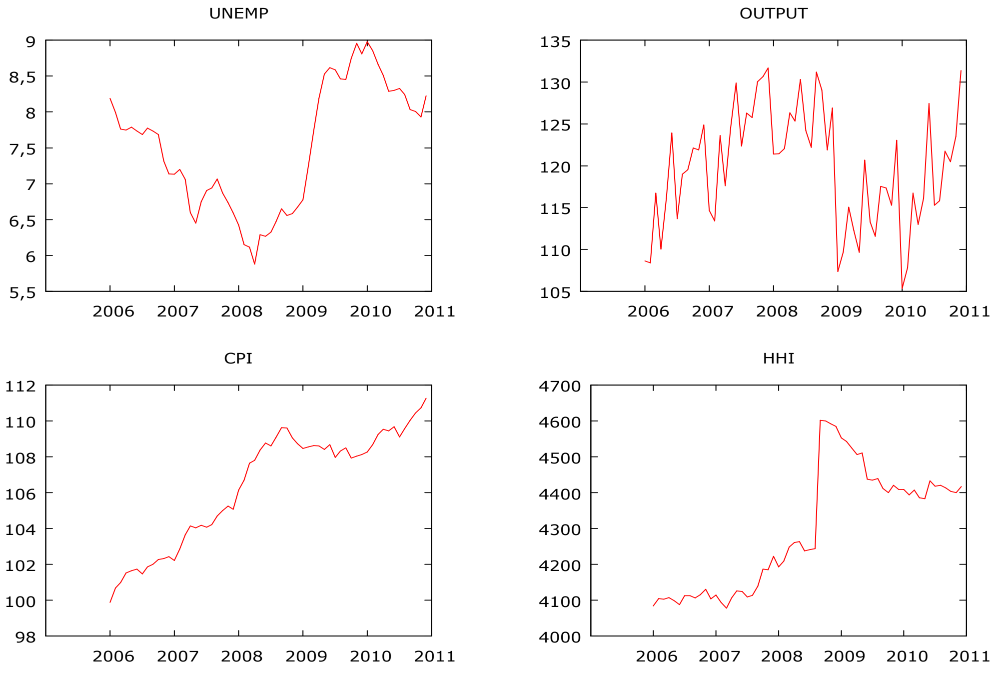
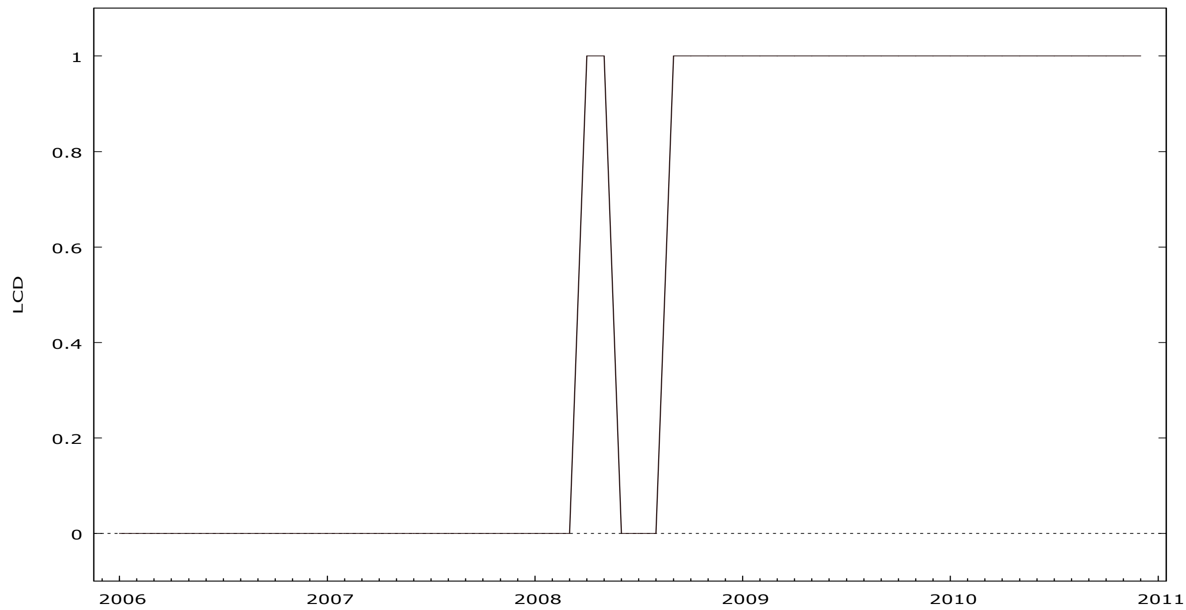


Figure 7: Historical development of low competition dummy variable

This figure presents the historical values for the low competition dummy variable (LCD). It is constructed based on the values of Herfindahl-Hirschman index (HHI) so that if the observed value for HHI is greater (less) than the sample median HHI, then LCD receives a value of 1 (0). Date (month/year) is presented in the X-axis and the LCD value in the Y-axis.



4.4. Summary of the Variables

In this section, I present the summary statistics concerning all the variables used in this thesis. These statistics presented are the number of observations in the sample (*N*), mean, median, 1st and 9th deciles, minimum, maximum, standard deviation, standard error, skewness, and excess kurtosis. The last two of these measures, skewness and excess kurtosis, describe the shape of the variable's probability distribution.[9] The summary statistics are presented in Table 1 and the correlation matrix between the variables in Table 2.

[9] To be more precise, skewness and excess kurtosis measure the distribution's deviation from normal distribution. Skewness measures the symmetry of a distribution on both sides of its mean value and excess kurtosis tells how "fat" the distribution's tails are. In the case of normal distribution, both skewness and excess kurtosis are zero. Excess kurtosis is sometimes reported as plain kurtosis, in which case a normal distribution is defined to have a kurtosis value of 3.

Table 1: Variables' summary statistics

This table presents the summary statistics of all the variables used in this thesis, with two exceptions. Low competition dummy (LCD) is left out because these statistics are not applicable to dummy variables. Case bank's deposit balance variable (DMEUR) is also excluded due to data confidentiality reasons. *N* denotes the number of observations in the sample, *s* denotes the sample standard deviation, and *S.E.* denotes the sample standard error (defined as *s* divided by the square root of *N*).

	RTEUR01	RDT	MFIRDT	RSPREAD	MFIRSPREAD	MFIDMEUR	UNEMP	OUTPUT	CPI	HHI
N	60	60	60	60	60	60	60	60	60	60
Mean	2.6	1.6	1.0	0.9	1.5	57,362.2	7.5	119.8	106.4	4,293.5
Median	2.9	1.4	0.9	1.4	2.0	54,253.7	7.7	121.0	108.0	4,254.7
1st decile	0.4	0.6	0.3	-0.1	0.1	51,264.3	6.4	109.7	101.7	4,103.7
9th decile	4.4	2.8	1.8	1.7	2.6	67,750.0	8.6	129.9	109.6	4,526.7
Min	0.4	0.5	0.3	-0.2	0.1	49,281.9	5.9	105.4	99.9	4,078.2
Max	4.8	3.5	2.1	2.1	3.0	70,274.1	9.0	131.7	111.3	4,601.6
s	1.6	1.0	0.6	0.7	1.1	6,466.9	0.9	7.0	3.2	169.4
S.E.	0.2	0.1	0.1	0.1	0.1	834.9	0.1	0.9	0.4	21.9
Skewness	-0.2	0.3	0.3	-0.4	-0.3	0.6	0.0	-0.1	-0.5	0.2
Excess kurtosis	-1.6	-1.5	-1.4	-1.5	-1.6	-1.1	-1.3	-0.9	-1.2	-1.4

As can be seen from the summary statistics, all of the variables' distributions have either positive or negative skewness. Also, all of these distributions have negative excess kurtosis, i.e. a kurtosis of less than 3, indicating that all of them have fat tails. A graphic representation of these distributions is given in Appendix 1.

Table 2: Correlations between variables

This table presents the correlation matrix between the variables used in this thesis, with two exceptions. Low competition dummy (LCD) is left out because it is based on an included variable, Herfindahl-Hirschman index (HHI). Case bank's deposit balance variable (DMEUR) is also excluded due to data confidentiality reasons. These correlations are calculated based on the historical data series of these variables.

	RTEUR01	RDT	MFIRDT	RSPREAD	MFIDMEUR	UNEMP	OUTPUT	CPI	HHI	MFIRSPREAD
RTEUR01	1.0									
RDT	1.0	1.0								
MFIRDT	1.0	1.0	1.0							
RSPREAD	0.9	0.8	0.8	1.0						
MFIDMEUR	-0.8	-0.7	-0.7	-0.9	1.0					
UNEMP	-0.9	-0.9	-0.9	-0.8	0.7	1.0				
OUTPUT	0.6	0.6	0.6	0.4	-0.2	-0.6	1.0			
CPI	-0.4	-0.2	-0.2	-0.7	0.8	0.2	0.1	1.0		
HHI	-0.5	-0.3	-0.3	-0.7	0.6	0.3	-0.1	0.9	1.0	
MFIRSPREAD	1.0	0.9	0.9	1.0	-0.9	-0.9	0.5	-0.6	-0.6	1.0

As expected, the correlations between the interest rate and spread variables are positive and very high, from approximately 0.8 to 1.0. Also the correlations between variables not derived from interest rate data and RTEUR01 are somewhat high, indicating that short-term market rate reflects the state of economy.

5. RESULTS

In this chapter, I present the results obtained in this study thoroughly and analyze the implications of the main results, which consist of DDA rents and interest rate risk estimates. These implications are mostly discussed from the point of view of case bank's risk management practices, but also in a wider context, i.e. from the viewpoint of regulators and the whole banking sector. Moreover, I compare my results to the findings in previous research.

5.1. Deposit Demand Functions

In this section, I introduce the estimated demand functions for DDAs, both from the case bank's and the banking sector's viewpoint. OLS regression is used to estimate these functions. Also, I will discuss the motivation of the variables included in the equations.

An OLS regression model has several desired characteristics which should be examined when modeling with it. Thus, the so called diagnostic tests and their results are also presented in this section. First, I will present the demand function and associated diagnostic tests for the case bank, and after that the same results will be shown from the whole sector's point of view.

5.1.1. Case Bank

The DDA demand function for case bank is estimated using the so called specific-to-general model building approach. In practice, the first step was to include only the constant term and RSPREAD as explanatory variables. After that, one extra variable at a time was added and the model with the highest adjusted R^2 and coefficient t-statistics was picked. Again, new variables were added one by one, as long as the extra variables did not enhance the model. The final regression model for estimating the DDA demand function for the case bank is presented in Table 3.

Table 3: Case bank's deposit demand function

This table presents the estimated OLS regression model, which represents the deposit demand function of the case bank. Heteroscedasticity consistent standard errors are used. */**/*** denotes significance at the 10/5/1 % level.

Dependent variable: DMEUR

	Coefficient	*S.E.*	*t*-ratio	*p*-value	
Constant	536.36	357.92	1.50	0.14	
RSPREAD	-377.39	43.43	-8.69	0.00	***
UNEMP	-69.94	25.58	-2.73	0.01	***
OUTPUT	6.47	1.99	3.25	0.00	***
LCD	133.85	38.70	3.46	0.00	***
R^2	0.93				
Adjusted R^2	0.92				

As can be seen from the model, RSPREAD, UNEMP, OUTPUT, and LCD can be considered as significant determinants of demand for case bank's DDAs. All of them are significant at the 1 % level. However, the constant term of the model is not statistically significant, even at the 10 % level. The fit of the model can be considered to be quite good, since the R^2 value is 0.93. This means that the model is able to explain 93 % of the variations in the dependent variable, DMEUR. Also the adjusted R^2, which takes into account the number of explanatory variables in the model, is as high as 0.92.

As stated in Kalkbrener and Willing (2004), modeling deposit volumes as a function of macroeconomic environment can give important insights. Thus, it is reasonable to analyze the relevance of the variables used to explain the demand for DDAs. First, the motivation of including RSPREAD, which is a variable that takes into account the short-term market rate and the deposit rate, is quite straightforward, because it is built in to the general model (Equation (1)-(2)) used in the study. However, some additional discussion about the relevance of including the other macroeconomic and market concentration variables is needed.

The Finnish unemployment rate (UNEMP) is included in the model as one explanatory macroeconomic variable. Jarrow and van Deventer (1998), for instance, state that even though they model the aggregate demand deposits as depending only on the evolution of the term structure of default free rates, additional randomness could be useful to include in deposit balance dynamics. Thus, they state that macroeconomic considerations, such as unemployment rate, could provide additional improvement to the model. The results of

Carmona (2007) indicate that the deposit balance dynamics reflect business cycle conditions and unemployment can be viewed to reflect the state of economy. Also, Carmona states that unemployment affects deposit balances because the unemployed are in need for short-term funding and they try to compensate their loss of income by using their assets to smooth out consumption. Finally, Hays et al. (2009) relate unemployment rate to the bank's yield on assets and, on the other hand, cost of funds. Like Carmona, also Hays et al. view the unemployment rate as a proxy for economic conditions. However, empirically they do not find significant relationship between yield on assets and the unemployment rate or between the cost of funds and the unemployment rate.

As mentioned earlier in the data section, OUTPUT is used as a proxy for the level of domestic income. There are a number of previous papers that relate some measure of income to the demand for deposits. First, Dickson and Starleaf (1972) include a measure of real income, gross national product (GNP), in their demand function for currency plus demand deposits (M1). They find that both the current value of GNP and four of its previous values are significant determinants of M1 demand. Goldberg and Rai (1996) use a slightly different measure for income level, the per capita income (PCI). According to them, the PCI of a country affects numerous factors related to the supply and demand for both loans and deposits.

Finally, the logic behind using LCD to measure market concentration is similar as in Kano et al. (2006). They first construct the HHI by bank type, and then define two dummy variables based on that data, namely intense competition dummy (ICD) and, as also done in this thesis, low competition dummy (LCD). The former takes a value of one when the HHI value is less than its median, whereas the latter takes a value of one in case of HHI being greater than its median. However, as opposed to Kano et al. who relate bank competition to the benefits of bank-borrower relationships, this thesis relates it to the demand for DDAs. Hays et al. (2009), on the other hand, present an approach that is closer to the one used here, as they examine the impact of HHI to the yield on assets and cost of funds for commercial banks. As deposits are the primary source of bank funding, this approach can be viewed as somewhat similar to mine.

5.1.1.1. Diagnostic Tests

OLS regression models have a number of desirable properties that should not be violated in order to validly conduct the hypothesis tests regarding the coefficient estimates. Thus, diagnostic tests should be carried out when building OLS regression models. There are seven model assumptions, presented in Brooks (2008, Chapter 4) that need to be tested using diagnostic tests. The assumptions are that (i) the expected value of the error term equals zero, (ii) the error terms are homoscedastic, (iii) the error terms are not autocorrelated, (iv) the explanatory variables are non-stochastic, (v) the error terms are normally distributed, (vi) linear function form is appropriate, and (vii) the model does not suffer from multicollinearity, which means that the correlations between explanatory variables are small. The results of all these tests for the case bank's DDA demand function are presented next.

First, no formal test is needed to estimate the expected value of the error term, because if a constant term is included in the regression equation, the expected value of the error term is always zero. Hence, the first assumption of the linear model is not violated.

The second assumption of error term homoscedasticity can be formally tested. Homoscedasticity means that the regression error term has a constant variance through time. If the variance varies in time, the error term is said to be heteroscedastic. One can find evidence about the possible heteroscedasticity by just studying the residual plots of the regression model, but there are also several statistical tests for that purpose. White's general test for heteroscedasticity is used in this thesis and the results concerning the case bank's DDA demand function are presented in Table 4.

Table 4: White's test for case bank's deposit demand function

This table presents the results for White's test for error term heteroscedasticity concerning the OLS regression model that determines the case bank's deposit demand function. The test is carried out for the variables' squares only, i.e. cross-product terms are excluded. The null hypothesis of the test is that error term is homoscedastic. The TR^2 test statistic, which follows a χ^2 distribution, and its associated *p*-value are also given in the bottom of the table. */**/*** denotes significance at the 10/5/1 % level.

Dependent variable: $\hat{u}^2$

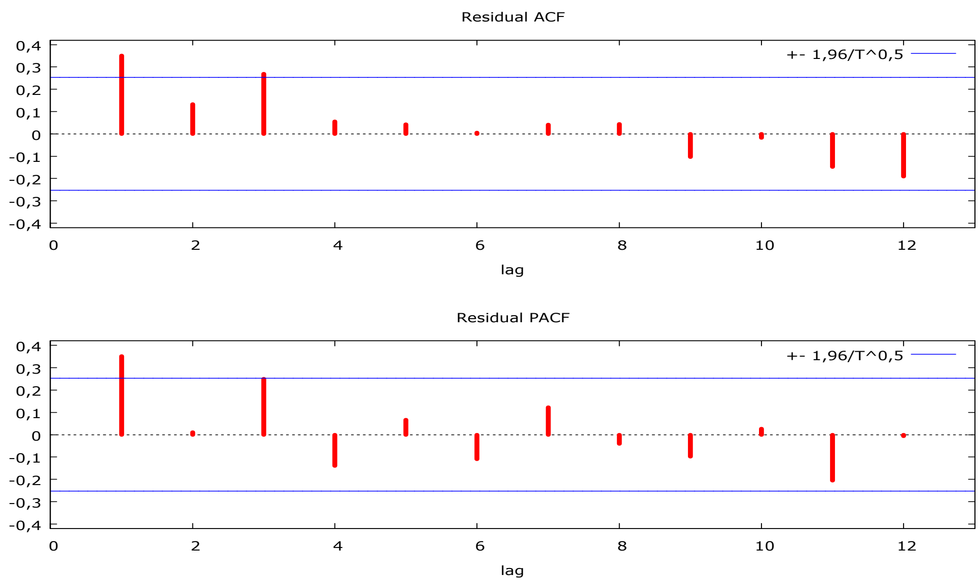
	Coefficient	*S.E.*	*t*-ratio	*p*-value	
Constant	74,215.50	345,885.00	0.21	0.83	
UNEMP	60,486.10	33,854.10	1.79	0.08	*
OUTPUT	-5,169.42	5,661.54	-0.91	0.37	
RSPREAD	-4,448.91	9,290.44	-0.48	0.63	
LCD	6,959.63	4,657.91	1.49	0.14	
$UNEMP^2$	-4,256.27	2,361.38	-1.80	0.08	*
$OUTPUT^2$	23.58	23.75	0.99	0.33	
$RSPREAD^2$	1,119.07	4,575.00	0.24	0.81	
R^2	0.27				
TR^2	16.13				
p-value	0.02				

As can be seen from the table, the test is conducted by running an auxiliary regression in which the square of the original model's residual is the dependent variable and the squares of the original explanatory variables are added as new regressors. The test statistic obtained from the regression, TR^2, and its *p*-value indicate that the null hypothesis of no heteroscedaticity should be rejected, because there is only a 2 % chance of obtaining a TR^2 statistic of 16.13 when the null hypothesis actually holds. Because of this observed heteroscedasticity, the so called robust, or heteroscedasticity consistent, standard errors are used in the case bank's DDA demand function presented earlier in Table 3. These robust standard errors are larger than the original ones, thus decreasing the *t*-ratios of coefficients and making interpretation of the regression results more conservative.

The third of the desired characteristics of a linear regression model is that the error term is not correlated with its previous values. In case of error term correlation, it is said to be serially correlated or autocorrelated. Similarly as in the case of heteroscedasticity, signs of autocorrelation can also be found by studying the residual plots of the model. In addition, the presence of autocorrelation is shown in the residual autocorrelation function and partial autocorrelation function. The former of these shows the correlation coefficients between the current observation and its previous lags, whereas the latter measures the correlation between observation *n* periods ago and the current observation, after controlling for observations at intermediate lags. For instance, the partial autocorrelation function for lag 2 would measure the correlation between y_t (current observation) and y_{t-2}, after removing the effect of y_{t-1}. Both autocorrelation and partial autocorrelation for the residual of case bank's DDA demand function are presented graphically in Figure 8.

Figure 8: Residual autocorrelation function and partial autocorrelation function for case bank's deposit demand function

This figure presents the autocorrelation function (ACF) and partial autocorrelation function (PACF) for the OLS regression model that determines the deposit demand function for the case bank. The blue lines represent the 5 % (two-sided) rejection bands for the null hypothesis of no autocorrelation.



In addition to graphical evidence of autocorrelation, there exist also several formal statistical tests for the purpose of identifying autocorrelated error term and the Breusch-Godfrey test is used in this thesis. The test is carried out by running an auxiliary regression in which the original residual of the model is used as a dependent variable and *n* of its lags are added as regressors to the right hand side of equation. According to a widely used approach with monthly data, 12 lags of residuals are used in the test. Results from Breusch-Godfrey test for the case bank's DDA demand function are presented in Table 5.

Table 5: Breusch-Godfrey test for case bank's deposit demand function

This table presents the results from Breusch-Godfrey test for error term autocorrelation in the OLS regression model that determines the case bank's deposit demand function. Under the null hypothesis, the current residual is not related to any of its 12 previous values. Three alternative test statistics and their associated *p*-values are presented in the bottom of the table: (i) *LMF* that follows an *F*-distribution, (ii) TR^2 that follows a χ^2 distribution, and (iii) Ljung-Box *Q** that also follows a χ^2 distribution. */**/*** denotes significance at the 10/5/1 % level.

Dependent variable: û

	Coefficient	*S.E.*	*t*-ratio	*p*-value	
Constant	-124.27	463.64	-0.27	0.79	
UNEMP	20.45	30.94	0.66	0.51	
OUTPUT	-0.73	2.22	-0.33	0.74	
RSPREAD	44.26	52.23	0.85	0.40	
LCD	35.79	52.51	0.68	0.50	
$\hat{u}_{t-1}$	0.47	0.17	2.83	0.01	***
$\hat{u}_{t-2}$	-0.11	0.17	-0.64	0.53	
$\hat{u}_{t-3}$	0.37	0.17	2.25	0.03	**
$\hat{u}_{t-4}$	-0.18	0.19	-0.91	0.37	
$\hat{u}_{t-5}$	0.16	0.18	0.90	0.37	
$\hat{u}_{t-6}$	0.00	0.20	-0.01	0.99	
$\hat{u}_{t-7}$	0.09	0.18	0.47	0.64	
$\hat{u}_{t-8}$	0.05	0.19	0.26	0.80	
$\hat{u}_{t-9}$	-0.23	0.20	-1.16	0.25	
$\hat{u}_{t-10}$	0.08	0.17	0.46	0.65	
$\hat{u}_{t-11}$	-0.22	0.17	-1.27	0.21	
$\hat{u}_{t-12}$	0.00	0.19	0.02	0.99	
R^2	0.31				
LMF	1.59				
p-value	0.13				
TR^2	18.47				
p-value	0.10				
Ljung-Box *Q**	19.50				
p-value	0.08				

As can be seen from the table, three alternative test statistics are given. All of these have a null hypothesis that the error term is not autocorrelated, but the distributions these test statistics follow differ. The *LMF* test statistic follows an *F*-distribution, whereas TR^2 and Ljung-Box *Q** follow a χ^2 distribution. The conclusion whether the model suffers from autocorrelation or not is a bit ambiguous here. With 90 % confidence, the *LMF* and TR^2 indicate that there is no significant evidence of autocorrelation, whereas the Ljung-Box *Q** indicates otherwise. However, since the majority of evidence suggests that there is no significant error term autocorrelation involved in the model, it is the conclusion made here.

The fourth assumption is that the explanatory variables are non-stochastic, because otherwise the OLS estimator will not yield reliable results. However, there is an exception; it turns out that the OLS estimator is reliable, i.e. consistent and unbiased, even in the presence of stochastic regressors, if the regressors are not correlated with the model's error term. If one or more of the regressors are contemporaneously correlated with the error term, the OLS estimator will not even be consistent. In practice, the interest in testing the fourth assumption is in the correlation matrix between the model residual and the explanatory variables. For the DDA demand function of case bank, this is given in Table 6.

Table 6: Correlations between the residual and explanatory variables in case bank's deposit demand function

This table presents the correlation matrix between the residual and explanatory variables in the OLS regression model that determines the case bank's deposit demand function. The residual is denoted by û.

	û	UNEMP	OUTPUT	RSPREAD	LCD
û	1.0				
UNEMP	0.0	1.0			
OUTPUT	0.0	-0.6	1.0		
RSPREAD	0.0	-0.8	0.4	1.0	
LCD	0.0	0.5	-0.2	-0.8	1.0

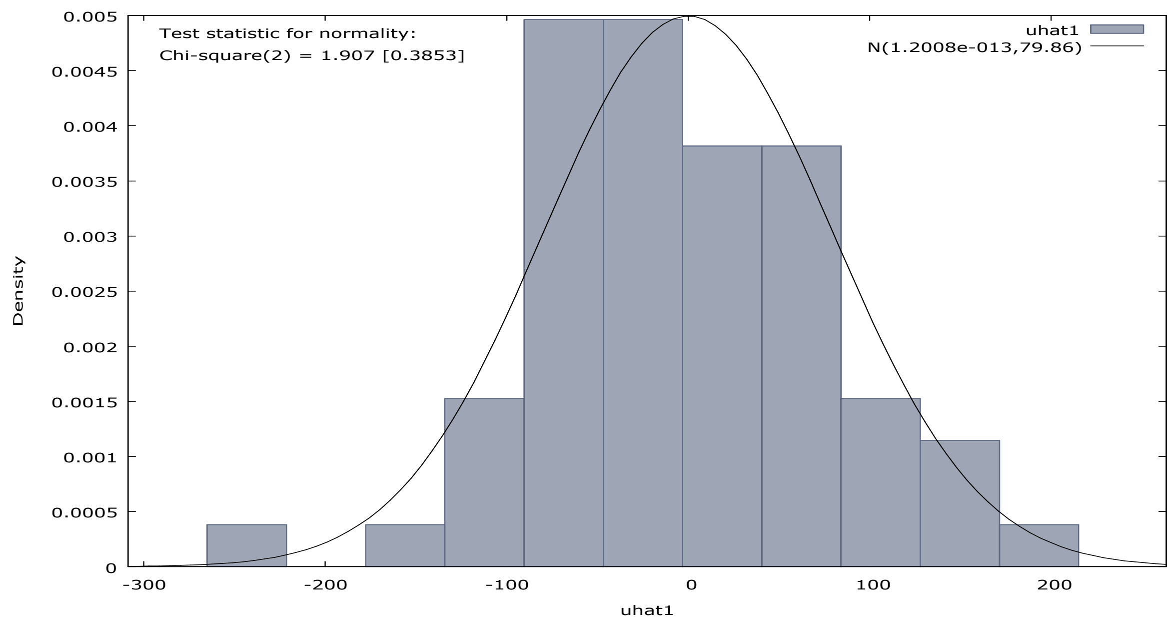
As desired, there is no evidence of correlation between the model residual and the explanatory variables. Thus, it can be concluded that no problems arise with the fourth assumption of linear regression model.

The fifth assumption that should not be violated is that the model's error term is normally distributed. Signs of non-normality can be found from the frequency distribution of the residual or from its skewness and kurtosis values. Also in this case, there are some formal tests for detection of non-normal error term. Two different tests are used in this thesis, which are the Jarque-Bera test and Doornik-Hansen test. The idea in the former is to test whether the coefficient of skewness and the coefficient of excess kurtosis are jointly zero. The test statistic follows a χ^2 distribution under the null hypothesis that the distribution is normal. Also the

Doornik-Hansen test statistic follows a χ^2 distribution and the null hypothesis is the same as well. The basis of the two tests is similar as they both take into account the distribution's skewness and kurtosis, but the Doornik-Hansen test performs better with small sample sizes. Hence, it is reasonable to study the results of both tests without jumping into conclusions. The probability distribution of the residual in the case bank's DDA demand function is presented in Figure 9. Also, it is compared to a normal distribution and the Doornik-Hansen test statistic is given as well.

Figure 9: Probability distribution for the residual of case bank's deposit demand function

This figure presents the probability distribution for the residual of the OLS regression model that determines the deposit demand function for the case bank. Also, the figure shows a normal distribution with an appropriate mean and variance (solid line). Doornik-Hansen test statistic for normality and its *p*-value are presented in the upper left corner of the figure.



As can be seen from the figure, the residual's distribution is somewhat close to normal. The Doornik-Hansen test statistic is approximately 1.91 with a *p*-value of 0.39 and the Jarque-Bera test statistic (not presented in the figure) equals 0.36 with a *p*-value of 0.84. According to these criteria, strong evidence for error term normality is obtained. Thus, the conclusion is that the fifth assumption of linear regression model is not violated in the case bank's DDA demand function.

The last two issues that need to be studied in OLS models are the appropriateness of the model's functional form and multicollinearity, which is the mutual correlation between explanatory variables. The former can be tested by using a RESET test, which is a general test for misspecification of functional form. Naturally, the functional form of an OLS regression model is linear. The test is carried out by running an auxiliary regression, where the dependent variable is same as in the original model. The explanatory variables, however, differ. In the auxiliary regression, the regressors are the powers of the dependent variable's fitted values together with the original explanatory variables. The results from the RESET test indicate that the linear function form of the case bank's DDA demand function is appropriate. The test statistic, which follows an F-distribution, obtains a value of 0.04 with a p-value of 0.84. Thus, strong evidence for appropriateness of linearity is presented.

Finally, the presence of multicollinearity can be found by calculating the so called variance inflation factors (VIFs) for the model's explanatory variables. VIF is defined as $1 / (1-\sqrt{\rho})$, where ρ is the correlation coefficient between a given variable and the other explanatory variables in the model. The smallest possible value of VIF equals 1, whereas values in excess of 10 may indicate a multicollinearity problem.[10] The VIFs obtained for UNEMP, OUTPUT, RSPREAD, and LCD equal 3.84, 1.46, 7.65, and 3.80, respectively. Hence, no evidence of multicollinearity is found.

5.1.2. Finnish Banking Sector

The DDA demand function for the Finnish banking sector is also estimated using linear regression and specific-to-general model building approach. Practically, the approach is similar to the one used with the case bank. The final regression model for estimating the DDA demand function for the banking sector is presented in Table 7.

[10] However, the interpretation of VIF values is somewhat ambiguous. As stated in O'Brien (2007), there are several rules of thumb regarding the threshold values of VIF that appear in both scholarly articles and statistical text books. The rule of 10 is the most commonly used practice for identifying multicollinearity from VIF and, thus, it is used in this thesis as well. Other threshold values suggested previously are, e.g., 5 and 20.

Table 7: Banking sector's deposit demand function

This table presents the estimated OLS regression model, which represents the deposit demand function of the Finnish banking sector. */**/*** denotes significance at the 10/5/1 % level.

Dependent variable: MFIDMEUR

	Coefficient	*S.E.*	*t*-ratio	*p*-value	
Constant	-41,518.40	12,824.00	-3.24	0.00	***
MFIRSPREAD	-5,689.55	392.72	-14.49	0.00	***
OUTPUT	202.84	44.15	4.60	0.00	***
CPI	796.00	139.56	5.70	0.00	***
LCD	-2,595.44	1,027.89	-2.53	0.01	**
R^2	0.93				
Adjusted R^2	0.93				

As shown in the table, MFIRSPREAD, OUTPUT, CPI, and LCD constitute the set of significant explanatory variables in the case of the whole banking sector's DDA demand function. All of them are significant at the 1 % level, except LCD, which is significant at the 5 % level. Again, the fit of the model can be considered to be quite good, since the R^2 value is 0.93. Also the adjusted R^2 is high, approximately 0.93 as well.

With one exception, the explanatory variables are the same in this model as they were in the case bank's model. Instead of UNEMP, the DDA demand function for the banking sector includes the consumer price index, CPI, as one of the regressors. As stated in the data chapter, CPI can be used as a proxy for inflation rate. This is done, e.g., by Virolainen (2004), who studies the explanatory power of inflation rate in determining the amount of corporate defaults. Moreover, the approach by Dickson and Starleaf (1972) is quite similar to mine, as they use "aggregate price index" as one of their explanatory variables in determining the demand for M1. They measure the aggregate prices by the GNP deflator, which incorporates all of the final goods produced by an economy, whereas the consumer price index is constructed based on upon a basket of goods and services. Dickson and Starleaf find that aggregate price index, along with three of its previous lags, is a significant determinant of M1 demand.

5.1.2.1. Diagnostic Tests

Next, the results of diagnostic tests for the banking sector's DDA demand function are presented. The model assumptions and tests carried out for the model are similar as in the case of case bank's DDA demand function. Again, the first assumption that the error term has an expected value of zero is not violated, because a constant term is included in the regression equation. However, the second assumption of error term homoscedasticity needs to be tested. Again, White's test for heteroscedasticity is used, and the results concerning the banking sector's DDA demand function are presented in Table 8.

Table 8: White's test for banking sector's deposit demand function

This table presents the results for White's test for error term heteroscedasticity concerning the OLS regression model that determines the Finnish banking sector's deposit demand function. The test is carried out for the variables' squares only, i.e. cross-product terms are excluded. The null hypothesis of the test is that the error term is homoscedastic. The TR^2 test statistic, which follows a χ^2 distribution, and its associated *p*-value are also given in the bottom of the table. */**/*** denotes significance at the 10/5/1 % level.

Dependent variable: $\hat{u}^2$

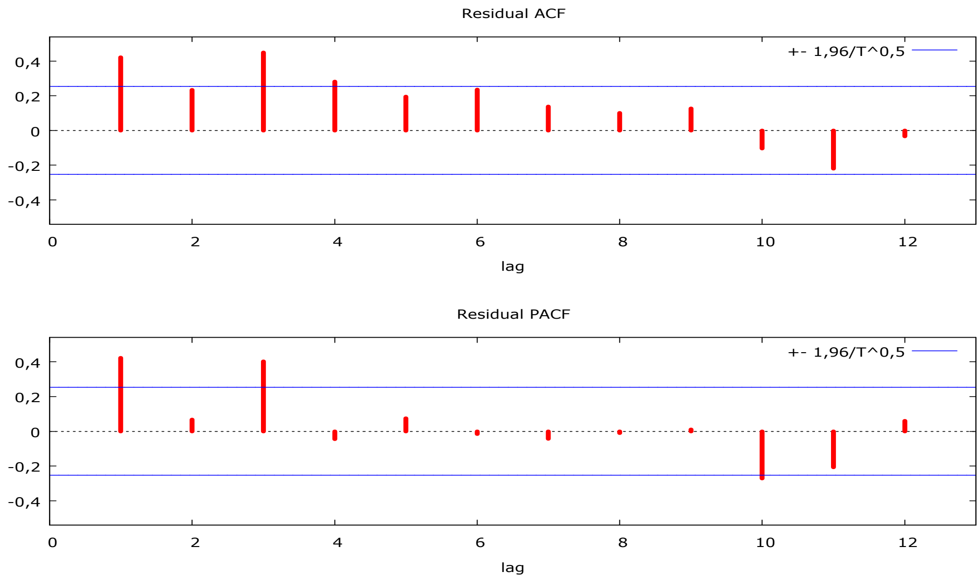
	Coefficient	*S.E.*	*t*-ratio	*p*-value	
Constant	-1.56E+08	6.80E+08	-0.23	0.82	
MFIRSPREAD	4.36E+06	2.34E+06	1.86	0.07	*
OUTPUT	1.44E+06	1.82E+06	0.79	0.43	
CPI	754,916.00	1.31E+07	0.06	0.95	
LCD	-2.24E+06	1.76E+06	-1.27	0.21	
$MFIRSPREAD^2$	-1.59E+06	889,321.00	-1.79	0.08	*
$OUTPUT^2$	-6,209.88	7,669.12	-0.81	0.42	
CPI^2	-453.95	61,934.30	-0.01	0.99	
R^2	0.19				
TR^2	11.18				
p-value	0.13				

As shown in the table, the test statistic obtained from the regression, TR^2, and its *p*-value indicate that the null hypothesis of homoscedasticity should not be rejected. Thus, the conclusion here is that the model does not suffer from heteroscedasticity, and the second assumption of the linear regression model is not violated.

Third of the desired characteristics of a linear regression model is that there is no autocorrelation in the model's error term. To test for this property, the residual autocorrelation function and partial autocorrelation function concerning the sector's DDA demand function are presented in Figure 10.

Figure 10: Residual autocorrelation function and partial autocorrelation function for banking sector's deposit demand function

This figure presents the autocorrelation function (ACF) and partial autocorrelation function (PACF) for the OLS regression model that determines the deposit demand function for the Finnish banking sector. The blue lines represent the 5 % (two-sided) rejection bands for the null hypothesis of no autocorrelation.



As can be seen from the figure, there are some potential evidence of autocorrelation, especially at lags 1 and 3. However, to accurately conclude whether the autocorrelation is present in the model or not, a formal test for autocorrelation has to be carried out. Similarly as was done with the case bank's DDA demand function, the Breusch-Godfrey test is used here as well. Again, 12 lags are used in the test. Results from Breusch-Godfrey test for the banking sector's DDA demand function are presented in Table 9.

Table 9: Breusch-Godfrey test for banking sector's deposit demand function

This table presents the results from Breusch-Godfrey test for error term autocorrelation in the OLS regression model that determines the Finnish banking sector's deposit demand function. Under the null hypothesis, the current residual is not related to any of its 12 previous values. Three alternative test statistics and their associated *p*-values are presented in the bottom of the table: (i) *LMF* that follows an *F*-distribution, (ii) TR^2 that follows a χ^2 distribution, and (iii) Ljung-Box *Q** that also follows a χ^2 distribution. */**/*** denotes significance at the 10/5/1 % level.

Dependent variable: û

	Coefficient	*S.E.*	*t*-ratio	*p*-value	
Constant	29,359.00	12,085.70	2.43	0.02	**
MFIRSPREAD	411.27	407.88	1.01	0.32	
OUTPUT	-24.31	41.03	-0.59	0.56	
CPI	-266.30	123.74	-2.15	0.04	**
LCD	2,661.76	960.19	2.77	0.01	***
$\hat{u}_{t-1}$	0.32	0.14	2.26	0.03	**
$\hat{u}_{t-2}$	0.00	0.14	-0.01	0.99	
$\hat{u}_{t-3}$	0.53	0.14	3.69	0.00	***
$\hat{u}_{t-4}$	0.02	0.15	0.11	0.91	
$\hat{u}_{t-5}$	0.24	0.16	1.51	0.14	
$\hat{u}_{t-6}$	0.18	0.16	1.12	0.27	
$\hat{u}_{t-7}$	0.07	0.16	0.40	0.69	
$\hat{u}_{t-8}$	0.07	0.17	0.43	0.67	
$\hat{u}_{t-9}$	-0.08	0.18	-0.43	0.67	
$\hat{u}_{t-10}$	-0.19	0.16	-1.22	0.23	
$\hat{u}_{t-11}$	-0.28	0.16	-1.73	0.09	*
$\hat{u}_{t-12}$	0.13	0.17	0.74	0.46	
R^2	0.55				
LMF	4.41				
p-value	0.00				
TR^2	33.09				
p-value	0.00				
Ljung-Box *Q**	47.29				
p-value	0.00				

Again, three alternative test statistics are given; *LMF*, TR^2, and Ljung-Box *Q**. The conclusion here is straightforward – since all the test statistics have *p*-values very close to zero, the model suffers from residual autocorrelation. This could be "cured" by, for example, including lagged values of the dependent variable as explanatory variables in the model. However, this can be problematic too, because the model can become too hard to interpret. Also, the inclusion of lagged values of the dependent variable as regressors violates the fourth assumption that explanatory variables are non-stochastic, because the dependent variable by definition is partly determined by the random error term, causing its lagged values to be stochastic to a certain extent. Hence, because the "cure" to autocorrelation can actually lead to additional problems, the autocorrelation of the model is ignored here.

The fourth assumption is that the explanatory variables are non-stochastic. However, if the regressors are not correlated with the residual, this question becomes irrelevant. In that case the OLS estimator is consistent and unbiased even in the presence of stochastic regressors. This issue can be studied by constructing a correlation matrix between the residual and the regressors, which is presented for the banking sector's DDA demand function in Table 10.

Table 10: Correlations between the residual and explanatory variables in banking sector's deposit demand function

This table presents the correlation matrix between the residual and explanatory variables in the OLS regression model that determines the Finnish banking sector's deposit demand function. û denotes the residual.

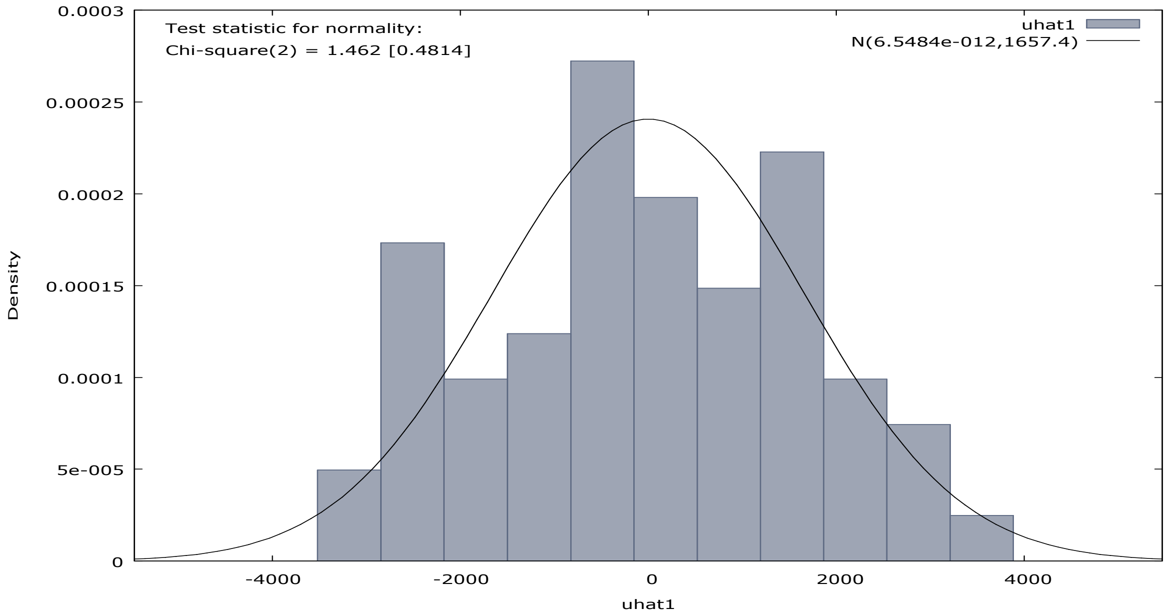
	û	MFIRSPREAD	OUTPUT	CPI	LCD
û	1.0				
MFIRSPREAD	0.0	1.0			
OUTPUT	0.0	0.5	1.0		
CPI	0.0	-0.6	0.1	1.0	
LCD	0.0	-0.8	-0.2	0.8	1.0

Again, there is no evidence of correlation between the model residual and the explanatory variables. Thus, it can be concluded that the fourth assumption of linear regression model is not violated.

The fifth assumption that should not be violated is that the model's error term is normally distributed. As stated earlier in the context of case bank, signs of non-normality can be found from the frequency distribution of the residual or from its skewness and kurtosis values, but there are also formal tests for that purpose. Again, the Jarque-Bera and Doornik-Hansen tests are used. The probability distribution of the residual in the banking sector's DDA demand function is presented in Figure 11. Also, it is compared to a normal distribution and the Doornik-Hansen test statistic is given too.

Figure 11: Probability distribution for the residual of banking sector's deposit demand function

This figure presents the probability distribution for the residual of the OLS regression model that determines the deposit demand function for the Finnish banking sector. Also, the figure shows a normal distribution with an appropriate mean and variance (solid line). Doornik-Hansen test statistic for normality and its *p*-value are presented in the upper left corner of the figure.



As can be seen from the figure, the residual's distribution is quite close to normal. The Doornik-Hansen test statistic is approximately 1.46 with a *p*-value of 0.48 and the Jarque-Bera test statistic (not presented in the figure) equals 1.67 with a *p*-value of 0.43. Again, according to these criteria, strong evidence for residual normality is obtained. Thus, the conclusion is that the fifth assumption of linear regression model is not violated in the sector's DDA demand function.

The last two issues that need to be studied in OLS models were the appropriateness of the linear function form and multicollinearity. Again, the former is tested by using a RESET test and the latter by calculating the VIF values for the regressors. The results from the RESET test indicate that the linear function form of the sector's DDA demand function may not be appropriate. The test statistic, which follows an *F*-distribution, obtains a value of 29.33 with a *p*-value quite close to zero. Thus, some other functional form could perform better than linear, but since the vast majority of the linear model assumptions are not violated, the results from the RESET test are set aside here. Finally, no evidence of multicollinearity was found. The obtained VIF values for OUTPUT, CPI, LCD, and MFIRSPREAD are equal to 1.90, 3.95, 5.38, and 3.50, respectively. Because all of these are less than 10, it can be concluded that the correlations between explanatory variables do not constitute a problem.

5.2. AR(2) Models

A majority of the variables in this thesis are modeled as autoregressive ARIMA(2,1,0) processes due to the observed lag structure and non-stationarity of data series used. As stated earlier in the methodology chapter, an ARIMA(2,1,0) model is equivalent to an AR(2) model for a series that is differenced once. The variables for which this model is applied are DMEUR, MFIDMEUR, UNEMP, OUTPUT, CPI, and HHI. The estimated AR(2) models for the differenced series of these variables are given in Table 11.

Table 11: Autoregressive models for deposit balance, macroeconomic, and market concentration variables

This table presents the estimated AR(2) models for the deposit balance, macroeconomic, and market concentration variables. Deposit balance variables include the case bank's demand deposit balance (DMEUR) and the aggregate demand deposit balance within the Finnish banking sector (MFIDMEUR). Macroeconomic variables include the Finnish unemployment rate (UNEMP), an index describing the cycles in economic output of Finland (OUTPUT), and the Finnish consumer price index (CPI). The variable measuring banking market concentration in Finland is the Herfindahl-Hirschman index (HHI). The models are constructed based on the series that are differenced once, causing the estimated models to be equivalent with ARIMA(2,1,0) models using the original data. The estimated coefficients and their respective *z*-statistics (in parentheses) are given. */**/*** denotes significance at the 10/5/1 % level.

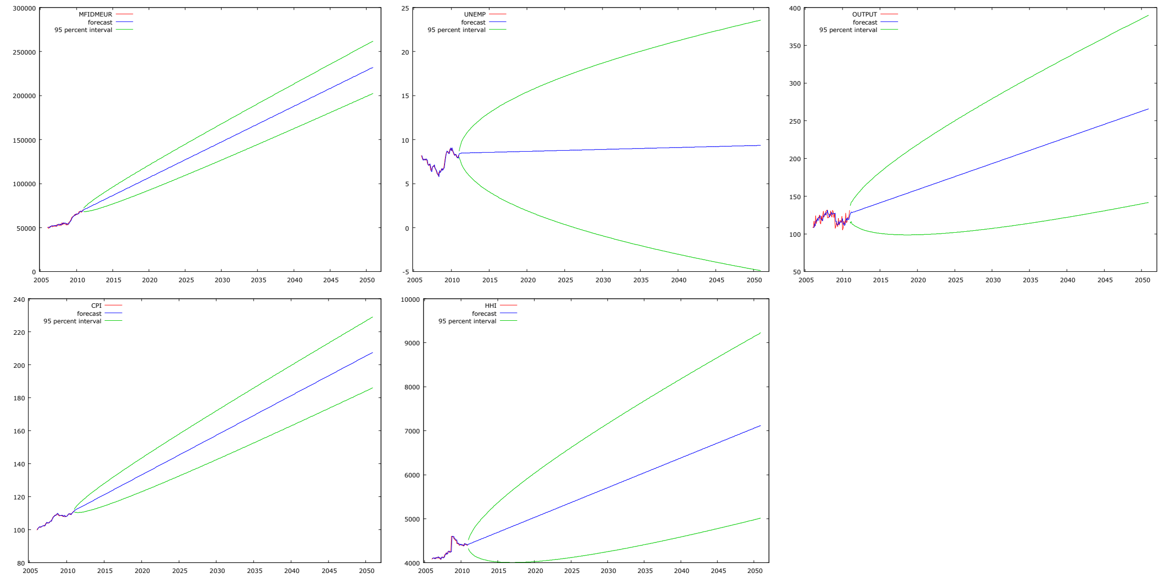
$$y_t = \mu + \phi_1 y_{t-1} + \phi_2 y_{t-2} + u_t.$$

Dependent variable	μ	Φ_1	Φ_2
DMEUR	14.29	0.34	0.10
	(4.97) ***	(2.62) ***	(0.71)
MFIDMEUR	337.74	-0.41	-0.09
	(3.72) ***	(-3.12) ***	(-0.73)
UNEMP	0.00	0.44	0.01
	(0.04)	(3.34) ***	(0.08)
OUTPUT	0.29	-0.55	-0.41
	(0.76)	(-4.56) ***	(-3.37) ***
CPI	0.20	0.14	0.14
	(3.09) ***	(1.08)	(1.09)
HHI	5.63	-0.01	-0.02
	(0.88)	(-0.12)	(-0.14)

The next step required in the analysis was to produce 40-year forecasts based on these AR(2) models. Autoregressive models suit well for forecasting purposes, but challenges arise with the unexpected movements of macroeconomic variables. Because of this, the forecasts produced here are based solely on historical data and it is assumed that the future development of variables can be derived from their historical fluctuations. The forecasted series based on the AR(2) models are given in Figure 12.

Figure 12: Forecasts for deposit balance, macroeconomic, and market concentration variables

This figure presents the autoregressive forecasts for the deposit balance, macroeconomic, and market concentration variables. The only deposit balance variable presented here is the aggregate demand deposit balance within the Finnish banking sector (MFIDMEUR). Macroeconomic variables included are the Finnish unemployment rate (UNEMP), an index describing the cycles in economic output of Finland (OUTPUT), and the Finnish consumer price index (CPI). The variable measuring banking market concentration in Finland is the Herfindahl-Hirschman index (HHI). The forecast for case bank's deposit balance variable (DMEUR) is excluded due to data confidentiality reasons. These forecasts are based on the estimated AR(2) models for the variables' differenced series. The historical development of a variable is presented by the red line, the forecast by the blue line, and 95 % confidence intervals by the green lines. Date (month/year) is presented in the X-axis and the observed/forecasted value of the variable in the Y-axis.



As can be seen from the figure, the majority of these forecasts have very wide 95 % confidence intervals. In other words, the forecasts contain quite a lot uncertainty, which can be expected when forecasting the future development of macroeconomic variables.

5.3. Cox-Ingersoll-Ross Model

In this section, I present the estimated Cox-Ingersoll-Ross model for the short-term market interest rate. As stated earlier, the short-term market rate is the only source of risk in the model, and hence it has to be modeled as a stochastic process. RTEUR01 is the variable used as the short-term market rate and a Cox-Ingersoll-Ross model is applied to describe its dynamics. Recall that the model was defined as follows in Equation (9):

$$r_t = r_{t-1} + \kappa(\theta - r_{t-1})\Delta t + \sigma\sqrt{r_{t-1}}\sqrt{\Delta t}z_t,$$

where r is the short-term interest rate, $\kappa(\theta\text{-}r_{t-1})$ is the drift factor that ensures the mean reversion of the process towards its long-term mean θ, σ is the volatility of the interest rate changes that is conditional on the square root of the variable's preceding value, and z_t is a normally distributed and stochastic Wiener process.

By regressing RTEUR01 on its one period lagged value, the parameter estimates were obtained. The longest possible period for Helibor/Euribor data was used in order to get as reliable parameter estimates as possible. This data spans from January 1987 to December 2010. After running the regression, the following model was obtained:

$$r_t = r_{t-1} + 0.01(2.99 - r_{t-1})\Delta t + 0.08\sqrt{r_{t-1}}\sqrt{\Delta t}z_t. \tag{11}$$

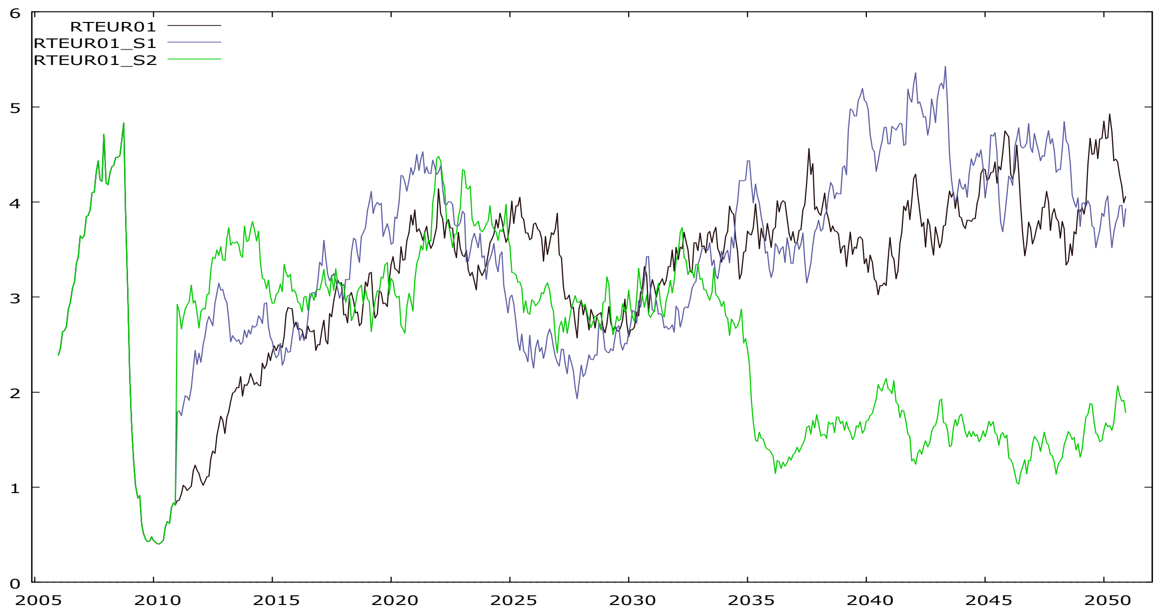
It can be inferred from the model that the speed of mean reversion, κ, equals 0.01, the long-term mean level, θ, equals 2.99 %, and the volatility of monthly interest rate changes, σ, equals 0.08 (8 %). Keeping in mind that monthly data is used in all phases, i.e. $\Delta t = 1$, and σ is expressed in monthly terms, the model can be simplified as follows:

$$r_t = 0.0299 + 0.99r_{t-1} + 0.08\sqrt{r_{t-1}}z_t. \tag{12}$$

After the model has been estimated, it is used for Monte Carlo simulation purposes. The fluctuating nature of the simulated paths comes from z_t, which is a random process. Figure 13 presents simulated 40-year paths for RTEUR01 under three different scenarios. First, the path where no interest rate shock is assumed to take place is given. Also, the paths assuming +100 and +200 bps shocks in the first simulated observation are presented. Since these shocks occur only in the first observation, they disappear gradually as the process moves on. The starting level of the interest rate process, r_0, is the observation of December 2010 (0.81 %) in each of the three cases.

Figure 13: Three simulated paths for the short-term market interest rate

This figure presents three different simulated paths that estimate the future fluctuations in the short-term market rate, i.e. one month Euribor rate (RTEUR01). The black line represents the simulated path with no artificially generated shocks. The blue (green) line, on the other hand, represents the estimated path when a +100 (+200) bps shock is assumed to occur in the first simulated observation. The model that the processes are assumed to follow is a Cox-Ingersoll-Ross model and the presented paths come from three independent simulation trials. The starting level of the processes is the observation of December 2010 and observations prior to that are historical quotes. Date (month/year) is presented in the X-axis and the interest rate in percentages in Y-axis.



As can be seen from the figure, the shocked paths “jump” upwards in the first observation, but in the future the effect of the shock vanishes. Also, the model’s mean-reverting condition is well visible in the figure as the processes tend to revert towards the long-term mean, 2.99 %.

5.4. DDA Rate and Rent Dynamics

In this section, the results concerning the dynamics of the optimal DDA rate and monthly rents are presented from both the case bank’s and the whole sector’s point of view. Even though the magnitude of deposit rents depends on the assumed future development of deposit balances, the dynamics of these monthly rent estimates and optimal deposit rates are similar regardless of the nominal amount of deposits in a bank’s balance sheet. Hence, the optimal DDA rate and rent dynamics are presented here assuming that deposit balances remain constant over time.

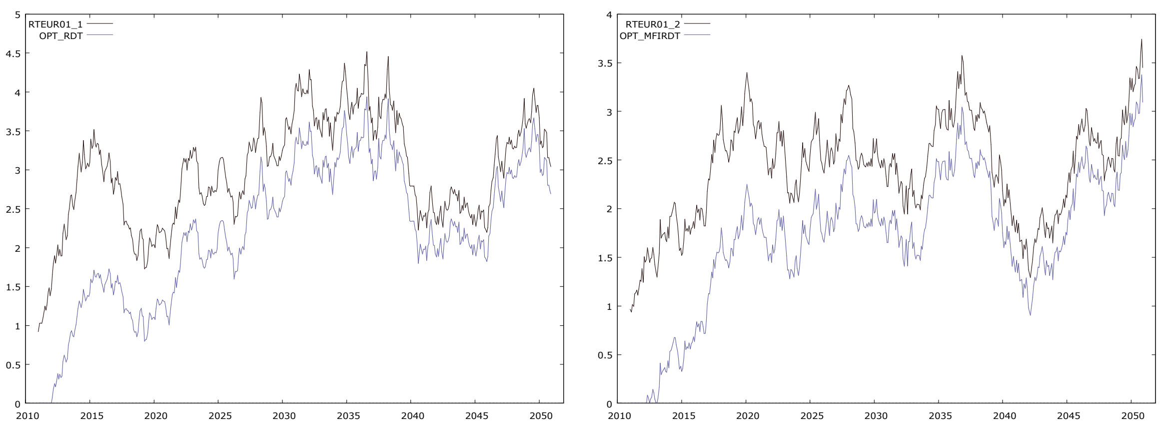
As presented in Equation (4), the optimal spread between the short-term market rate and the DDA rate is given by the following formula:

$$(r(t) - r_d(t))^* = -c(t) - D/(\partial D/\partial(r - r_d)),$$

where the left-hand side of the equation represents the optimal spread, $c(t)$ is the noninterest cost of accepting demand deposits (assumed to be equal to zero), D is the quantity of DDAs demanded by depositors, and $\partial D / \partial(r - r_d)$ is the elasticity of DDA demand with respect to changes in the spread between the market rate and the DDA rate. After the resulting spread is found, the optimal DDA rate can be easily obtained by subtracting this spread from the short-term market rate. Appendix 2 presents the estimated paths for spread elasticities of DDA demand and the corresponding optimal spreads from individual simulation trials for the case bank and the whole banking sector. The optimal DDA rate paths and the corresponding values for the short-term market rate from the same simulation trials are presented in Figure 14.

Figure 14: Simulated short-term market interest rate and the corresponding optimal deposit rate for case bank and banking sector

This figure presents the simulated short-term market rates and the corresponding optimal demand deposit rates for both the case bank and the Finnish banking sector. RTEUR01_1 and RTEUR01_2 are two independent paths for the short-term market rate, and OPT_RDT and OPT_MFIRDT are the optimal demand deposit rates for the case bank and the sector, respectively. Two simulation trials were needed to obtain these figures: RTEUR01_1 and OPT_RDT come from the first trial and RTEUR01_2 and OPT_MFIRDT from the second. The case bank's (sector's) optimal demand deposit rate and RTEUR01_1 (RTEUR01_2) is presented in the left (right) graph. Date (month/year) is presented in the X-axis and the interest rates in percentages in the Y-axis. Deposit balances are assumed to be constant through time.



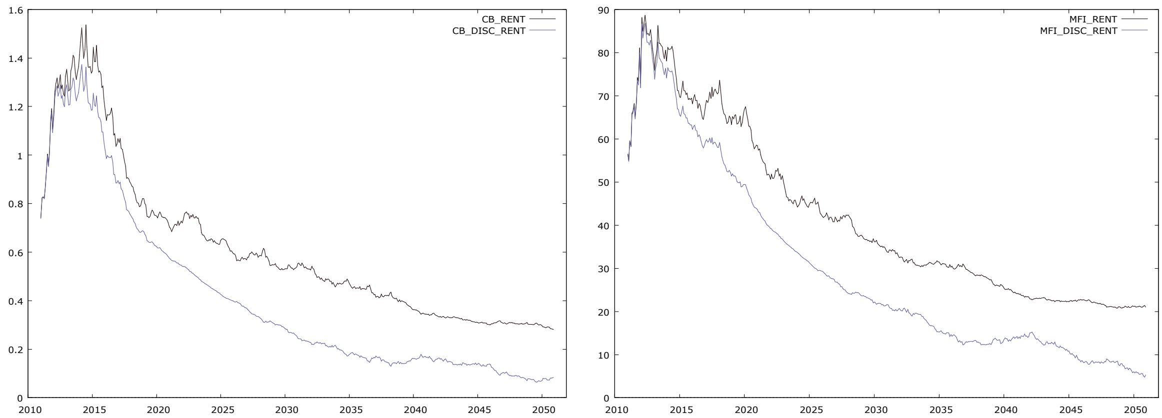
As shown in the figure, the optimal DDA rate converges to the short-term market rate in both cases as the simulation horizon extends. This means that for both the case bank and the whole banking sector the optimal spread between the short-term market rate and the DDA rate narrows as time passes.

This observed behavior of the optimal spread derives from the future estimates for spread elasticity of DDA demand (∂D / $\partial(r$ - $r_d)$), which is assumed to be linearly dependent on the estimated future levels of the variables affecting DDA demand and also relative to the amount of DDAs accepted. Because of the forecasted development of these variables the future values of spread elasticity of DDA demand are both negative and have a downward sloping trend. One example of the factors affecting this development is the unemployment rate in Finland, which is forecasted to grow in the future (see Figure 12). It is likely that increasing unemployment causes the consumers' wealth to decrease, which results in lower DDA demand, decreasing bank market power, and, eventually, narrower optimal spreads between the market rate and the DDA rate.

The next step after obtaining the optimal spread between the market rate and the DDA rate is to calculate the resulting deposit rents for all future dates, or as is done in this thesis, for the 40-year simulation horizon. At time point *t*, this rent is calculated by multiplying the estimated deposit balance by the optimal spread and it can be viewed as the monthly profit for the bank from accepting DDAs. After the rents are calculated for all the future observations, their present values are calculated by discounting them by the simulated short-term market rate. The last phase in the valuation exercise is to sum these discounted future monthly rents and divide it by the initial deposit balance. Simulated paths for future rents and discounted rents for both the case bank and the whole banking sector are given in Figure 15.

Figure 15: Simulated monthly deposit rents and discounted rents for case bank and banking sector

This figure presents the simulated future deposit rents and discounted monthly rents for both the case bank (left graph) and the Finnish banking sector (right graph). CB_RENT and CB_DISC_RENT (MFI_RENT and MFI_DISC_RENT) denote the case bank's (sector's) future monthly rent and discounted rent, respectively. Date (month/year) is presented in X-axis and the rents in millions of euros in Y-axis. Deposit balances are assumed to be constant through time.



In both cases, the future rents have a decreasing trend. Of course, this is a logical consequence when the optimal spread between market rate and the DDA rates narrows as time passes and the deposit balances remain constant at the same time. Appendix 2 presents the estimated paths for the discount factors used in both graphs of Figure 15.

5.5. DDA Rent, Liability, and Interest Rate Risk Estimates

In this section, I present the results concerning DDA valuation and interest rate risk measurement, which constitute the primary objective of this thesis. For case bank, these results are presented assuming different deposit balance dynamics. These dynamics are (i) constant deposits, (ii) decaying deposits (10-50 % p.a., with 10 % intervals), and (iii) growing deposits, which means that the deposits are assumed to grow according to the AR(2) forecast presented earlier. For the whole sector, only the case of growing deposits is covered, since the results under constant and decaying balances are similar to the case bank due to assumed similarities in the dynamics of interest rate spread elasticity. Hence, the value added by the calculations considering the whole sector is in the analysis on how different future growth rates, derived from historical data, affect the value and risk estimates of DDAs.

First, the results concerning DDA rents and liabilities for both the case bank and the banking sector are covered. As discussed earlier, the deposit liability value is defined as the nominal value of DDAs accepted minus the rent, i.e. $L_0 = D_0 - P_0$. According to the established practice in the literature, rent and liability estimates are reported as percentages of initial DDA balance (P_0/D_0 and L_0/D_0, respectively). Moreover, the *z*-statistics for mean rent estimates are presented in order to test the H_1 hypothesis that the average rents are significantly in excess of zero. Estimated rents and liabilities in the absence of short-term rate shocks are presented in Tables 12 and 13, and the rents' frequency distributions in Figure 16. Appendix 3 presents the rent and liability estimates under +100 and +200 bps shocks.

Table 12: Deposit rent estimates

This table presents the demand deposit (DDA) rent estimates under different deposit balance dynamics and in the absence of short-term market rate shocks. Rents are reported as percentages of initial DDA balance, i.e. P_0/D_0, where P_0 is the sum of discounted future monthly rents and D_0 is the initial DDA balance at $t = 0$. Estimates are obtained from 1,000 Monte Carlo simulation trials. *z*-statistics are given in parentheses. */**/*** denotes significance at the 10/5/1 % level.

P_0/D_0

		Mean	Median	Min	Max	1st decile	9th decile
Case bank							
Decay rate	Constant[A]	19.66 %	19.63 %	16.67 %	22.48 %	18.60 %	20.70 %
		(735.96) ***					
	10 %	8.10 %	8.11 %	6.26 %	10.27 %	7.40 %	8.76 %
		(469.97) ***					
	20 %	4.70 %	4.72 %	3.13 %	6.39 %	4.17 %	5.19 %
		(368.40) ***					
	30 %	3.06 %	3.07 %	2.05 %	4.03 %	2.68 %	3.44 %
		(327.75) ***					
	40 %	2.15 %	2.16 %	1.51 %	2.83 %	1.86 %	2.44 %
		(300.42) ***					
	50 %	1.55 %	1.55 %	0.99 %	2.09 %	1.30 %	1.77 %
		(271.67) ***					
	Growing[B]	61.70 %	61.69 %	53.00 %	71.06 %	58.01 %	65.29 %
		(674.21) ***					
Sector							
	Growing[B]	32.90 %	32.88 %	28.27 %	39.10 %	31.10 %	34.78 %
		(710.99) ***					

[A] DDA balance is assumed to remain constant through time.

[B] DDA balance is assumed to grow according to an AR(2) forecast.

Table 13: Deposit liability estimates

This table presents the demand deposit (DDA) liability estimates under different deposit balance dynamics and in the absence of short-term market rate shocks. Liability values (L_0) are defined as the nominal value of DDAs minus the rent and they are reported as percentages of initial DDA balance, i.e. L_0/D_0. Estimates are obtained from 1,000 Monte Carlo simulation trials.

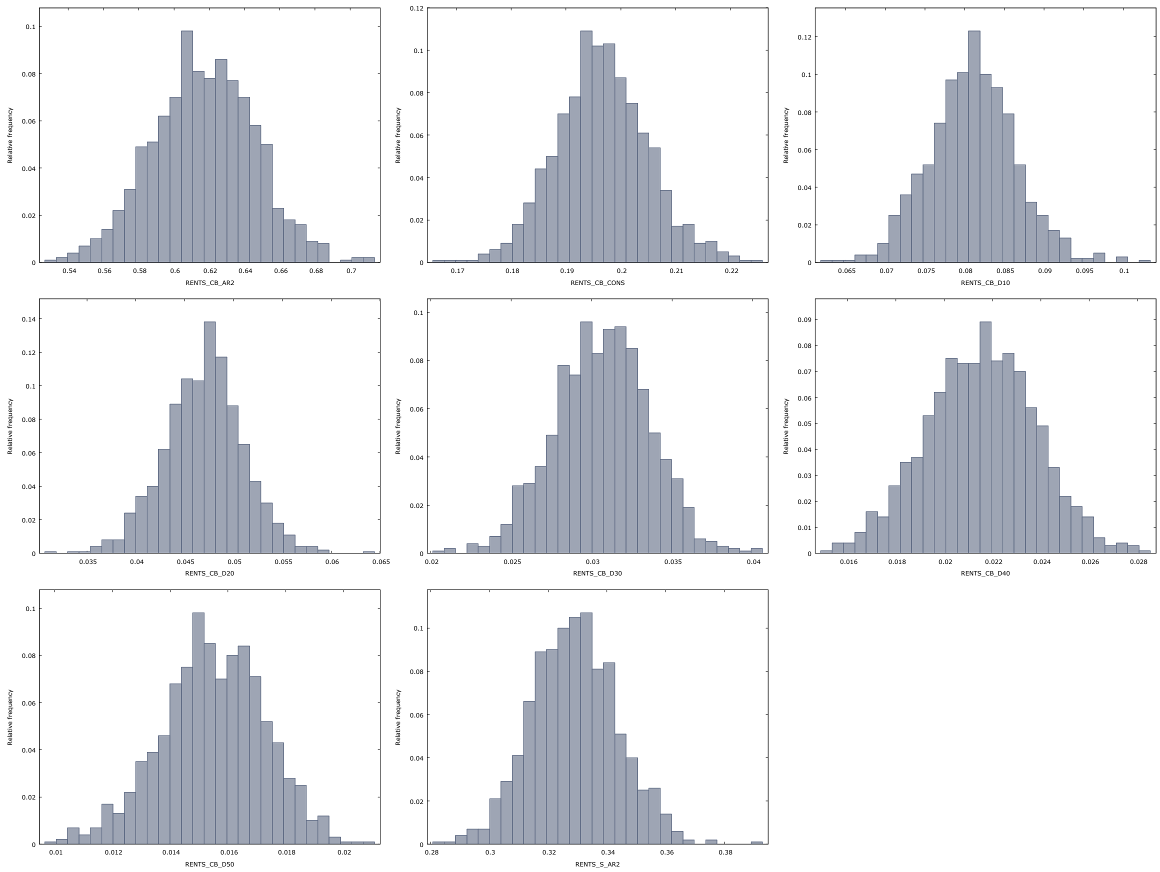
L_0/D_0							
Case bank							
		Mean	Median	Min	Max	1st decile	9th decile
	Constant[A]	80.34 %	80.37 %	77.52 %	83.33 %	79.30 %	81.40 %
Decay rate	10 %	91.90 %	91.89 %	89.73 %	93.74 %	91.24 %	92.60 %
Decay rate	20 %	95.30 %	95.28 %	93.61 %	96.87 %	94.81 %	95.83 %
Decay rate	30 %	96.94 %	96.93 %	95.97 %	97.95 %	96.56 %	97.32 %
Decay rate	40 %	97.85 %	97.84 %	97.17 %	98.49 %	97.56 %	98.14 %
Decay rate	50 %	98.45 %	98.45 %	97.91 %	99.01 %	98.23 %	98.70 %
	Growing[B]	38.30 %	38.31 %	28.94 %	47.00 %	34.71 %	41.99 %
Sector							
	Growing[B]	67.10 %	67.12 %	60.90 %	71.73 %	65.22 %	68.90 %

[A] DDA balance is assumed to remain constant through time.

[B] DDA balance is assumed to grow according to an AR(2) forecast.

Figure 16: Frequency distributions of deposit rents

This figure presents the frequency distributions of demand deposit rents under different deposit balance dynamics and in the absence of short-term market rate shocks. Distributions are obtained from 1,000 Monte Carlo simulation trials. Starting from the figure in the upper left corner and moving from left to right, the figures show rent distributions for (i) case bank under growing deposit balances (RENTS_CB_AR2), (ii) case bank under constant deposit balances (RENTS_CB_CONS), (iii) case bank under deposit balances decaying 10-50 % p.a. (RENTS_CB_D10 - RENTS_CB_D50), and (iv) Finnish banking sector under growing deposit balances (RENTS_S_AR2). Rents are reported as percentages of the initial deposit balance.



As can be seen from both tables and rent distributions above, the assumed deposit balance dynamics play an important role in the valuation of DDAs. For example, the mean P_0/D_0 (L_0/D_0) for the case bank varies between 1.55 and 8.10 % (91.90-98.45 %) under different annual decay rates, whereas in the case of constant deposits it is as much as 19.66 % (80.34 %). However, the case of growing deposits is naturally even more extreme: the mean P_0/D_0 (L_0/D_0) is 61.70 % (38.30 %) for the case bank and 32.90 % (67.10 %) for the whole banking sector. Hence, the forecasted growth has an important effect on the valuation of DDAs and it can be concluded that banks that grow faster than average are likely to enjoy relatively larger future rents than the banking sector as a whole. Of course, this statement holds here due to assumed similarities in interest rate spread elasticities of DDA demand between the rapidly growing case bank and the banking sector, but if they were to differ, the conclusion could be different. Moreover, as the *z*-statistics obtained for the mean P_0/D_0 values indicate, it is likely that the obtained mean rent estimates for both the case bank and the banking sector are significantly greater than zero under all DDA balance dynamics studied. Hence, strong evidence is found to support H_1.

The results concerning the other important aspect of this thesis, DDA interest rate risk, are covered next. Interest rate risk is defined as the interest rate sensitivity of DDA value, i.e. the change in rent/liability value due to a given shock in the short-term market rate. Two shocks are considered, +100 and +200 bps, and the interest rate risk estimates, $\Delta P_0/D_0$ and $\Delta L_0/D_0$, are presented as percentage changes in the simulated mean values of P_0/D_0 and L_0/D_0. Also, the *z*-statistics for $\Delta P_0/D_0$ under both shocks are presented in order to test the hypothesis that positive interest rate shocks result to an increase in mean DDA rent values (H_2). The results for interest rate risk of DDAs are presented in Table 14.

Table 14: Deposit interest rate risk estimates

This table presents the results concerning the interest rate risk estimates for demand deposits (DDAs) under different deposit balance dynamics. Interest rate risk is measured as percentage change in the mean value of rent or liability caused by either a +100 or +200 bps shock in the short-term market rate, i.e. the interest rate sensitivity. The shock is artificially generated only to the first simulated observation. Interest rate risk estimate for rent (liability) value is denoted by $\Delta P_0/D_0$ ($\Delta L_0/D_0$). Estimates are obtained from 1,000 Monte Carlo simulation trials. *z*-statistics are in parentheses and */**/*** denotes significance at the 10/5/1 % level.

		+100 bps	+200 bps	+100 bps	+200 bps
		$\Delta P_0/D_0$	$\Delta P_0/D_0$	$\Delta L_0/D_0$	$\Delta L_0/D_0$
	Case bank				
Decay rate	Constant[A]	9.35 %	19.13 %	-2.22 %	-4.62 %
		(40.42) ***	(66.46) ***		
	10 %	19.07 %	38.49 %	-1.63 %	-3.34 %
		(54.13) ***	(76.09) ***		
	20 %	27.56 %	53.76 %	-1.31 %	-2.59 %
		(59.36) ***	(76.01) ***		
	30 %	36.16 %	70.35 %	-1.10 %	-2.17 %
		(66.47) ***	(88.60) ***		
	40 %	43.83 %	82.48 %	-0.93 %	-1.77 %
		(71.89) ***	(94.50) ***		
	50 %	52.10 %	98.37 %	-0.79 %	-1.50 %
		(78.07) ***	(98.43) ***		
	Growing[B]	4.07 %	8.18 %	-5.65 %	-12.31 %
		(18.43) ***	(33.54) ***		
	Sector				
	Growing[B]	6.28 %	12.67 %	-2.93 %	-6.06 %
		(28.84) ***	(50.48) ***		

[A] DDA balance is assumed to remain constant through time.

[B] DDA balance is assumed to grow according to an AR(2) forecast.

Again, the assumed DDA balance dynamics play an important role in determining the DDAs' exposure to interest rate risk. For example, under constant balances and assuming a +100 bps shock, the value of case bank's rents increase by 9.35 %, whereas under balances that decay 10 % annually the change in the value of rents is 19.07 %. Naturally, the effect is reverse in the case of liability values, because an increase in the value of rents causes, by definition, the value of liabilities to decrease. Since shocks are assumed to gradually vanish, their effect on rent values is large with high decay rates. When the decay rate is high the future rents become smaller all the time as time passes, causing the value of near rents to increase relatively more than, e.g., in the case of constant deposit balances.

Additionally, an interesting issue considers the difference in the effect of forecasted DDA balance growth on the interest rate risk estimates (Table 14) and deposit rent valuation (Table

12). When deposit rents are valued under growing deposits, the results indicate that more rapid growth results in higher deposit rents. Case bank's growth rate is estimated to be faster than the sector's aggregate growth rate, causing the P_0/D_0 to equal 61.70 % for the case bank and 32.90 % for the sector. However, positive interest rate shocks seem to be more advantageous in the case of slower growth, i.e. P_0/D_0 increases relatively more due to a shock. This can be seen from Table 14 so that $\Delta P_0/D_0$ for a +100 bps (+200 bps) shock equals 4.07 % (8.18 %) for case bank, and 6.28 % (12.67 %) for the whole sector. Moreover, the *z*-statistics for the interest rate sensitivities of DDA rents ($\Delta P_0/D_0$) presented in Table 14 suggest that H_2 is supported. Hence, the conclusion is that positive market rate shocks seem to cause statistically significant positive changes in DDA rents.

5.6. Analysis and Discussion

The results concerning DDA valuation and their interest rate risk have many implications, from both the case bank's and the whole banking sector's viewpoint. Also, many interesting questions from the viewpoints of bank regulator and supervisor arise as well.

First, the presence of DDA rents and their valuation have an impact on the case bank's asset and liability management. In addition to concentrating on the nominal amount of DDAs accepted, i.e. the "adequacy of funding", the bank should also take into account that the DDAs' profitability depends on the spread between market rate and the DDA rate. Hence, the bank should set its DDA interest rate at such level that maximizes its profits from accepting these deposits. It is also worth noting that since the profitability of DDAs increases when the market rate rises, some of the value losses on the asset side may be offset by the additional gains from issuing deposits, thus causing the profitability of DDAs to have an influence on the bank's asset side as well.

The results on DDA valuation have implications to the case bank's liquidity risk management as well. Because the valuation procedure contains some uncertainty, the bank cannot accurately forecast the future monthly rents. In this case, it would be reasonable to study the estimated rent distribution and then prepare appropriate practices to manage this uncertainty, e.g. with additional liquid assets. By doing so, the risk to engage in harmful asset fire sales decreases. Moreover, the results concerning the interest rate risk of DDAs emphasize some hedging policies the case bank should consider. Because the changes in market rates are likely to cause changes in the value of DDAs, it could be reasonable to hedge these positions, so that exposure to these market rate movements decreases. Interest rate derivatives, such as swaps, could be used for hedging purposes. Under an interest rate swap contract the bank would effectively face fixed deposit rates in place of floating rates, which in turn could stabilize the fluctuations in the DDA rent/liability values and thus reduce the associated interest rate risk. Also, it should be noted that the bank's assets will hedge the interest rate risk associated with DDAs if they both have similar value sensitivities with relation to a given shock in the market rate.

The results have implications from the viewpoint of the Finnish banking sector as well. For example, the sensitivity of DDA rent estimates to changes in the market rate can be used to measure the system-wide riskiness of the whole sector. If the profitability of DDAs is very sensitive to movements in the short-term rate, it can be inferred that the system-wide interest rate risk in the deposit market is high. On the contrary, the banking sector can be seen as somewhat stable in the case on DDA insensitivity to market rate fluctuations. Also, the sector's potential to make positive rents at the cost of depositors can be seen as evidence of banks' market power indicating that the competition between banks is imperfect. When the rents increase, it is likely that the competitive environment has become less intense, and on the contrary, if the rents decrease, the market is likely to be more competed. This competition aspect is of interest for the bank regulator and supervisor as well, because abnormally large rents may indicate that the banks in the market exercise excessive monopoly power that is not favorable to the consumers. Hence, in such a case the regulator may want to set restrictions to the banks, for example in the form of merger regulations.

Moreover, the valuation of DDAs presents two additional questions that are interesting from the regulation's point of view. First, as the interest rate risk estimates show, banks' profits from accepting DDAs vary with market rate movements. As a result of this, the banks' availability of liquidity becomes more uncertain in the presence of volatile interest rates. This has to be taken into account by the bank regulator, who should set sufficient capital buffers for banks to meet. This would enhance the ability of banks to meet their liabilities that come due. Second, a question related to the balance sheet treatment of DDAs arises. Currently, the common practice is to value DDAs at their nominal values in banks' balance sheets, whereas their valuation is actually affected significantly by the rents the deposits generate. Hence, the regulator should consider possible refinements in the treatment of DDAs in the banks' balance sheets. A refinement of this kind might be to, for example, adjust the DDAs' balance sheet valuation by the rents that are likely to be generated in the upcoming few years under some conservative scenario, say, 50 % annual balance decay rate and some negative interest rate shock. This way, a more accurate estimate of the DDAs' actual value would be obtained in a way that does not underestimate the interest rate risk associated with them.

Even though the findings in previous literature are somewhat ambiguous, my results are well in line with some of the previous papers. There are three basic reasons why some of the results differ between the three main reference papers, Hutchison and Pennacchi (1996), O'Brien (2000), and Dewachter et al. (2006). The first one of these reasons is the fact that their samples consist of banks from different kinds of markets. Hutchison and Pennacchi, as well as O'Brien, examine U.S. banks, whereas Dewachter et al. concentrate on Belgian banks. Second, differences may arise from the time periods used for historical data, as the basic model used in all of these papers is essentially a model for stable economic environment. Hence, it may be problematic to use data from times of economic downturn to, for example, estimate the parameter dynamics used in a study. Finally, third, the methodologies used in all of these papers differ somehow. For example, Hutchison and Pennacchi present an analytical solution to valuation of rents, whereas O'Brien and Dewachter et al. use numerical methods.

One of the main results obtained in this thesis is that the mean (median) rent under constant deposits is estimated to be 19.66 % (19.63 %) for the case bank, and the results of O'Brien (2000) indicate that the median rent under the same assumptions is 21.10 % for the U.S. banks' NOW accounts (12.20 % for MMDAs). The same results, however, are somewhat different in the papers by Hutchison and Pennacchi (1996) and Dewachter et al. (2006). The former finds rents to be lower, as their results indicate a median rent of 6.55 % (7.88 %) for NOW accounts (MMDAs). On the other hand, the rents on Belgian banks' savings deposit accounts reported by Dewachter et al. are significantly greater, as the mean rent equals 47.80 %.

In addition to this thesis, deposit valuation under decaying deposit balances is studied in Dewachter et al. (2006). Again, their estimates for Belgian banks' deposit rents are greater than the ones obtained for the Finnish case bank in this thesis. They find that the average rents range from 7.90 % to 29.00 % depending on the decay rate assumed, whereas my results indicate that under similar decay rate assumptions, the range spans from 1.55 % to 8.10 %. However, the reason for that difference is likely to be the fact that Dewachter et al. report the average rents across the whole banking sector, whereas my results concerning decaying balances are only for a single bank. This is partly supported by the additional representations by Dewachter et al., as they show that the estimates for individual banks within their sample differ significantly.

The case of growing deposits is also studied in this thesis, as it is in O'Brien (2000) as well, whose results are quite different for NOW accounts and MMDAs. He finds that the median rent for NOW accounts under growing deposit balances equals 44.70 % or 62.40 %, depending on the underlying model for deposit evolvement. The same results for MMDAs are 5.00 % and 8.70 %, indicating that the differences in profitability between NOW accounts and MMDAs are substantial. The results obtained in this thesis are well in line with O'Brien's NOW account estimates, as the mean DDA rent under growing deposit balances for the case bank (banking sector) equals 61.70 % (32.90 %).

The interest rate risk estimates reported in this thesis are somewhat well in line with those obtained in previous literature. Assuming constant deposits and +100 bps shock in the short-term market rate, Dewachter et al. (2006) find that the change in DDA liability value equals -1.66 %. My results are quite well in line with that since $\Delta L_0/D_0$ for constant deposits equals -2.22 %. Concerning decaying balances, Dewachter et al. find that a +100 bps shock causes a liability value change between -1.38 % and -3.11 %, depending on the assumed decay rate. Again, my results are quite similar to those, as I find that $\Delta L_0/D_0$ varies between -0.79 % and -1.63 % for decaying deposit balances. O'Brien (2000), who reports his interest rate risk estimates as percentage points, finds that under +100 bps (+200 bps) shock the interest rate sensitivity for NOW accounts assuming constant deposit balances equals -0.87 (-0.93) percentage points and for MMDAs -0.45 (-0.51) percentage points. Again, the effect of positive interest rate shock on deposit liability values is negative. My results, reported as percentage points, indicate a greater DDA sensitivity to interest rate changes than the results of O'Brien, as I find that under constant deposit balances the average $\Delta L_0/D_0$ is -1.80 (-3.72) percentage points for a +100 bps (+200 bps) shock.

6. CONCLUSION

This thesis provided important insights and analysis about the rents that banks earn from accepting demand deposits (DDAs) and the interest rate risk associated with these deposits. Additional attention was given to the banks' market power, since the study is carried out in an environment of concentrated banking sector. A fundamental assumption in previous literature studying deposit valuation and interest rate risk has been that deposit balances remain constant over time, but the analysis carried out in this thesis assumes different scenarios for DDA balance dynamics. A majority of previous work on deposit valuation has been carried out from the viewpoint of U.S. banks, whereas the focus of this thesis is to analyze DDA rents and interest rate risk for a single Finnish case bank, and, to some extent, the whole Finnish banking sector. Moreover, the research methodologies used in earlier studies differ somewhat and this thesis employs a methodology that is a combination of the previous ones. The general model of bank profit maximization is similar as in Hutchison and Pennacchi (1996), whereas calculating the rents and interest rate risk using Monte Carlo simulation follows the work of O'Brien (2000) and Dewachter et al. (2006).

The findings in previous literature are somewhat ambiguous. For instance, under the assumption of constant deposit balances, Hutchison and Pennacchi (1996) find that the U.S. banks' demand deposit accounts earn rents (expressed as a percentage of the deposits' nominal value) of approximately 7-9 %, whereas the results of O'Brien (2000) indicate rents between 12 % and 21 %. Even more extreme results are reported in Dewachter et al. (2006), whose analysis considers Belgian banks. They find the average rent across different banks to be as high as 47.80 %.

The results obtained in this thesis indicate that there are several macroeconomic and market concentration factors that significantly affect the public's demand for DDAs and the assumptions concerning deposit balance dynamics and growth rates play an important role in the valuation of DDAs. In addition, it is found that the case bank and the Finnish banking sector as a whole exercise market power, as the DDA rents in both cases are significant. The magnitude of these rents is mostly consistent with the findings of O'Brien (2000), as I find that the mean (median) rent for the case bank assuming constant deposit balances equals 19.66 % (19.63 %). The interest rate risk estimates obtained in this thesis are also somewhat well in line with previous research. For example, Dewachter et al. (2006) find that the change in DDA liability value due to a +100 bps shock in the short-term market rate equals -1.66 %

and I find that to be -2.22 %. However, the results of O'Brien are slightly different here, as I find that the case bank has a greater sensitivity to interest rate changes than can be inferred from his results. Despite the differences in the actual interest rate risk estimates, the dynamics of rent and liability values due to a given market rate shock are similar in both this thesis and previous papers. Finally, strong evidence is found to support both the hypothesis that banks earn positive rents (H_1) and a positive interest rate shock causes the value of rents to increase (H_2).

In addition to academic contribution, the results obtained in this thesis have practical implications from the viewpoints of the case bank, Finnish banking sector, and bank regulator. First, in order to manage its deposit liabilities accurately, the case bank should recognize both of the components that affect the profitability of DDAs, which are their outstanding balance and the spread between the short-term market rate and the DDA rate. For example, raising the amount of deposits by paying out very high rates may not be an optimal choice, when greater profits could actually be achieved by wider spreads and lower balances. Also, the results have implications for the bank's liquidity risk management as well, because the rents earned from DDAs can be considered as somewhat liquid assets and fluctuations in their magnitude can cause uncertainty with relation to the bank's liquidity position. Finally, the bank should consider carefully its hedging procedures based on the interest rate risk estimates. The value of the rents is exposed to changes in market rates, and hence the bank should consider hedging this position, at least to some extent, using interest rate derivatives. This would also enhance the liquidity management procedures since the availability of liquidity would be easier to predict.

From the viewpoint of the Finnish banking sector, the first implication of the results is that the interest rate sensitivity of DDA valuation can be used to measure the system-wide riskiness of the DDA market. Also, potential signs of bank market power can be inferred from the rents generated by the banks as an aggregate. If banks generate substantially large rents, the most likely reason for that would be the imperfect competition within the sector. This concentration aspect is of interest for the competition authorities as well, as they are responsible for maintaining the sector competitive and favorable to consumers. Hence, in the presence of abnormally large rents, the authorities should consider their policies with respect to, for example, banking sector mergers and antitrust laws. The banking regulator that is responsible for maintaining the sector healthy can also obtain important insights from the results. For instance, different interest rate environments affect, at least to some extent, the liquidity positions of banks. Hence, the regulator should be aware of this and set the banks' regulatory capital buffers at an adequate level. Moreover, the balance sheet treatment of DDAs should be reconsidered, as the common practice is to value them at their nominal values. As shown in this thesis, the rent part of the deposit value can be somewhat substantial forcing the actual liability part to decrease. This indicates that it could be reasonable to reconsider the balance sheet valuation of DDAs.

The research carried out in this thesis contains some limitations resulting in fruitful topics for further research. First, for analytical simplicity, it is assumed that the interest rate elasticities for the case bank and the whole banking sector have similar dynamics, controlling for the level of deposit balances. This analysis could be enhanced by conducting the research for a number of Finnish banks individually, assuming independent interest rate elasticity dynamics for each of these banks. Second, the variables used in this thesis are modeled independently so that their mutual correlations are not considered. Thus, it would be of interest to take these correlations into account in a study similar to this thesis. Third, the interest rate risk estimates reported here are only for positive term structure slope shocks in the market interest rate, causing the effect of a shock to gradually vanish and the value change of rents (liabilities) to be positive (negative). Hence, it would be reasonable to include negative interest rate shocks in the analysis as well and to focus on term structure level shocks, under which the effect would last longer.

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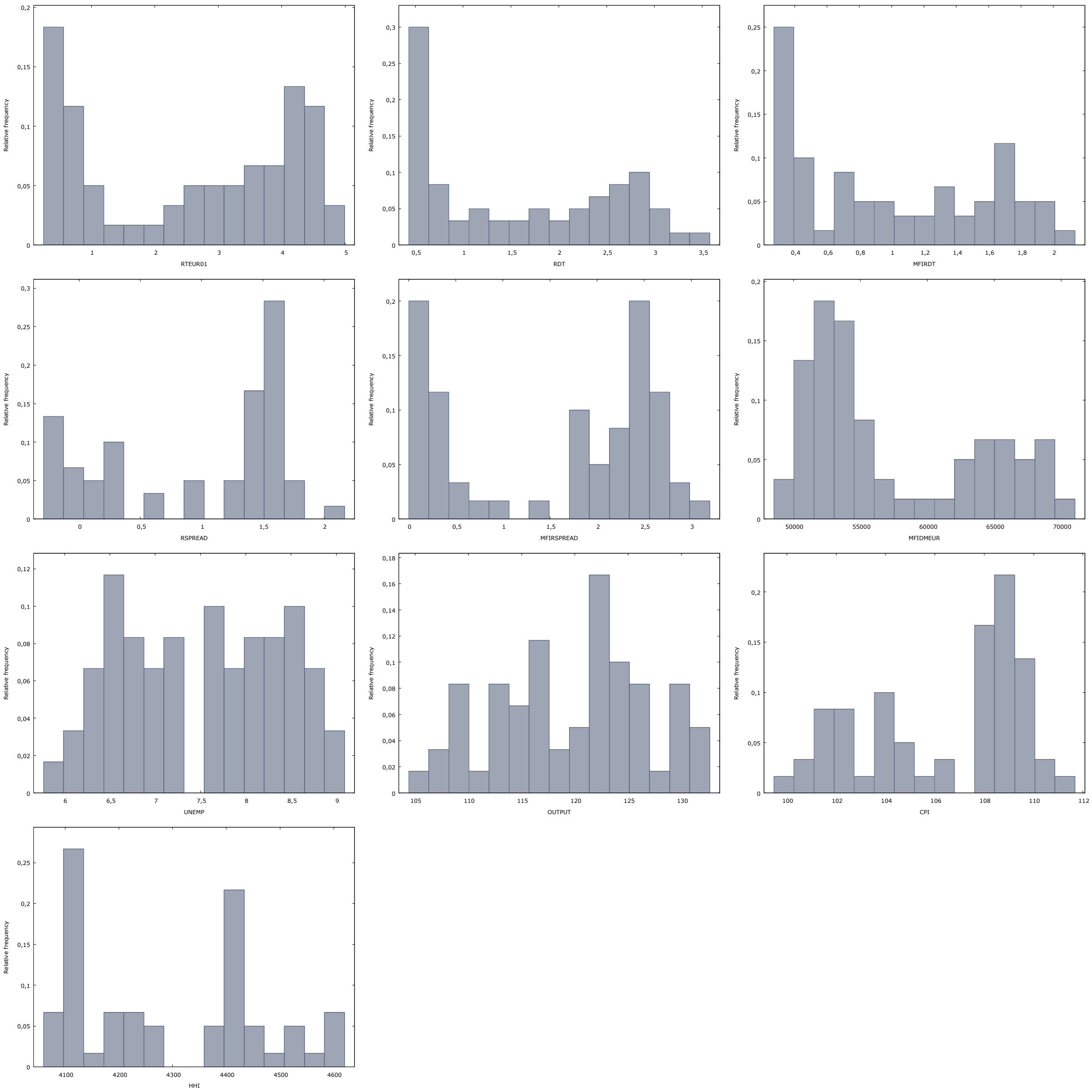
8. APPENDIX 1: VARIABLES' PROBABILITY DISTRIBUTIONS

Figure 17: Variables' probability distributions

This figure presents the probability distributions of the variables used in this thesis. However, case bank's deposit balance variable (DMEUR) is excluded due to data confidentiality reasons and low competition dummy (LCD) because it is based on an included variable, Herfindahl-Hirschman index (HHI). In addition to HHI, the variables presented here are the one month Euribor rate (RTEUR01), case bank's demand deposit rate (RDT), Finnish banking sector's demand deposit rate (MFIRDT), the spread between RTEUR01 and RDT (RSPREAD), the spread between RTEUR01 and MFIRDT (MFIRSPREAD), deposit balance within the banking sector (MFIDMEUR), unemployment rate in Finland (UNEMP), an index measuring the cycles in the economic output in Finland (OUTPUT) and Finnish consumer price index (CPI).



9. APPENDIX 2: INTEREST RATE SPREAD ELASTICITY, OPTIMAL DEPOSIT RATE SPREAD, AND THE DISCOUNT FACTOR

Three different graphs for both the case bank and the whole banking sector are presented in this appendix. These are the optimal spread between short-term market rate and the DDA rate, the elasticity of DDA demand with respect to changes in the DDA spread, and the discount factor used to calculate the present value of DDA rents. These graphs are presented in Figure 18 for the case bank and in Figure 19 for the banking sector.

Figure 18: Optimal deposit interest rate spread, spread elasticity of deposit demand, and discount factor for case bank

This figure presents three graphs: (i) the optimal spread between short-term market rate and the case bank's demand deposit rate (OPT_RSPREAD), (ii) the elasticity of deposit demand with respect to changes in the spread between the short-term market rate and the deposit rate (CB_IRSE), and (iii) the discount factor used to calculate the present values of simulated future deposit rents (CB_DF). All these paths are obtained from the same simulation trial. Date (month/year) is presented in the X-axis and the simulated value for the process in the Y-axis.

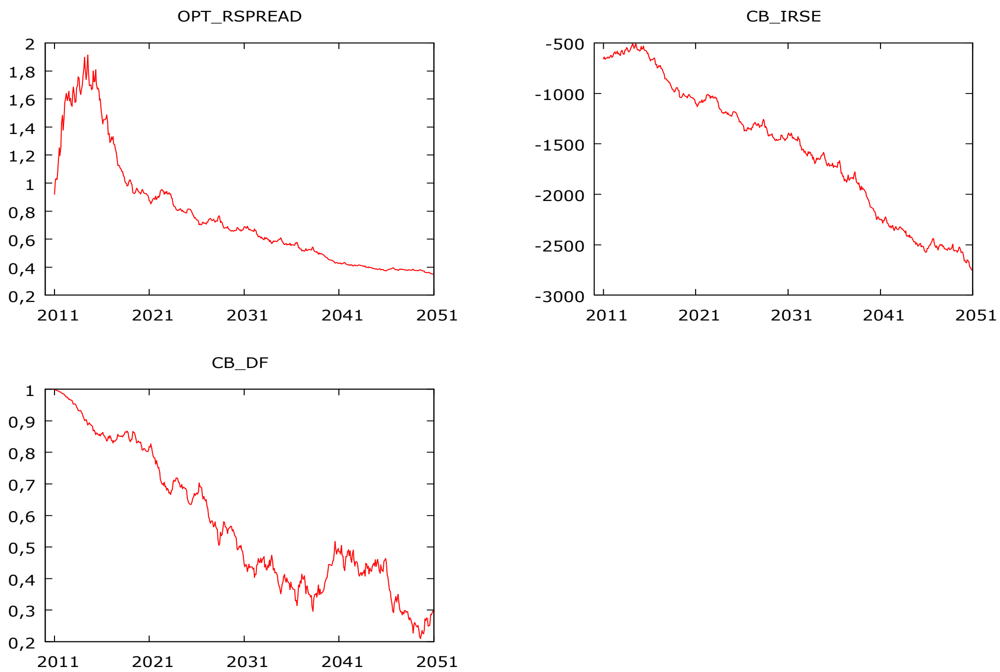
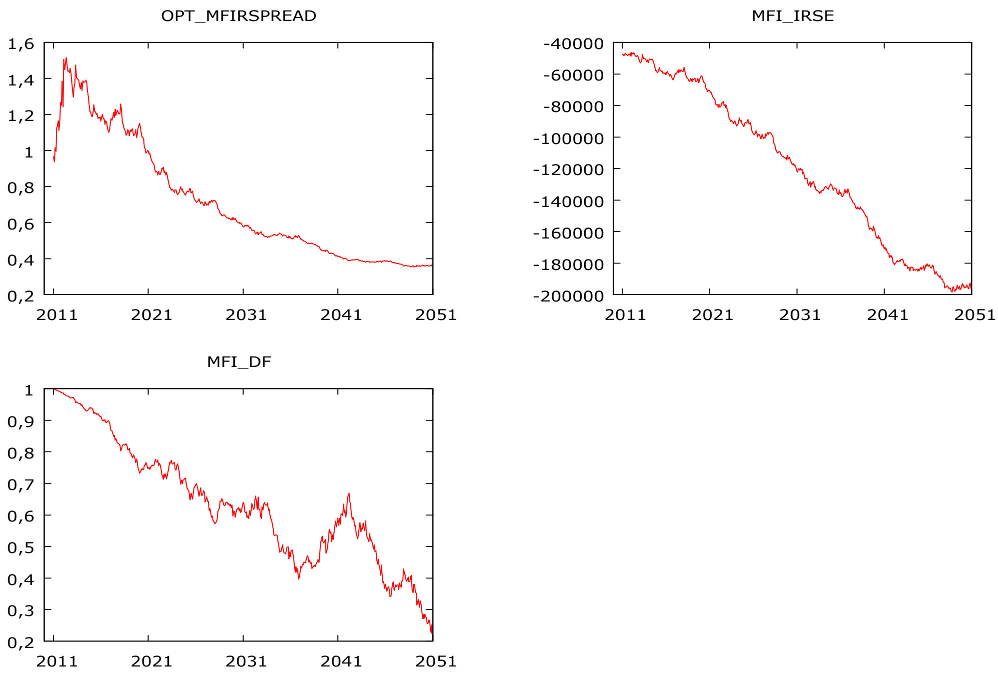


Figure 19: Optimal deposit interest rate spread, spread elasticity of deposit demand, and discount factor for banking sector

This figure presents three graphs: (i) the optimal spread between short-term market rate and the Finnish banking sector's demand deposit rate (OPT_MFIRSPREAD), (ii) the elasticity of deposit demand with respect to changes in the spread between the short-term market rate and the deposit rate (MFI_IRSE), and (iii) the discount factor used to calculate the present values of simulated future deposit rents (MFI_DF). All these paths are obtained from the same simulation trial. Date (month/year) is presented in the X-axis and the simulated value for the process in the Y-axis.



10. APPENDIX 3: DEPOSIT RENT AND LIABILITY ESTIMATES UNDER MARKET RATE SHOCKS

Table 15: Deposit rent estimates under +100 bps market rate shock

This table presents the demand deposit (DDA) rent estimates under different deposit balance dynamics. These rent estimates are obtained assuming that a +100 bps shock in the short-term market rate takes place in the first simulated observation. Rents are reported as percentages of initial DDA balance, i.e. P_0/D_0, where P_0 is the sum of discounted future monthly rents and D_0 is the initial DDA balance at t = 0. Estimates are obtained from 1,000 Monte Carlo simulation trials. z-statistics are given in parentheses. */**/*** denotes significance at the 10/5/1 % level.

P_0/D_0 - +100 bps shock

		Mean	Median	Min	Max	1st decile	9th decile
Case bank							
	Constant[A]	21.45 %	21.29 %	18.90 %	32.16 %	20.36 %	22.68 %
		(629.61) ***					
Decay rate	10 %	9.60 %	9.53 %	8.02 %	12.44 %	8.95 %	10.37 %
		(518.10) ***					
	20 %	5.95 %	5.91 %	4.75 %	7.84 %	5.48 %	6.48 %
		(453.35) ***					
	30 %	4.13 %	4.10 %	3.27 %	5.57 %	3.78 %	4.49 %
		(431.12) ***					
	40 %	3.06 %	3.05 %	2.37 %	3.99 %	2.81 %	3.33 %
		(438.98) ***					
	50 %	2.32 %	2.32 %	1.82 %	3.07 %	2.12 %	2.51 %
		(451.06) ***					
	Growing[B]	64.07 %	64.10 %	55.97 %	76.02 %	60.05 %	67.94 %
		(657.03) ***					
Sector							
	Growing[B]	34.89 %	34.78 %	30.47 %	45.74 %	32.99 %	36.95 %
		(686.44) ***					

[A] DDA balance is assumed to remain constant through time.

[B] DDA balance is assumed to grow according to an AR(2) forecast.

Table 16: Deposit liability estimates under +100 bps market rate shock

This table presents the demand deposit (DDA) liability estimates under different deposit balance dynamics. Liability values (L_0) are defined as the nominal value of DDAs minus the rent and they are reported as percentages of initial DDA balance, i.e. L_0/D_0. These liability estimates are obtained assuming that a +100 bps shock in the short-term market rate takes place in the first simulated observation. Estimates are obtained from 1,000 Monte Carlo simulation trials.

L_0/D_0 - +100 bps shock

	Case bank	Mean	Median	Min	Max	1st decile	9th decile
Decay rate	Constant[A]	78.55 %	78.71 %	67.84 %	81.10 %	77.32 %	79.64 %
	10 %	90.40 %	90.47 %	87.56 %	91.98 %	89.63 %	91.05 %
	20 %	94.05 %	94.09 %	92.16 %	95.25 %	93.52 %	94.52 %
	30 %	95.87 %	95.90 %	94.43 %	96.73 %	95.51 %	96.22 %
	40 %	96.94 %	96.95 %	96.01 %	97.63 %	96.67 %	97.19 %
	50 %	97.68 %	97.68 %	96.93 %	98.18 %	97.49 %	97.88 %
	Growing[B]	35.93 %	35.90 %	23.98 %	44.03 %	32.06 %	39.95 %
	Sector						
	Growing[B]	65.11 %	65.22 %	54.26 %	69.53 %	63.05 %	67.01 %

[A] DDA balance is assumed to remain constant through time.

[B] DDA balance is assumed to grow according to an AR(2) forecast.

Table 17: Deposit rent estimates under +200 bps market rate shock

This table presents the demand deposit (DDA) rent estimates under different deposit balance dynamics. These rent estimates are obtained assuming that a +200 bps shock in the short-term market rate takes place in the first simulated observation. Rents are reported as percentages of initial DDA balance, i.e. P_0/D_0, where P_0 is the sum of discounted future monthly rents and D_0 is the initial DDA balance at t = 0. Estimates are obtained from 1,000 Monte Carlo simulation trials. z-statistics are given in parentheses. */**/*** denotes significance at the 10/5/1 % level.

P_0/D_0 - +200 bps shock

		Mean	Median	Min	Max	1st decile	9th decile
Case bank							
Decay rate	Constant[A]	23.38 % (481.23) ***	23.14 %	20.19 %	34.19 %	21.73 %	25.39 %
	10 %	11.17 % (321.14) ***	10.98 %	8.93 %	17.71 %	10.04 %	12.57 %
	20 %	7.17 % (286.45) ***	7.04 %	5.58 %	12.94 %	6.35 %	8.13 %
	30 %	5.17 % (275.72) ***	5.06 %	4.18 %	9.05 %	4.54 %	5.91 %
	40 %	3.88 % (301.45) ***	3.81 %	3.05 %	5.77 %	3.44 %	4.44 %
	50 %	3.03 % (312.10) ***	2.98 %	2.36 %	4.67 %	2.68 %	3.42 %
	Growing[B]	66.60 % (580.44) ***	66.35 %	56.46 %	81.41 %	62.01 %	71.43 %
Sector							
	Growing[B]	36.99 % (571.33) ***	36.91 %	31.27 %	48.57 %	34.55 %	39.52 %

[A] DDA balance is assumed to remain constant through time.

[B] DDA balance is assumed to grow according to an AR(2) forecast.

Table 18: Deposit liability estimates under +200 bps market rate shock

This table presents the demand deposit (DDA) liability estimates under different deposit balance dynamics. Liability values (L_0) are defined as the nominal value of DDAs minus the rent and they are reported as percentages of initial DDA balance, i.e. L_0/D_0. These liability estimates are obtained assuming that a +200 bps shock in the short-term market rate takes place in the first simulated observation. Estimates are obtained from 1,000 Monte Carlo simulation trials.

L_0/D_0 - +200 bps shock

		Mean	Median	Min	Max	1st decile	9th decile
Case bank							
Decay rate	Constant[A]	76.62 %	76.86 %	65.81 %	79.81 %	74.61 %	78.27 %
	10 %	88.83 %	89.02 %	82.29 %	91.07 %	87.43 %	89.96 %
	20 %	92.83 %	92.96 %	87.06 %	94.42 %	91.87 %	93.65 %
	30 %	94.83 %	94.94 %	90.95 %	95.82 %	94.09 %	95.46 %
	40 %	96.12 %	96.19 %	94.23 %	96.95 %	95.56 %	96.56 %
	50 %	96.97 %	97.02 %	95.33 %	97.64 %	96.58 %	97.32 %
	Growing[B]	33.40 %	33.65 %	18.59 %	43.54 %	28.57 %	37.99 %
	Sector						
	Growing[B]	63.01 %	63.09 %	51.43 %	68.73 %	60.48 %	65.45 %

[A] DDA balance is assumed to remain constant through time.

[B] DDA balance is assumed to grow according to an AR(2) forecast.