DNB Working Paper

No. 721 / July 2021

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Jorien Freriks and Jan Kakes

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EUROSYSTEEM

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* Views expressed are those of the authors and do not necessarily reflect official positions of De Nederlandsche Bank.

Working Paper No. 721

July 2021

De Nederlandsche Bank NV
P.O. Box 98
1000 AB AMSTERDAM
The Netherlands

Bank interest rate margins in a negative interest rate environment*

Jorien Freriks [a]
Jan Kakes [a]

July 2021

[a] De Nederlandsche Bank, Amsterdam.

Abstract[1]

This paper studies the impact of the negative interest rate policy (NIRP) on euro area banks' interest rate margins, using bank-individual data for the 2007-2019 period. An important extension to other studies is our breakdown of banks' interest rate margin into a funding and lending component. Because of banks' reluctance to reduce the interest rate on household deposits below zero, the funding margin of banks more reliant on deposit funding has declined compared to that of other banks. Our evidence shows that these banks have been unwilling or unable to compensate this by boosting their lending margins. Therefore, negative rates have significantly reduced the overall net interest margin of deposit-dependent banks compared to other banks.

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Keywords: monetary policy, negative interest rates, banks, interest margin
JEL codes: E43, E52, G21

[1] We are grateful to Joost Bats, Maurice Bun, Jan Willem van den End, Niels Gilbert, Willem Heeringa, Jurian Hoondert, Michael Kurz, Sebastiaan Pool, René Rollingswier, Daniël van Schoot, Garyn Tan and participants of the DNB Research Seminar for their useful advice and comments.

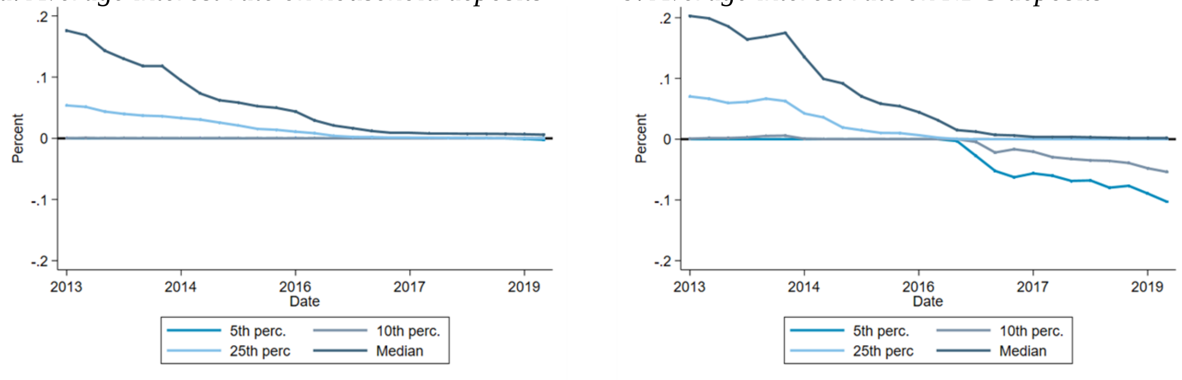
1. Introduction

In June 2014, the European Central Bank (ECB) reduced one of its main policy rates into negative territory. Further interest rate cuts followed, bringing the ECB's Deposit Facility Rate (DFR) – the rate banks receive when they deposit funds with the Eurosystem – to -0.50% in September 2019. Negative interest rates are controversial and have received a lot of attention, both from academics and policymakers. A key question is whether the transmission of monetary policy to bank interest rates and the real economy changes when interest rates are in negative territory. We contribute to this debate by investigating the impact of negative interest rates on bank interest rate margins.

When rates are very low or negative, the monetary policy transmission may be hindered by a lower bound on deposit rates. Banks are reluctant to charge a negative interest rate on deposits, because of the possibility of households and (to a lesser extent) firms to hoard cash, which yields a nominal return of zero. Reputational considerations may also play a role. Data on bank deposit rates in the euro area confirm the existence of a lower bound: interest rates on short-term deposits, especially for households, appear to be bound by zero. As illustrated in Figure 1, no bank in our sample has – on average – charged a negative interest rate on household deposits, although in recent years some banks did start charging negative rates above a certain threshold. As regards deposits of non-financial companies (NFCs), over time, an increasing proportion of banks started charging negative deposit rates, as also demonstrated by Altavilla et al (2019). Still, the vast majority of banks continues to charge an average rate that is positive or close to zero (see Figure 1b, which shows that any rates from the 25th percentile onwards have remained positive).

Figure 1: Development of deposit rates in the euro area over time (overnight deposits only)

a. Average interest rate on household deposits *b. Average interest rate on NFC deposits*



Source: ECB

The lower bound on deposit rates squeezes banks' net interest rate margin (NIM), especially if banks fully pass on lower interest rates to lending rates. This hurts bank profitability and may eventually, through its impact on bank capital, decrease banks' intermediation capacity, reducing the effectiveness of an interest rate cut. Brunnermeier and Koby (2018) formalized this idea and introduced the so-called "reversal rate", below which a reduction of the policy rate may actually have a contractionary impact on the economy.

Our analysis adds to the reversal rate literature by disentangling the different components of the NIM. We focus on the NIM because it is a key element of the reversal rate mechanism and the main determinant of bank profitability. According to the Eurosystem's Consolidated Banking Data, the NIM comprised almost 60 percent of banks' total operating income in 2014. As such, it is difficult for banks to fully compensate the loss in interest income through other means.

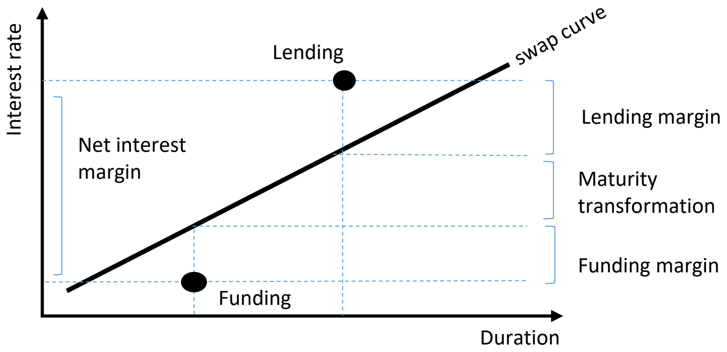
Our decomposition of the NIM can be derived from a bank's net interest income (see Section 4) and is illustrated by Figure 2:

1. *Lending margin*: the difference between the lending rates earned on outstanding assets and a corresponding risk-free market interest rate, i.e. the swap rate with the same duration. This is the markup that banks earn by setting lending rates higher than the market interest rate.
2. *Funding margin*: the difference between the interest rate paid on liabilities and corresponding swap rates. In our paper we also distinguish the deposit margin, which is the funding margin on deposits (defined as the difference between the interest rate paid to depositors and corresponding swap rates).
3. *Maturity transformation*: the difference between risk-free (swap) interest rates that correspond to the assets and liabilities. Banks can decide to hedge this position, except for the part funded with equity.

The funding and lending margins together comprise a commercial margin, which compensates the bank for the operational costs of providing financial services and expected losses and reflects other markups such as a bank's risk aversion and shareholders' expected return (Ho and Saunders, 1981; Chaudron et al., 2020). Banks' ability to set deposit and lending rates is typically attributed to their special role to mitigate informational frictions, which gives them pricing power vis-à-vis intermediary-dependent counterparties.[2] Earnings from maturity transformation depend on banks' exposure to interest rate risk and the shape of the yield curve.

[2] There is a long-standing literature on the role of banks as intermediaries to reduce information frictions, particularly (e.g. Leland and Pyle, 1977; Diamond, 1984). Drechsler et al. (2021) present a model of banks' unique role in deposit markets, which gives them significant pricing power.

Figure 2: Decomposition net interest margin



The typical textbook assumption is that banks borrow short and lend long, earning a significant profit on maturity transformation. In practice, however, since deposits tend to have a large behavioural duration, banks' exposure to interest rate mismatch tends to be much smaller than contractual maturities suggest (Drechsler et al., 2021). Moreover, many banks largely hedge any remaining duration mismatch with interest rate swaps (Chaudron, 2018; Hoffmann et al., 2019), which reduces their exposure to, and hence earnings from, interest rate risk. We therefore isolate the commercial margins, the implicit assumption being that banks have fully hedged their interest rate exposure due to maturity transformation. Decomposing the NIM is furthermore important to improve our understanding of the different channels through which negative interest rates may impact the NIM.

The funding margin is particularly relevant in the context of low or negative interest rates, as the funding margin on deposits ("the deposit margin") is likely to be squeezed by the lower bound on retail deposit rates (Borio et al., 2017). The impact is expected to be largest for banks more reliant on deposit funding, as those banks are impacted more by the lower bound on deposit rates. The first two hypotheses that we would like to test are therefore that negative interest rates have reduced the funding margin of banks (hypothesis I), and that the effect is larger the more banks rely on deposit funding (hypothesis II). We indeed find evidence that this is the case in the euro area.

The impact of negative interest rates on the lending margin is less obvious, as there are several channels that work in opposite ways. First, policy rate cuts are expected to stimulate the economy, improve the repayment capacity of borrowers and lower credit risk. All else equal, this should reduce the lending margin of banks.[3] In the ECB's Bank Lending Survey (ECB, 2020), banks indeed report a negative impact of the NIRP on lending margins. Second, policy rate cuts may stimulate credit demand, encouraging banks to keep rates high and boost their lending margin. Third, depending on the level of competition, banks can try to compensate for the reduction in the deposit margin by increasing their lending margin (i.e. not lowering the lending rate to the same extent as the market interest rate). The latter should be especially relevant for deposit dependent banks, whose deposit margin has decreased most. Amzallag et al (2019) and Chaudron et al. (2020) find evidence that in response to negative interest rates, banks have increased lending rates in Italy and The Netherlands, respectively. Our third and fourth hypotheses are therefore that in response to negative interest rates, banks have increased lending margins (hypothesis III), and that the impact is larger for banks more reliant on deposit funding (hypothesis IV).

We use individual bank data to test the impact of a negative policy rate on euro area banks' (new business) interest rate margins. This allows us to use the

[3] A similar channel may exist for the funding margin: higher economic activity is expected to boost bank solvency and therefore reduce bank funding costs. For banks, however, this channel is weaker than for NFCs and households because of deposit guarantees and banks' access to safety nets.

heterogeneity across banks to identify the impact of NIRP on funding and lending margins. More specifically, we investigate whether banks heavily relying on deposit funding are more affected by NIRP relative to banks that are less dependent on deposit funding.

As will be further discussed in Section 4, our analysis is subject to potential identification problems and other caveats. To address these issues, we present various specifications, which differ with respect to the inclusion of bank and time fixed effects, other control variables and two alternative indicators for (negative) interest rate policy. We also present various robustness checks, using alternative measures of bank deposit dependency, an alternative approach to calculating funding margins and pooled regressions to address potential multicollinearity.

We find that the funding margins of banks more reliant on deposit funding have decreased more in response to NIRP than those of banks that use less deposit funding. Compared to a bank with no deposit funding, NIRP reduces the funding margin of the average bank in our sample (with 35 percent of deposit funding) by about 18 basis points in the long run. At the same time, we do not find evidence that deposit dependent banks compensate their loss by keeping lending margins high. One possible explanation is that competitive pressures, both from banks less affected by negative interest rates and from non-banks, prevented these banks from doing so.

Our results suggest that when interest rates stay low for a prolonged period of time, the overall interest margin of deposit dependent banks declines compared to other banks. And although the impact is likely to be gradual, our analysis does suggest that the impact can be substantial. In the long-run, the Return on Equity of the average bank in our sample is, all else equal, close to 1,6 percentage points lower compared to a bank with no deposit funding.

The rest of this paper is organized as follows. In Section 2, we discuss recent literature on the reversal rate and how banks deal with interest rate risk. Section 3 describes our data sources and presents descriptive statistics of our main variables. Section 4 discuss our methodology and defines our main hypotheses. Our main results are presented in Section 5, with further evidence provided in Section 6. Finally, Section 7 presents our robustness checks, while Section 8 concludes.

2. Related literature

Our paper is related to the relatively recent literature that focuses on the reversal rate. Several theoretical papers have assessed the possibility of a reversal rate. In addition to the study by Brunnermeier and Koby (2018) mentioned in the introduction, Eggertson et al. (2019) and Kumhof and Wang (2020) have developed theoretical models of the reversal rate. It should be noted that these models focus on transmission via the banking sector. It cannot be ruled out that even when the banking channel is impaired, negative interest rates could still have a positive impact on economic activity and inflation through other channels such as the exchange rate or wealth effects.

In recent years, several studies have investigated the impact of low and negative interest rates empirically. We refer to a recent paper by Heider et al (2021) for an extensive overview of the literature. Many papers look at the transmission of negative interest rates to bank lending behaviour. Focusing on Sweden, Eggertson et al. (2019) find that negative policy rates have been ineffective because of a lack of transmission to lending rates. These findings are however partly disputed by

Erikson and Vestion (2019), who conclude that the pass-through of policy rate cuts to short-term household lending rates in Sweden was almost complete, albeit sluggish. Using a sample of German banks, Eisenschmidt and Smets (2019) also find no indications that the negative interest period has changed the pass-through to bank lending rates. Altavilla et al. (2019) conclude that euro area banks have been able to pass on negative rates to corporate depositors, which provides incentives for firms to increase investments. Other studies have looked at the impact of negative interest rates on bank lending. Heider et al. (2019) conclude that euro area banks which rely on deposit funding have reduced their credit supply and increased their risk profile compared to other banks in the syndicated loan market after the start of the ECB's negative interest policy in 2014. By contrast, Tan (2019) and Demiralp et al. (2021) find that negative rates stimulate lending.

Our paper is most closely related to a number of empirical studies that study the impact of unconventional monetary policy on bank profitability. Most of these studies focus on the impact of NIRP. Borio et al. (2017) find, for a large sample of international banks, that higher short-term interest rates and a steeper yield curve are positive for bank profitability, implying that ongoing low interest rates are likely to reduce profits. In contrast, Claessens et al. (2018) conclude for a large, global cross-country panel that a reduction in interest rates squeezes banks' interest margin, particularly in a low interest rate environment, but that overall profitability is less affected. Altavilla et al. (2018) find similar results for the euro area. Their results suggest that low interest rates also have positive effects on bank profitability that are – at least temporarily – beneficial for banks, such as capital gains on securities holdings, higher demand for credit, and a reduction in credit risk.

Molyneux et al. (2019) investigate the impact of NIRP on bank profitability and the NIM for banks from 33 OECD countries, which allows them to compare differences between jurisdictions that adopted NIRP and those that did not. In contrast to the aforementioned studies and our results, they find that banks located in NIRP countries performed worse, also in terms of overall profitability, than those located in other countries. Particularly smaller banks with relatively high capital ratios and interest-oriented business models are negatively affected. Finally, Ampudia and Van den Heuvel (2018) analyze the impact of interest rate changes on bank performance as reflected by the response of stock prices. They find that in periods of negative interest rates, stock prices of banks relying on deposit funding fall relatively more following a rate cut. Bats et al. (2020) confirm this result and find that especially downward movements in the shorter-end of the yield curve negatively affect bank stock prices.

Another strand of empirical literature that is related to our paper focuses on banks' interest risk and the extent to which banks hedge this risk. Drechsler et al. (2021) find that, because assets and liabilities of US banks are largely matched in terms of the interest sensitivity, banks' de facto interest rate risk is limited. They argue that banks' de facto matching of assets and liabilities is conceptually similar to an interest rate swap. The stickiness of deposit rates reflects banks' deposit franchise, which gives them market power but entails significant fixed operating costs, similar to the fixed lag in a swap contract. Hoffmann et al. (2019) conclude that banks with high initial interest risk – which can often be attributed to mortgage exposures – tend to hedge a larger proportion of this risk. Chaudron (2018) finds that Dutch banks are relatively insensitive to interest rate changes, as they hedge most of their duration gap. Similarly, Chaudron et al. (2020) show that Dutch banks' NIM remained broadly constant in recent years despite a decline in interest rates and a flattening of the yield curve. They find that the constant NIM is the net result of declining maturity transformation and higher commercial margins, implying that overall income has not been affected much by lower interest rates.

3. Data

3.1 Data sources

Our two main data sources are the ECB's Individual Balance Sheet Items (IBSI) and the Individual Monetary and Financial institution Interest rates (IMIR). These confidential datasets are available for over 300 Monetary and Financial Institutions (MFIs) located in the euro area. IBSI contains monthly series of banks' main assets and liabilities; IMIR adds information on lending and deposit rates.[4] We use data from the third quarter of 2007 up to and including the second quarter of 2019. The panel is unbalanced; individual bank data either starts at the start of the sample period, when a bank is created, or when a country joins the euro area. For some banks, the data end after mergers or acquisitions. The data are non-consolidated, i.e. MFIs can be part of a larger banking group.

Our main interest is the impact of the negative interest rate on banks' net interest margins. To calculate interest margins, we first need to construct banks' funding costs (the weighted average interest rate paid on liabilities) and their interest income (the weighted average interest rate earned on loans). We use interest rates on new business volumes rather than on outstanding volumes, as this is where

[4] More detailed information on these data is provided by the Manual on MFI balance sheet statistics (ECB, 2019) and the Manual on MFI interest rate statistics (ECB, 2017).

the impact is expected to show up first. We calculate the funding costs and interest income with IBSI/IMIR data, which are available for households and non-financial companies (NFCs), but not for financial counterparties and central bank borrowing. To estimate total funding costs, we therefore use supplementary data sources.

The cost of borrowing from the Eurosystem is based on confidential information on banks' participation in monetary refinancing operations. For targeted longer-term refinancing operations (TLTROs) – which have been substantial for several institutions – we assume that banks have met the lending benchmark that is part of such operations (which has been the case for a large majority of banks).[5] The costs of borrowing from financial counterparties (i.e. from other banks, insurers, pension funds and other financials) are based on market information. More specifically, we assume that banks pay EONIA on deposits held by financials, and the five-year swap rate plus a CDS premium for debt securities issued. This CDS-premium is a country-specific average for five-year senior unsecured bank debt. Finally, to calculate funding and lending margins, we take swap interest rates from Bloomberg, which we use as a benchmark (see Annex).

To control for additional bank-specific indicators, we add quarterly information on bank regulatory capital ratios and credit ratings, which are obtained from SNL Financial. The capital ratio is the risk-weighted Tier 1 ratio (more recent measures such as the CET1 are only available for a few years). Ratings are based on Moody's/S&P/Fitch (or the average if more than one of these is available), and

[5] TLTROs are similar to funding-for-lending schemes offered by other central banks. The interest rate banks pay on this type of central bank funding is conditional on whether the increase in their lending to corporates and households meets a predetermined benchmark. See for example Bats and Hudepohl (2019) or Andreeva and García-Posada (2020) for more details.

translated to a quantitative scale that runs from 1 (D) to 22 (AAA). Since not all MFIs in the IBSI dataset are included in the SNL Financial database, using these indicators reduces our sample significantly to about 80 MFIs. Data from Eurostat and the ECB Statistical Data Warehouse on GDP and HICP inflation are used to construct country-specific controls.

3.2 Data treatment

MFIs can be classified into six different categories (Table 1): standalone entity, parent entity, and four types of subsidiaries: domestic (subsidiary or branch parent located in the same country as the parent), other EMU (parent located in a different EMU country), other EU (parent not located in the EU, but not in the EMU) and non-EU (parent not located in the EU).

Table 1: MFI classification

	Number	**Total assets**
	# MFIs	Average, EUR bn
Stand-alone entity	31	367
Parent	113	63
Subsidiary – domestic	56	59
Subsidiary - other EMU	12	12
Subsidiary - other EU	52	40
Subsidiary - non-EU	30	42
	294	

Data are at monthly frequency covering the period 2007Q3-2019Q2. Number of MFIs as measured on 2014Q2.

To obtain a robust and relevant sample, we exclude a number of banks. We drop institutions that play a limited role in the transmission of monetary policy and are therefore less relevant for our analysis. These include branches and subsidiaries of a non-EMU parent (i.e. the last two categories in Table 1), niche players (e.g. CCP-related entities) and very small entities (below the first percentile of our sample, based on total assets). Given our interest in the impact of negative interest rates on bank intermediation, we also exclude specialized banks with little (less than 5 percent of total assets) or no lending to the real economy. We exclude banks from Cyprus and Greece, which were hit by a systemic banking crisis during most of the period of our sample. Moreover, we exclude Estonia, Latvia, Lithuania, Luxemburg, Slovenia and Slovakia, because of limited availability of supplementary data such as CDS spreads, which we use to calculate the cost of market debt financing. Finally, we drop a few banks with frequent and large jumps in total assets. More specifically, we drop banks for whom the absolute quarterly growth rate of total assets exceeds the 99th percentile four times over our sample period. For the remaining large jumps, we create a dummy variable that equals one on the date the event takes place and zero otherwise. We further correct our data for outliers by winsorizing some variables at the 1st and 99th percentiles.

Our final panel includes 170 MFIs from 10 euro area countries, which comprise about 50 percent of total euro area bank assets. As not all MFIs are covered by SNL, when we use bank-specific variables from the SNL Financial database our sample reduces to about 80 banks (approximately 40 percent of total euro area bank assets). Although IMSI and IMIR are available at a monthly frequency, our analysis is based on quarterly data to match macroeconomic variables and bank-specific data obtained from SNL Financial.

3.3 Descriptive statistics

Descriptive statistics are shown in Table 2. There is significant variation within our dataset regarding the size of banks, their capital position, the proportion of deposit funding, the importance of net interest income and credit ratings. Borrowing and lending rates (on new business volumes) also vary, but that mainly reflects a substantial decline over time rather than cross-sectoral variation. On average, deposit funding constitutes the most important funding source, representing about 35% of total liabilities. For some banks, however, deposit funding can be as high as 70% of total liabilities. Most deposits are from households.

Table 2: Descriptive statistics

	# Obs.	Mean	Std. Dev.	10th perc.	90th perc.
Macroeconomic variables					
EONIA	7498	0.58	1.28	-0.35	2.97
GDP growth	7498	0.56	1.36	-0.41	1.41
Inflation	7498	1.47	1.19	-0.03	3.07
Bank-specific variables					
Total assets (EUR mln)	7498	95,208	156,249	8,470	244,125
Capital share (%TA)	7498	7.63	4.18	3.08	12.82
Deposits (%TA)	7498	35.89	24.81	0.38	69.99
NFC deposits (%TA)	7498	7.38	5.83	0.15	14.31
HH deposits (%TA)	7498	28.51	22.47	0.06	59.25
Total lending rate	7066	2.88	1.35	1.48	5.07
HH lending rate	6636	3.02	1.25	1.63	4.90
NFC lending rate	6823	2.85	1.45	1.40	5.17
Total deposit rate	6820	0.68	0.81	0.01	1.82
HH deposit rate	6729	0.67	0.77	0.01	1.74
NFC deposit rate	6679	0.64	0.93	0.00	2.00
Variables SNL database					
Tier1-ratio	4911	12.73	4.95	7.72	18.06
Credit rating	3968	16.14	2.78	12.00	19.00

Data are at quarterly frequency covering the period Q32007-Q2019. Unless otherwise specified, variables are defined in percentage.

3.4 Decomposition of NIM

Our analysis focuses on the impact of low interest rates on the different components of the NIM. The decomposition of the NIM can be derived from a bank's net interest income (NII):

$$(\mathbf{1})\quad \boldsymbol{NII_{i,t}} = \text{interest received on lending – interest paid on funding}$$

$$= \left(r_t^{A,market} + r_{i,t}^{A,lending\ margin}\right) \cdot A_{i,t} - \left(r_t^{L,market} - r_{i,t}^{L,funding\ margin}\right) \cdot \left(A_{i,t} - E_{i,t}\right)$$

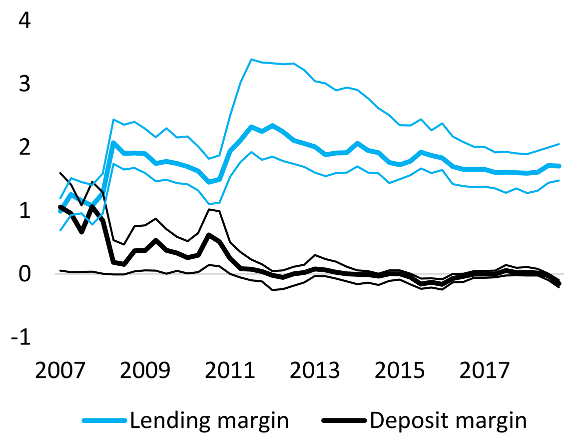
where $A_{i,t}$ = total assets, $E_{i,t}$ = equity; i and t are subscripts for individual banks and time periods. The lending rate consists of the risk-free market interest rate $r_t^{A,market}$ with the same duration as the assets and a lending margin $r_{i,t}^{A,lending\ margin}$. Similarly, the borrowing rate consists of the risk-free market interest rate $r_t^{L,market}$ minus a funding margin $r_{i,t}^{L,funding\ margin}$. We expect the latter markdown to be larger than zero only for deposit funding. We obtain the NIM by dividing NII by total (interest earning) assets, which results in:

$$(2)\ \ NIM_{i,t} = r_{i,t}^{A,lend.mgn} + r_{i,t}^{L,fund.mgn} \cdot \left(\frac{A_{i,t} - E_{i,t}}{A_{i,t}}\right) + \left[r_t^{A,market} - r_t^{L,market} \cdot \left(\frac{A_{i,t} - E_{i,t}}{A_{i,t}}\right)\right]$$

This expression consists of the three components – a lending margin, a funding margin and a remainder that reflects maturity transformation and may be hedged – as illustrated in Figure 2.

Both the lending margin and the funding margin are not directly observable but have to be estimated, based on banks' lending rates and borrowing costs (which are available) and assumptions regarding the duration of assets and liabilities. Our main approach to approximate the duration relies on information in our database on the (remaining) contractual maturities. The IMIR dataset includes breakdowns of assets and liabilities into different maturity buckets. In some cases, however – particularly (demand) deposits – the duration established by empirical analysis is much longer (typically 2-3 years) than their contractual maturities suggest, as reflected by stickiness in deposit interest rates (Hoffmann et al. 2019, Drechsler et al., 2021). In these cases we impose a duration typically found in the literature. For each subcategory, a margin is subsequently calculated by deducting funding rates from the corresponding swap interest rate (funding margin) or deducting the swap rate from lending rates (lending margin). The overall funding and lending margins are then calculated as a weighted average of these subcategories. Figure 3 shows the development of lending and funding margins as calculated. Annex A provides more information on the calculations used.[6]

Figure 3: Lending and funding margins
Based on new business; thin lines mark interquartile ranges.



Source: own calculations (see Annex A)

4. Hypotheses and methodology

As indicated in the introduction, we define the following main hypotheses:

1. Once the lower bound on retail deposits is reached, further interest rate cuts reduce the funding margin $r_{i,t}^{L,funding\ margin}$;
2. Funding margins decline more for banks more reliant on deposit funding;

[6] In the robustness section we also use a second method, which derives the duration from a replicating portfolio of market interest rates.

3. To compensate for declining funding margins, following an interest rate cut in negative territory, banks increase their lending margins $r_{i,t}^{A,lending\ margin}$;
4. Lending margins increase more for banks more reliant on deposit funding;

To test our hypotheses, we follow a strategy similar to Altavilla et al (2018) and Claessens et al (2018). In particular, we start with the following baseline specification:

$$y_{it} = \beta_1 y_{it-1} + \alpha_i + \beta_2 \boldsymbol{NIRP}_t + \beta_3 \boldsymbol{Deposit\ share}_{i,t} + \beta_4[\boldsymbol{NIRP}_t \times \boldsymbol{Deposit\ share}_{i,t}] + \theta' \boldsymbol{x}_{it} + \varphi' \boldsymbol{z}_t + \varepsilon_{it} \quad (1)$$

where the dependent variable y_{it} is a NIM component of bank *i* at time *t*. In line with most empirical literature on the impact of interest rates movements, we use a dynamic model and include the lagged dependent variable to account for partial adjustment by banks in each period. Our two main dependent variables are the funding margin and the lending margin (based on new business). In addition to the funding and lending margins, we also consider the total NIM as a dependent variable. The total NIM comprises both the funding and lending margins as well as income from maturity transformation (implicitly ignoring any potential interest risk hedging).

Our main explanatory variables of interest are the dummy variable $\boldsymbol{NIRP}_t$, which equals one for all observations beginning in June 2014 (the introduction of the negative interest rate policy) and zero otherwise, and its interaction with banks' dependency on deposit funding (as measured by the share of total deposits over total liabilities). We include bank fixed effects (α_i) to control for possible timeinvariant differences across banks. As is common in the literature, we also include a set of country- and bank-specific controls that vary over time, indicated by $\boldsymbol{x}_{it}$ and $\boldsymbol{z}_t$ respectively, with corresponding coefficient vectors θ and φ. Country-specific controls include the real GDP growth rate and HICP-inflation. The set of time-varying bank-specific controls include banks' leverage ratios, here proxied by the share of capital and reserves over total assets, and the size of the bank (as measured by the logarithm of total assets). Finally, we include dummies to control for structural breaks in our sample, such as mergers and acquisitions. Standard errors are always clustered at the bank level.

In a second specification, we include a full set of year-quarter time dummies, to control for unobserved (macroeconomic) factors that are common to all banks, but vary over time and are not captured by our control variables. Including time dummies, however, means that we can no longer estimate the absolute effects of the NIRP dummy on bank margins (β_2), but only the interaction term. In a third specification, we add more bank-specific variables that we take from SNL Financial. These include the Tier 1 capital ratio (instead of the leverage ratio taken from IBSI) and a bank's credit rating. Since these data are not available for all banks in our sample, we can only run these extended regression equations for a subsample of our banks.[7]

Equation (1) is a dynamic fixed-effects panel model. Although the inclusion of a lagged dependent variable implies that the model may suffer from Nickell bias (Nickell, 1981), this bias is likely to be small as our 48 quarter sample

[7] We also have information on the share of bank loans that are non-performing loans (NPLs). However, data on NPLs are only available for a limited number of banks in our SNL-sample. Since including this variable in our regressions did not materially change our results, we decided to exclude this variable in the regressions shown.

is sufficiently long (Judson and Owen, 1999). Hence, there is no strong case to apply methods that address this bias, such as the Arellano-Bond estimator.

Another potential concern is endogeneity. First, there could be omitted variable bias when banks' interest rate margins are driven by factors other than monetary policy, which may themselves influence the monetary policy stance. One likely candidate is the state of the economy or competition from non-banks. We control for this by including macroeconomic variables and, in the second and third specifications, year-quarter time effects (although we admit this is imperfect, as monetary policy is forward looking). We also do not explicitly take into account other unconventional monetary policy measures which the ECB launched during the same period. Most noteworthy are the different asset purchase programmes launched between 2014 and 2016, such as the third covered bond purchase programme, the public sector purchase programme, and the corporate sector purchase programme. That said, when we include time dummies, we implicitly also control for other unconventional measures taken during our sample period. Second, our estimation may suffer from reverse causality if central banks respond to changes in banks' interest rate margins rather than the other way around. The main aim of negative interest rates was to bring inflation back to target, and we do not expect that bank interest rate margins were a key consideration (a line of reasoning also followed by Molyneux et al., 2019). However, it cannot be ruled out that policy makers do take into account bank performance when deciding on monetary policy measures, especially if this is important for the transmission of monetary policy.

To mitigate the aforementioned issues, we exploit the heterogeneity in our sample by considering the impact of NIRP on deposit dependent banks versus other banks. Our identifying assumption is that the impact of shocks other than NIRP on interest margins is the same across banks, regardless of the degree of deposit funding.

Another concern with our estimation strategy is that a bank's dependence on deposit funding may be endogenous if banks adapt their funding profile to the change in margins (e.g. by attracting more market funding and/or funding from the central bank). We have therefore examined the development of the deposit share over time for the different quartiles of banks. For all quartiles, the share of deposit funding actually *increased* after the introduction of negative interest rates, suggesting that banks did not adjust their funding profile in order to be less sensitive to negative interest rates. Regulatory changes, such as the introduction of the Net Stable Funding Ratio (NSFR) may have stimulated the importance of deposit funding, as it is considered a relatively stable financing source.

Relatedly, the inclusion of bank fixed effects in addition to the deposit share may result in multicollinearity, especially if the dependency on deposit funding does not change much over time. To see whether this makes a big impact, we also investigate specifications without bank fixed effects in the robustness section.

5. Results

5.1 Funding margin

The first three columns of Table 5.1 report the regression results for three different specifications of our baseline model, with the funding margin as the dependent variable. The first specification (Column 1) includes our two main explanatory variables of interest – NIRP and the proportion of deposit funding – as well an interaction term [NIRP × deposit share]. Moreover, we include bank fixed effects and macroeconomic controls at the country level, but we still exclude the time dummies. Both the NIRP dummy and its interaction with the share of deposits have a negative sign, therefore supporting our first two hypotheses: negative interest rates erode banks' funding margin, particularly for banks that rely on deposit funding. However, we are careful with interpreting the results, because we have not yet included time dummies.

Column 2 presents a more robust specification in which we include, besides bank fixed effects, also time fixed effects to control for unobserved (macroeconomic) variables that vary over time. Because of the inclusion of time dummies, we can no longer estimate the time series that are not bank-specific (i.e. our NIRP variable). Importantly, the [NIRP × deposit funding] interaction term can be retained, which allows us to identify the relative impact of NIRP. Again, the coefficient of the interaction term is significantly negative, implying that the funding margin of high deposit banks declines more in response to negative interest rates than that of low deposit banks. Column 3 repeats the analysis in Column 2, but adds additional bank-specific controls taken from the SNL database. Although these variables are only available for a subset of our sample, the outcomes remain similar, albeit less pronounced.[8]

[8] To check whether these differences are due to the inclusion of new control variables or due to the usage of a different, smaller sample of banks, we have also run the regressions for the SNL sub-sample only, but excluding the additional variables. Those results are very similar to the results including the additional variables, which suggests that sample selection plays a role.

Table 5.1: Funding and lending margin

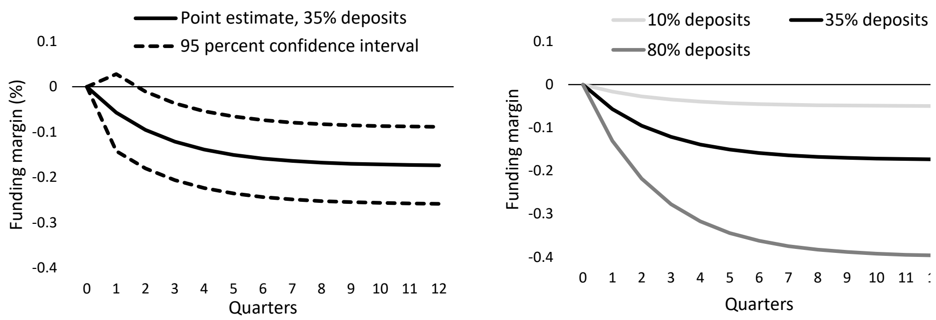
	Funding Margin			Lending Margin		
	(1)	(2)	(3)	(4)	(5)	(6)
Y_{t-1}	0.715***	0.674***	0.772***	0.824***	0.798***	0.814***
	(0.0328)	(0.0421)	(0.0180)	(0.0147)	(0.0189)	(0.0237)
NIRP	-0.0144			-0.0337**		-0.0753**
	(0.0115)			(0.0139)		(0.0314)
Deposit share	-0.00104	0.000862	-0.000312	-0.00167*	-0.00238***	-0.00174
	(0.000792)	(0.000821)	(0.000703)	(0.000861)	(0.000901)	(0.00138)
NIRP * Deposit share	-0.000917***	-0.00163***	-0.000510***	-0.000323	-0.0000315	-0.000286
	(0.000304)	(0.000358)	(0.000185)	(0.000266)	(0.000279)	(0.000399)
GDP growth	0.0234***	0.0101**	0.00664*	-0.0172***	-0.00231	-0.00949
	(0.00520)	(0.00490)	(0.00372)	(0.00644)	(0.00461)	(0.00973)
Inflation	0.00494	0.000312	-0.0112**	0.0224***	0.0325***	0.0392***
	(0.00318)	(0.00577)	(0.00450)	(0.00467)	(0.00670)	(0.00953)
Total assets (log)	-0.0954***	-0.0149	-0.0372*	0.0695**	0.0126	0.0559
	(0.0270)	(0.0224)	(0.0200)	(0.0310)	(0.0303)	(0.0498)
Leverage ratio	-0.0128***	-0.00498**		0.00153	-0.00213	
	(0.00259)	(0.00198)		(0.00395)	(0.00383)	
Tier1-ratio			0.000425			-0.000542
			(0.00153)			(0.00219)
Credit rating			0.00173			0.00484
			(0.00262)			(0.00559)
Bank FE	YES	YES	YES	YES	YES	YES
Time FE	NO	YES	YES	NO	YES	YES
N	7122	7122	3815	6890	6890	3739
adj. R^2	0.699	0.777	0.866	0.737	0.798	0.806

Standard errors (in parentheses) clustered at bank level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

The impact of control variables is largely consistent across the different specifications and mostly in line with the existing literature, with a few exceptions where one or more coefficients are insignificant. GDP growth has a positive impact on the funding margin, which may reflect the impact of favourable economic conditions on banks' risk profile, lowering funding costs. Inflation is insignificant or has a slightly negative impact, whereas the size of banks (log of total assets) has a negative impact (but the coefficient is not always significant). Although the literature (see for example Babihuga and Spaltro (2014); Arnould et al (2020); Schmitz et al. (2017)) mostly finds a negative relationship between bank solvency and funding costs, implying that better capitalized banks would (ceteris paribus) have lower funding costs, our measures of financial soundness have a mixed impact on the funding margin. The impact of the risk-weighted regulatory Tier 1 ratio – which is only available for the SNL subset – is insignificant. Also a higher credit rating (indicated by a higher value in our regressions) has no significant effect on the funding margin in our sample. The impact of the unweighted leverage ratio – which is available for the entire sample – is significantly negative, which suggests that better capitalized banks actually have higher funding costs. A possible explanation is that the banks in our sample with a higher leverage ratio have a higher risk profile. In support of this, our data shows a positive correlation between the leverage ratio and the share of non-performing loans. Another potential explanation is the imperfectness of our measure of the funding margin, which partly relies on non-bank-specific country data to proxy for funding costs of market instruments.

How material is the relative impact of negative rates on the funding margin? The interaction term in Column 2 implies that the higher the proportion of banks' deposit funding, the more they are affected. For a bank with 35 percent deposit funding – about the average in our sample – the long-term negative impact of NIRP on the funding margin is 18 basis points higher than for a bank with zero deposit funding (Figure 4, left). This is about half of banks' average funding margin in the years prior to 2014, when NIRP was implemented, or about one third of the average bank's return on equity.[9] Obviously, for banks with higher deposit funding ratios, the impact of NIRP is much higher (Figure 4, right). Figure 4 illustrates how the relative impact on the funding margin evolves over time, showing that it takes more than two years before most of the impact has materialized. This slow adjustment reflects banks' reluctance to adjust deposit rates to market rates, which also explains the relatively high duration of deposits. Relevant in this context is also that we have used interest rates on new business to construct margins; on outstanding deposits the impact is even more gradual.

Figure 4: Dynamic impact of NIRP on funding margin



Source: Table 5.1, Equation (2)

5.2 Lending margin

The last three columns of Table 5.1 presents the outcomes of our regression analysis when using the lending margin as the dependent variable. All other variables are

[9] The impact on return on equity can be calculated as follows. As our funding ratio is based on two thirds of total assets, 18 bp margin loss implies 12 bp loss in terms of total assets. Assuming that equity as a percentage of total assets is equal to the average leverage ratio in our sample (7.6 percent, see Table 2), this means that return on equity is reduced by 0.12 / 7.6 = 1.6 percentage points. This is equal to about one third of euro are banks' return on equity, which was around 5 percent over the 2014-2019 period according to the ECB's Consolidated Banking Data.

the same as in the previous section. In all specifications, the interaction term of NIRP with the share of deposit funding is *not* statistically significant. Adding more controls from the SNL database (Column 6) does not change this result. Hence, compared to other banks, we find no evidence that banks more reliant on deposit funding have on average increased their lending margin in the period of negative rates. Overall, therefore, our findings do not indicate that banks compensated any loss in funding margin by increasing their lending margin. This result suggests that euro area banks have continued to transmit the cuts in the policy rate to lending rates, in line with the results obtained by Eisenschmidt and Smets (2019).

We do not investigate banks' reluctance to increase lending margins. Possibly, competitive pressure (both from other banks as well as from non-banks) plays a role, as established by Molyneux et al. (2019) for a sample of banks covering the OECD countries, Maudos and Guavara (2004) for European banks and Chaudron et al. (2020) for Dutch banks. Another explanation could be that most of the NIRP period coincides with economic recovery and declining credit risk in the euro area which, if insufficiently captured by our explanatory variables, would counteract upward pressure on lending rates.

5.3 Total interest rate margin

Table 5.2 shows the regression results taking the total interest rate margin as the dependent variable. The interaction [NIRP × deposit funding] is significantly negative in all cases. This pattern is consistent with Table 5.1 and Table 5.2, implying that negative rates have reduced not only the funding margin of high deposit banks compared to other banks, but also their overall NIM (on new business). The order of magnitude is similar to that of the deposit margin, implying that changes in maturity transformation only play a minor role. As regards the control variables, the signs of the coefficients are mostly in line with the literature, although the coefficients are not always significant.

Overall, the regression results show a consistent pattern. Because of the lower bound on deposit interest rates, banks are hurt by negative rates through their funding side. They are not able to compensate this by increasing lending rates relative to market interest rates, which implies that their overall interest margin is also eroded.

Table 5.2: Total interest rate margin

	NIM		
	(1)	(2)	(3)
Y_{t-1}	0.807***	0.801***	0.805***
	(0.0155)	(0.0161)	(0.0207)
NIRP	0.00152		
	(0.0206)		
Deposit share	0.000116	-0.000889	0.00177
	(0.00109)	(0.00112)	(0.00141)
NIRP*Deposit share	-0.00163***	-0.00146***	-0.00169***
	(0.000428)	(0.000421)	(0.000555)
GDP growth	0.00829*	0.00397	-0.00347
	(0.00438)	(0.00461)	(0.00968)
Inflation	0.0120***	-0.00366	0.00102
	(0.00417)	(0.00934)	(0.0114)
Total assets (log)	0.0507	-0.000751	0.0825
	(0.0352)	(0.0353)	(0.0537)
Leverage ratio	0.0111***	0.00463	
	(0.00390)	(0.00421)	
Tier1-ratio			0.0000495
			(0.00276)
Credit rating			-0.00242
			(0.00662)
Bank FE	YES	YES	YES
Time FE	NO	YES	YES
N	6890	6890	3739
adj. R^2	0.713	0.739	0.738

Standard errors (in parentheses) are clustered at the bank level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

6. Further evidence

6.1 Low for long

We argued that one of the main impediments to the transmission of negative interest rates is the lower bound on retail deposit rates, which reduces the margin banks earn on deposit funding. However, the moment at which this friction becomes binding does not necessarily coincide with the moment that the policy rate turns negative. For example, if bank deposit margins would normally be around 50 basis points, a reduction of policy rates below 0.5 percent would already have a negative impact on these margins. Moreover, the impact on bank interest rate margins is likely to increase the longer interest rates stay negative, as illustrated by our results in the previous section. To account for this, instead of including the NIRP dummy, we follow Claessens et al. (2018) and include a "low-for-long" variable. This variable measures the number of quarters since short-term interest rates fell below 0.5 percent (excluding a short period in 2009/2010, this has been the case since the first quarter of 2012). Hence, we estimate the following specification:

$$
\begin{aligned}
y_{it} = \beta_1 y_{it-1} + \alpha_i + \beta_2 \boldsymbol{Low\ for\ long}_t \\
+ \beta_3 [\boldsymbol{Low\ for\ long}_t \times \boldsymbol{Deposit\ share}_t] + \theta \boldsymbol{x}_{it} \\
+ \varphi \boldsymbol{z}_t + \varepsilon_{it}
\end{aligned}
\quad (1)
$$

Table 6.1 shows the results. To save space, in what follows we only show the specifications including time fixed effects (i.e. specifications 2 and 3 in the tables of Section 5).[10] The results are in line with our previous conclusions. Low-for-long interest rates reduce funding margins for banks with a high share of

[10] We also ran the regressions without time fixed effects and obtained qualitatively similar results.

deposit funding relative to other banks (Columns 1 and 2), which also impacts the overall interest rate margin (Columns 5 and 6). We do not find evidence that banks with a higher share of deposit funding increase their lending margin when interest rates are low for long compared to banks with a lower deposit share (Columns 3 and 4).

Table 6.1: Low for long

	Funding margin		Lending margin		Total NIM	
	(1)	(2)	(3)	(4)	(5)	(6)
Y_{t-1}	0.671***	0.772***	0.798***	0.810***	0.802***	0.804***
	(0.0425)	(0.0180)	(0.0189)	(0.0244)	(0.0160)	(0.0211)
Deposit share	0.00128	-0.000291	-0.00273***	-0.00193	-0.000813	0.00183
	(0.000908)	(0.000736)	(0.000913)	(0.00143)	(0.00116)	(0.00149)
Lowlong * Deposit share	-0.0000892***	-0.0000237**	0.0000124	-0.00000600	-0.0000665***	-0.0000783**
	(0.0000200)	(0.0000112)	(0.0000138)	(0.0000212)	(0.0000235)	(0.0000303)
GDP growth	0.0103**	0.00671*	-0.00223	-0.00946	0.00410	-0.00322
	(0.00495)	(0.00374)	(0.00461)	(0.00971)	(0.00458)	(0.00960)
Inflation	0.000819	-0.0112**	0.0322***	0.0389***	-0.00366	0.00109
	(0.00574)	(0.00454)	(0.00672)	(0.00956)	(0.00934)	(0.0114)
Total assets (log)	-0.00567	-0.0369*	0.00519	0.0518	0.00103	0.0833
	(0.0240)	(0.0204)	(0.0308)	(0.0510)	(0.0369)	(0.0549)
Leverage ratio	-0.00494**		-0.00219		0.00476	
	(0.00198)		(0.00383)		(0.00420)	
Tier1-ratio		0.000396		-0.000529		-0.0000468
		(0.00155)		(0.00219)		(0.00275)
Credit rating		0.00166		0.00474		-0.00262
		(0.00261)		(0.00557)		(0.00659)
Bank FE	YES	YES	YES	YES	YES	YES
Time FE	YES	YES	YES	YES	YES	YES
N	7122	3815	6890	3739	6890	3739
adj. R^2	0.778	0.866	0.798	0.806	0.739	0.738

Standard errors (in parentheses) are clustered at the bank level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 6.2: EONIA

	Funding margin		Lending margin		Total NIM	
	(1)	(2)	(3)	(4)	(5)	(6)
Y_{t-1}	0.624***	0.747***	0.798***	0.813***	0.801***	0.807***
	(0.0508)	(0.0222)	(0.0189)	(0.0238)	(0.0160)	(0.0205)
Deposit share	-0.000539	-0.000567	-0.00236***	-0.00208	-0.00220**	0.000375
	(0.000731)	(0.000754)	(0.000881)	(0.00132)	(0.00106)	(0.00127)
EONIA * Deposit share	0.00152***	0.000746***	0.000105	0.0000241	0.000733***	0.000830**
	(0.000351)	(0.000222)	(0.000118)	(0.000214)	(0.000165)	(0.000358)
GDP growth	0.0104**	0.00703*	-0.00234	-0.00948	0.00423	-0.00346
	(0.00488)	(0.00395)	(0.00461)	(0.00973)	(0.00456)	(0.00963)
Inflation	0.00416	-0.0105**	0.0329***	0.0388***	-0.00310	0.000277
	(0.00634)	(0.00467)	(0.00668)	(0.00962)	(0.00948)	(0.0116)
Total assets (log)	-0.00824	-0.0315	0.0164	0.0493	-0.00634	0.0729
	(0.0227)	(0.0212)	(0.0290)	(0.0481)	(0.0330)	(0.0506)
Leverage ratio	-0.00538***		-0.00212		0.00498	
	(0.00204)		(0.00384)		(0.00411)	
Tier1-ratio		0.000299		-0.000518		-0.000163
		(0.00176)		(0.00219)		(0.00262)
Credit rating		0.00255		0.00471		-0.00280
		(0.00273)		(0.00556)		(0.00658)
Bank FE	YES	YES	YES	YES	YES	YES
Time FE	YES	YES	YES	YES	YES	YES
N	7122	3815	6890	3739	6890	3739
adj. R^2	0.783	0.867	0.798	0.806	0.739	0.737

Standard errors (in parentheses) are clustered at the bank level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Alternatively, we could include the short-term interest rate directly to test the impact of low/negative interest rates. One advantage of this approach is that it does not require any presumption about the level below which interest rates would start having an impact on bank interest rate margins. We use the Euro overnight index average (EONIA) as the relevant short-term interest rate. The results, shown in Table 6.2, confirm our baseline regressions. More specifically, the first two columns indicate that when EONIA goes down, the funding margin of banks with a higher deposit share decreases in comparison to banks with a lower deposit share. There is no differential impact on the lending margin (Columns 3 and 4). Moreover, compared to banks with a low deposit share, for banks with a higher deposit share the overall NIM decreases when the short-term interest rate goes down.

6.2 Different types of loans

So far, we have investigated the impact of low interest rates on banks' total lending margin, which includes both mortgage loans to households and loans to non-financial companies. The granularity of the data allows us to also consider the impact on each type of borrower separately. Because of differences in market structure and competitiveness, the impact could vary across market segments. For example, differences in competitive pressure across market segments would imply that banks may have room to increase lending margins for some borrowers but not for others. Table 6.3 shows that, compared to low deposit banks, high deposit banks did not increase margins on loans to NFCs in response to negative interest rates, although there is some evidence that they increased lending margins on mortgages. However, we find the latter result only for the extended regression based on SNL data (Column 2) and also in this specification the coefficient is only marginally significant.

For NFC loans, the data allow a further breakdown into small loans (up to and including EUR 1 million) and large loans (over EUR 1 million). Loan size can be seen as a proxy for the type of borrower, as small loans are more likely to be provided to relatively small companies. Our expectation is that banks face less competitive pressure in the market for small companies than in the market for large companies, as the latter could also turn to the market to obtain financing. Moreover, information asymmetry is expected to constitute a bigger obstacles for smaller companies, making it more costly for them to turn to a different bank to obtain funding. As such, if banks wanted to increase lending margins in response to a reduction in the deposit margin, we would expect to see this especially in the small loans business segment. However, the results in Table 6.4 show that this is not the case. Neither for small loans, nor for large loans do we find evidence that banks with a higher share of deposit funding have increased lending margins compared to other banks after the policy rate turned negative.

Table 6.3: Lending margins for different types of borrowers

	Households		Non-financial companies	
	(1)	(2)	(3)	(4)
Y_{t-1}	0.709**	0.667**	0.638**	0.567**
	(0.0456)	(0.0647)	(0.0928)	(0.155)
Deposit share	-0.00298*	-0.00767**	-0.00524**	-0.00489
	(0.00161)	(0.00249)	(0.00244)	(0.00363)
NIRP*Deposit share	-0.000377	0.00142*	0.0000296	-0.000133
	(0.000509)	(0.000748)	(0.000520)	(0.000833)
GDP growth	0.00774**	0.0105*	-0.0406	-0.0800
	(0.00345)	(0.00610)	(0.0293)	(0.0518)
Inflation	0.0405**	0.0501**	0.0297**	0.0486**
	(0.00912)	(0.0138)	(0.0137)	(0.0220)
Total assets (log)	-0.0665	-0.120	0.00808	0.127
	(0.0707)	(0.105)	(0.0609)	(0.112)
Leverage ratio	0.000704		-0.000794	
	(0.00419)		(0.00708)	
Tier1-ratio		-0.00457		0.000131
		(0.00369)		(0.00480)
Credit rating		0.00106		-0.00828
		(0.00955)		(0.0141)
Bank FE	YES	YES	YES	YES
Time FE	YES	YES	YES	YES
N	6436	3602	6626	3655
adj. R^2	0.724	0.695	0.592	0.540

Standard errors (in parentheses) are clustered at the bank level. * $p < 0.10$, ** $p < 0.05$

Table 6.4: Small versus large NFC loans

	Small loans		Large loans	
	(1)	(2)	(3)	(4)
Y_{t-1}	0.797**	0.798**	0.639**	0.670**
	(0.0301)	(0.0457)	(0.0274)	(0.0356)
Deposit share	-0.00432**	-0.00669**	-0.00591**	-0.00388
	(0.00161)	(0.00230)	(0.00219)	(0.00277)
NIRP*Deposit share	-0.000147	0.000225	0.000221	-0.000296
	(0.000435)	(0.000627)	(0.000547)	(0.000697)
GDP growth	0.0203	0.0410	-0.0285	-0.0476
	(0.0221)	(0.0351)	(0.0193)	(0.0360)
Inflation	0.0584**	0.0729**	0.0485**	0.0619**
	(0.00816)	(0.0149)	(0.0123)	(0.0178)
Total assets (log)	-0.00929	0.0139	0.0235	0.0638
	(0.0436)	(0.0596)	(0.0567)	(0.0798)
Leverage ratio	-0.00402		-0.00162	
	(0.00481)		(0.00618)	
Tier1-ratio		0.00384		-0.00216
		(0.00340)		(0.00466)
Credit rating		0.00764		-0.00288
		(0.00617)		(0.00705)
Bank FE	YES	YES	YES	YES
Time FE	YES	YES	YES	YES
N	6430	3581	6260	3549
adj. R^2	0.785	0.794	0.585	0.620

Standard errors (in parentheses) are clustered at the bank level. * $p < 0.10$, ** $p < 0.05$

7. Robustness

7.1 Different measures of bank deposit dependence

We have investigated whether using alternative measures of the importance of deposit funding lead to different results. In our baseline regressions, we include both total household and NFC deposits in the calculation of a bank's deposit share. However, as illustrated in the introduction, and also shown by Altavilla et al (2019), it is mostly household deposits which are affected by the lower bound. We have therefore also run our regressions using only household deposits as an indication of the extent to which a bank may be affected by the lower bound. The results, shown in Table B1 in Annex B, are very similar, which is perhaps not surprising, given that household deposits constitute on average a far more important funding source than NFC deposits. In addition, we have analyzed whether it makes a difference if we use only *overnight* deposits, since the lower bound is expected to be most binding on deposits with a relatively short maturity. Therefore, banks that are heavily dependent on overnight deposits are expected to be most affected by negative interest rates. Investigating the impact of negative rates on the deposit margin, we indeed find evidence that this is the case. Compared to our baseline regression, the coefficients are about twice as large (Table B2).

7.2 Alternative method to calculate funding and lending margins

Given the importance of the funding and lending margins in our analysis, and the uncertainty around their calculation, we have also used an alternative approach to calculate the commercial margins. Like in the main approach, lending and funding margins are calculated as the difference between, respectively, lending and funding rates and a corresponding market interest rate with the same duration. Under this approach, however, to determine the duration, we compare the weighted average funding and lending rates with the evolution of different portfolios of market interest rates (overnight rates and two-year and ten-year swap rates). More specifically, the market portfolio that matches weighted deposit or lending rates most closely determines the duration (see Annex A for a more detailed discussion). Compared to our main approach, the alternative approach does not exploit the information on maturities in our dataset. However, the alternative approach has the advantage that the derived duration is based on the empirical relationship of funding and lending rates with actual market interest rates in our dataset.

Figure 5 shows the evolution of the margins when we use this alternative calculation method. Compared to Figure 3, it can be observed that patterns are similar, whereas margin levels, especially in the initial years of our sample, are different. Lending margins are significantly higher than funding margins according to our main approach, whereas they were broadly similar according to the approach used in this section.

Figure 5: Margins under alternative method
Based on new business; thin lines mark interquartile ranges.

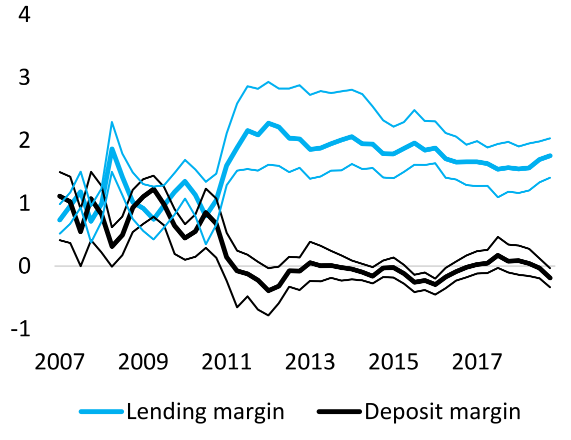


Table B3 in Annex B reports the results, using the same three estimation specifications as in the main section.[11] These results are qualitatively very similar to our baseline results. The interaction term [NIRP × deposit share] has a significantly negative impact on the funding margin (the first three columns), although the coefficients are somewhat smaller than in Table 5.1. Similarly to our baseline regression, we find no significant impact of the interaction term on the lending margin (Columns 4 tot 6). The fact that we find qualitatively similar results, although we have used very different methods to calculate the commercial margins, gives us comfort about the robustness of our results.

7.3 Pooled regressions with correlated random effects

Our baseline regressions include bank fixed effects to control for differences across banks that do not vary over time and that are not captured by our explanatory variables. However, the bank fixed effects may introduce multicollinearity if these explanatory variables do not vary much over the sample period. In particular, whereas banks' deposit dependency has on average increased over the period we consider, for several banks it has remained broadly constant. Hence, as a robustness check, we repeated the analysis by estimating pooled regressions with correlated random effects, i.e. adding sample means of the explanatory variables as supplementary regressors (a simple pooled regression without the supplementary regressors yields almost identical results).

[11] We have also ran the other regressions (e.g. using low-for-long, EONIA) while using our alternative estimation techniques. In general, our main results remained robust, although the signs of some control variables do sometimes change across specifications.

The results of the pooled regressions are presented in Table B4 in Annex B. These are very similar to our baseline results, the most important difference being that in the funding margin regression, the [NIRP × deposit share] interaction term is still negative but no longer statistically significant for the SNL subsample of banks. For the lending margin regressions, the interaction terms are insignificant just like in our baseline results. Hence, although the interaction term loses significance in one specification, the overall conclusions are not materially affected.

7.4 Additional lags for the dependent variable

So far, we have presented specifications including one lag of the dependent variable, which is in line with similar studies. Including more lags may help however to reduce any bias in our estimates due to higher-order autocorrelation, although it could come at the cost of introducing multicollinearity. To see whether this materially affects our results, we reran our regressions including more lags. For several specifications these additional lags are indeed statistically significant, as illustrated by Table B5 of Annex B, which presents the results of our baseline equation including two lags of the dependent variable. In general, adding more lags leads to some loss of statistical significance of the other coefficients. However, the overall results and conclusions do not change materially.

8. Concluding thoughts

Based on individual bank data, this paper investigates the impact of negative interest rates on euro area bank interest rate margins. What distinguishes our paper from other studies is that we have broken down the NIM into a funding margin and a lending margin, which allows us to look at the impact on the different components of the NIM separately. We exploit the heterogeneity in our sample and compare banks with different levels of deposit funding.

We find evidence that negative interest rates have reduced the funding margins of deposit dependent banks compared to other banks, as banks are reluctant to reduce deposit rates below zero. The impact is material. For the average bank in our sample, with 35 percent deposit funding, the funding margin is about 18 basis points lower relative to a bank with zero deposits, which is equal to about half the average funding margin in the years prior to NIRP. At the same time, we hardly find evidence that banks compensate for this by increasing lending margins – the evidence is at best mixed for mortgages and absent for lending to NFCs. Our results therefore imply that commercial interest margins gradually shrink. In future research it would be interesting to dive deeper into this result, for example by examining the impact of competition from other banks as well as non-banks.

The impact of negative interest rates on bank margins may take several years to materialize. We have investigated the impact of NIRP on new business margins; it can take several years before the lower margins are fully transmitted to the outstanding assets and liabilities of banks. Moreover, in some euro area countries, deposit rates were still relatively high at the moment negative rates were introduced, meaning there was still room for these banks to move deposit rates lower. By the end of the sample, this is no longer the case. The impact may therefore become larger over time.

Our findings support a key element of the reversal rate literature, which states that low and negative interest rate gradually erode bank margins. Does this mean that negative interest rates hurt bank profitability, and, through its impact on bank capital and intermediation capacity, reduce the effectiveness of monetary policy? To answer this question, we need to take into account other factors as well, which are beyond the scope of this paper.

First, a decline in interest rates also affects profitability through other channels. For example, lower interest rates improve banks' financial position through capital gains on their fixed-income portfolios. Moreover, by improving the economic outlook and increasing the value of collateral, they improve borrower creditworthiness, lowering loan loss provisions. Demand for loans is also expected to increase. Altavilla et al. (2018) argue that these channels may explain why thus far they find no negative impact on bank overall profitability, despite the reduction in margins. Some of these channels may prove not be sustainable however in a less favourable environment, such as the one created by the Covid-19 virus in 2020-2021. This is an important area for future research.

Second, the ECB has introduced other policies that mitigate the impact of negative interest rates on bank profitability (Schnabel, 2020). Especially noteworthy is the introduction of a two-tier system, which increases the average remuneration banks receive on their excess liquidity holdings.

Finally, banks may try to compensate for the reduction in interest margins by boosting profitability in other ways. For example, banks could try to increase non-interest income or reduce operating expenses. Yet another possibility is that banks rebalance their portfolios towards assets with a higher interest rate margin, potentially increasing the risk profile of their assets (see for example Hernández de Cos, 2019). The latter could bring new challenges from a prudential point of view and therefore warrants close monitoring.

Annex A Calculation of interest rate margins

A.1 Main approach: using maturities from our dataset and insights from other studies.

We define the lending margin as the difference between the average interest rate received on new business loans and the respective risk free rate. To determine the appropriate risk free rate we use information from the IMIR database regarding the date of initial rate fixation (Table A1).

Table A1: Duration assumptions loans

Date of initial rate fixation (irf)	Assumed risk free rate
Loans to households	
Floating rate and irf < 1y	EONIA
1y<irf < 5y	Three year swap rate
5y<irf < 10y	Seven year swap rate
10y<irf	Ten year swap rate
Loans to non-financial companies	
Floating rate and irf < 1y	EONIA
1y<irf <5y	Three year swap rate
5y<irf	Seven year swap rate

The funding margin is defined as the difference between the average interest rate banks pay on their liabilities (including non-deposit liabilities) and the respective risk free interest rate. We use outstanding amounts to determine the weights.[12] Unfortunately, for banks' liabilities we do not have information regarding the date of initial rate fixation, which complicates the calculation of their durations. For deposit liabilities (households and non-financial companies), we therefore use the agreed maturity to approximate the average date of interest rate fixation. We assume that the average duration of overnight deposits is about 2.5 years, which is based on insights from other sources (Table A2). For debt instruments issued we assume that the average maturity (or more precisely, the average date of interest rate fixation) at issuance is equal to five years.[13] For central bank financing, we take the MRO-rate for MRO-financing and the one and three year swap rate for the LTROs and VLTROs respectively. Table A3 summarizes our main assumptions.

[12] Since we use new business interest rates, we construct a measure of the marginal financing costs (and hence margin). We choose to weight interest rates by outstanding amounts, rather than new business volumes, to prevent an overweight of relatively short-term liabilities, which are more frequently rolled over and therefore overrepresented in the new business volume data.

[13] We used Bloomberg data to calculate the average period of interest rate fixation of bank bonds at issuance. Assuming the period of interest rate fixation is 0.25 year for a floating-rate bond, the average for all bonds in Europa is equal to about 5 years.

Table A2: Estimated duration of demand deposits previous studies

Reference	Banks	Result
Dewachter et al. (2006)	Belgian banks	Broad range of duration estimates between 0.2 and 4.5 years.
BCBS (2016)	Standardised approach	Average maturity of core deposits capped at 5 years (retail, transactional) and 4 years (wholesale). Proportion of core deposis capped at 90 percent (retail, transactional) and 50 percent (wholesale).
Hoffmann et al. (2019)	Euro area banks	Average duration 2.0 years for retail deposits and 1.0 year for corporate deposits.

Finally, the total interest rate margin is defined as the difference between the average interest rate on new loans (weighted average lending rate on new loans to households for house purchase purposes and non-financial companies) and the average interest rate banks pay on their liabilities (weighted average marginal interest rate paid on main liabilities, where the outstanding volumes are used to construct the weights).

Table A3: Duration assumptions liabilities

Maturity	Assumed risk free rate
Household deposits	
Overnight	Average of the two-year and three-year swap rates
Up to two year	Two-year swap rate
Over two year	Three-year swap rate
Redeemable at notice (of up to 3 months)	Three-year swap rate
Redeemable at notice (of over 3 months)	Three-year swap rate
Non-financial companies deposits	
Overnight	Two-year swap rate
Up to two year	One-year swap rate
Over two year	Three-year swap rate
Other liabilities	
Debt securities issued	Five-year swap rate
Central bank financing	EONIA, one and three year swap rate (for MRO, LTRO and VLTRO respectively)
Other liabilities	We assume that the interest rate paid is equal to the risk free rate

A.2 *Alternative calculation approach: using a replicating portfolio of market interest rates*

Like in the first approach, lending and funding margins are calculated as the difference between, respectively, lending and funding rates and a corresponding market interest rate with the same duration. A key difference with the main approach is that the duration of assets and liabilities is now directly derived from the relationship between lending and deposit rates with market interest rates. This involves the following steps, similar to Maes and Timmermans (2005) and Drechsler et al. (2021):

- For each bank, an overall lending (funding) interest rate is calculated based on lending rates (funding costs) on new business by subcategory, weighted by amounts outstanding.
- A combination of market interest rates is constructed such that it mimics the development of the bank's lending (funding) rate as closely as possible, which is determined by the minimum standard deviation of the difference between both rates. The portfolio consists of three market rates: the overnight rate (EONIA), the two-year swap rate and the ten-year swap rate. The relative weights of these three market rates that result in the lowest standard deviation determine the replicating portfolio.
- The duration of the replicating portfolio is equal to the average maturity of its three components. For instance, if the optimal portfolio consists of 20 percent EONIA, 40 percent two-year rate and 40 percent ten-year rate, the duration is 0.0 + 0.8 + 4.0 = 4.8 years. The "4.8 year" interest rate (between four-year and five-year swap rates, determined by linear interpolation) is then the benchmark to calculate lending and deposit margins
- The lending margin is equal to the overall lending rate minus the corresponding benchmark rate calculated in the previous step. The funding margin is equal to the benchmark rate minus the funding rate.
- Finally, the total interest rate margin is based on average lending rates and funding costs, without corrections for differences in duration. Hence, this margin is identical to the one under the first approach.

Table A4 presents average durations for our sample calculated under the two approaches. The duration gap is very small for the first (rule of thumb) approach and even negative for the second (replicating portfolio) approach. This seems inconsistent with the traditional textbook model of banking, which assumes that banks engage in maturity transformation by borrowing short-term and lending long-term. However, it is in line with Hoffmann et al. (2019) who show, using supervisory data, that around half of the banks in the euro area have a negative duration gap. Table A4 also makes a distinction between banks from fixed-rate countries and banks from variable-rate countries. As one would expect, and again in line with Hoffmann et al. (2019), banks from fixed-rate countries are more consistent with the traditional model as the duration of their assets is significantly longer than the duration of their liabilities.

Table A4: Durations for assets and liabilities

	Total	**Fixed-rate**	**Variable-rate**
Main approach (rule of thumb)			
Lending	2.47	3.89	0.81
Funding	2.38	2.40	2.36
Gap	0.09	1.49	-1.55
Alternative approach (replicating portfolio)			
Lending	3.61	4.65	2.50
Funding	4.23	3.71	4.79
Gap	-0.61	0.94	-2.29

Fixed-rate countries are Belgium, Germany, France and the Netherlands; variable-rate countries are Austria, Finland, Ireland, Italy, Portugal and Spain (Hoffmann at al., 2019).

Annex B Tables robustness section

Table B1: Household deposits only

	Funding margin		Lending margin		Total NIM	
	(1)	(2)	(3)	(4)	(5)	(6)
Y_{t-1}	0.684***	0.779***	0.799***	0.811***	0.800***	0.802***
	(0.0417)	(0.0179)	(0.0189)	(0.0243)	(0.0162)	(0.0216)
HH deposit share	0.00209*	0.000115	-0.00213**	-0.00247	-0.000599	0.000548
	(0.00112)	(0.000880)	(0.000990)	(0.00149)	(0.00127)	(0.00146)
NIRP*HH deposit share	-0.00195***	-0.000597***	-0.000165	-0.000268	-0.00180***	-0.00177***
	(0.000425)	(0.000219)	(0.000301)	(0.000426)	(0.000445)	(0.000574)
GDP growth	0.00942**	0.00641*	-0.00248	-0.00897	0.00385	-0.00310
	(0.00451)	(0.00358)	(0.00461)	(0.00969)	(0.00461)	(0.00974)
Inflation	0.00341	-0.00836*	0.0327***	0.0389***	-0.00313	-0.000658
	(0.00580)	(0.00472)	(0.00667)	(0.00989)	(0.00930)	(0.0117)
Total assets (log)	-0.0122	-0.0480**	0.0202	0.0509	0.00524	0.0524
	(0.0217)	(0.0204)	(0.0315)	(0.0515)	(0.0346)	(0.0540)
Leverage ratio	-0.00552***		-0.00191		0.00486	
	(0.00204)		(0.00380)		(0.00417)	
Tier1-ratio		0.000193		-0.000468		0.0000227
		(0.00157)		(0.00225)		(0.00280)
Credit rating		0.00260		0.00500		-0.00147
		(0.00284)		(0.00586)		(0.00696)
Bank FE	YES	YES	YES	YES	YES	YES
Time FE	YES	YES	YES	YES	YES	YES
N	7326	3757	6890	3683	6890	3683
adj. R^2	0.772	0.870	0.797	0.802	0.739	0.731

Standard errors (in parentheses) are clustered at the bank level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table B2: Overnight deposits only

	Funding margin		Lending margin		Total NIM	
	(1)	(2)	(3)	(4)	(5)	(6)
Y_{t-1}	0.674***	0.768***	0.795***	0.804***	0.802***	0.802***
	(0.0412)	(0.0155)	(0.0196)	(0.0259)	(0.0160)	(0.0210)
Overnight deposit share	0.00543***	0.00325***	-0.00406***	-0.00539***	-0.00213	-0.00304*
	(0.00129)	(0.000907)	(0.00120)	(0.00176)	(0.00130)	(0.00168)
NIRP*overnight deposit share	-0.00420***	-0.00228***	0.000812	0.000919	-0.00132**	-0.000977
	(0.000742)	(0.000390)	(0.000507)	(0.000711)	(0.000601)	(0.000856)
GDP growth	0.00874*	0.00554*	-0.00171	-0.00763	0.00447	-0.00193
	(0.00451)	(0.00331)	(0.00449)	(0.00959)	(0.00452)	(0.00981)
Inflation	-0.00344	-0.00931**	0.0345***	0.0400***	-0.00530	-0.00284
	(0.00545)	(0.00466)	(0.00672)	(0.0100)	(0.00944)	(0.0121)
Total assets (log)	-0.00191	-0.0208	0.0194	0.0441	-0.00280	0.0261
	(0.0205)	(0.0177)	(0.0281)	(0.0527)	(0.0311)	(0.0536)
Leverage ratio	-0.00454**		-0.00253		0.00449	
	(0.00197)		(0.00397)		(0.00426)	
Tier1-ratio		0.000262		-0.000680		-0.0000149
		(0.00131)		(0.00222)		(0.00248)
Credit rating		0.00161		0.00687		0.000184
		(0.00272)		(0.00584)		(0.00672)
Bank FE	YES	YES	YES	YES	YES	YES
Time FE	YES	YES	YES	YES	YES	YES
N	7326	3757	6890	3683	6890	3683
adj. R^2	0.774	0.871	0.798	0.748	0.739	0.732

Standard errors (in parentheses) are clustered at the bank level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table B3: Alternative method to calculate interest rate margins (see Annex A)

	Funding margin			Lending margin		
	(1)	(2)	(3)	(4)	(5)	(6)
Y_{t-1}	0.852***	0.864***	0.869***	0.812***	0.764***	0.777***
	(0.00598)	(0.00681)	(0.00881)	(0.0150)	(0.0208)	(0.0232)
NIRP	-0.0329***			-0.0149		
	(0.0104)			(0.0163)		
Deposit share	-0.00000252	0.000160	0.00148**	-0.000140	0.00199**	0.000899
	(0.000742)	(0.000733)	(0.000636)	(0.000980)	(0.000911)	(0.00145)
NIRP*Deposit share	-0.000522***	-0.000725***	-0.000559***	0.000473	-0.000139	0.000263
	(0.000189)	(0.000139)	(0.000196)	(0.000288)	(0.000278)	(0.000429)
GDP growth	0.00640***	0.00621***	0.00935**	0.00776*	0.00487	0.0152*
	(0.00220)	(0.00197)	(0.00365)	(0.00421)	(0.00454)	(0.00864)
Inflation	-0.0381***	-0.0224***	-0.0363***	-0.0424***	-0.0237***	-0.0443***
	(0.00319)	(0.00734)	(0.0102)	(0.00512)	(0.00908)	(0.0120)
Total assets (log)	-0.113***	-0.0369	0.00106	-0.164***	-0.0320	-0.114**
	(0.0283)	(0.0349)	(0.0246)	(0.0354)	(0.0323)	(0.0456)
Leverage ratio	-0.00513***	0.00133		-0.00963**	0.00222	
	(0.00187)	(0.00169)		(0.00372)	(0.00341)	
Tier1-ratio			0.000263			-0.00187
			(0.00106)			(0.00193)
Credit rating			-0.000705			0.00386
			(0.00183)			(0.00520)
Bank FE	YES	YES	YES	YES	YES	YES
Time FE	NO	YES	YES	NO	YES	YES
N	7327	7327	3819	6890	6890	3739
adj. R^2	0.808	0.900	0.933	0.698	0.803	0.811

Standard errors (in parentheses) are clustered at the bank level.* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table B4: Pooled regressions: correlated random effects

	Funding margin			Lending margin		
	(1)	(2)	(3)	(4)	(5)	(6)
Y_{t-1}	0.772***	0.762***	0.838***	0.911***	0.919***	0.898***
	(0.00693)	(0.00711)	(0.00787)	(0.00486)	(0.00476)	(0.00729)
NIRP	-0.0108			-0.0132		
	(0.0116)			(0.0156)		
Deposit share	-0.000360	0.00122**	0.0000382	-0.00215***	-0.00180**	-0.000329
	(0.000582)	(0.000534)	(0.000536)	(0.000824)	(0.000781)	(0.00119)
NIRP*Deposit share	-0.000824***	-0.00127***	-0.000239	-0.0000255	0.000102	-0.000415
	(0.000247)	(0.000219)	(0.000202)	(0.000327)	(0.000291)	(0.000436)
GDP growth	0.0228***	0.00952***	0.00562**	-0.0151***	-0.00114	-0.00804
	(0.00247)	(0.00219)	(0.00231)	(0.00312)	(0.00324)	(0.00864)
Inflation	-0.000347	-0.00395	-0.0119***	0.0342***	0.0296***	0.0341***
	(0.00268)	(0.00486)	(0.00437)	(0.00370)	(0.00679)	(0.00970)
Total assets (log)	-0.0583***	0.00204	-0.0259*	-0.0266	-0.0354*	0.00973
	(0.0153)	(0.0141)	(0.0149)	(0.0219)	(0.0212)	(0.0325)
Leverage ratio	-0.00967***	-0.00397***		-0.00437**	-0.00435**	
	(0.00148)	(0.00136)		(0.00211)	(0.00200)	
Tier1-ratio			-0.000591			0.00121
			(0.00100)			(0.00218)
Credit rating			0.000431			0.00692*
			(0.00168)			(0.00367)
Bank FE	NO	NO	NO	NO	NO	NO
Time FE	NO	YES	YES	NO	YES	YES
N	7122	7122	3815	6890	6890	3739
adj. R^2	0.750	0.812	0.893	0.885	0.910	0.906

Standard errors (in parentheses) are clustered at the bank level.* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table B5: Additional lag for the dependent variable

	Funding margin			Lending margin		
	(1)	(2)	(3)	(4)	(5)	(6)
Y_{t-1}	1.033*** (0.0216)	1.063*** (0.0295)	1.084*** (0.0394)	0.783*** (0.0228)	0.667*** (0.0273)	0.677*** (0.0352)
Y_{t-2}	-0.212*** (0.0207)	-0.229*** (0.0315)	-0.237*** (0.0372)	0.0378** (0.0174)	0.130*** (0.0197)	0.132*** (0.0277)
NIRP	-0.0212* (0.0123)			-0.0209 (0.0163)		
Deposit share	0.0000437 (0.000805)	0.000552 (0.000725)	0.00144** (0.000640)	-0.000532 (0.000988)	0.00133 (0.000832)	0.00125 (0.00146)
NIRP*Deposit share	-0.000929*** (0.000225)	-0.00115*** (0.000180)	-0.000795*** (0.000202)	0.000678** (0.000289)	0.0000947 (0.000271)	0.000416 (0.000444)
GDP growth	0.00146 (0.00149)	0.00617*** (0.00188)	0.0101*** (0.00350)	0.00975* (0.00494)	0.00460 (0.00430)	0.0145 (0.0109)
Inflation	-0.0341*** (0.00276)	-0.0203*** (0.00620)	-0.0309*** (0.00746)	-0.0457*** (0.00505)	-0.0367*** (0.00938)	-0.0503*** (0.00129)
Total assets (log)	-0.129*** (0.0321)	-0.0440 (0.0373)	-0.00563 (0.0242)	-0.175*** (0.0340)	-0.0480* (0.0254)	-0.0966** (0.0431)
Leverage ratio	-0.00679*** (0.00200)	0.000835 (0.00170)		-0.00950** (0.00366)	0.00261 (0.00308)	
Tier1-ratio			-0.000136 (0.00100)			-0.000954 (0.00184)
Credit rating			0.00147 (0.00161)			0.000385 (0.00502)
Bank FE	NO	NO	NO	NO	NO	NO
Time FE	NO	YES	YES	NO	YES	YES
N	7122	7122	3765	6717	6717	3679
adj. R^2	0.807	0.900	0.936	0.696	0.808	0.811

Standard errors (in parentheses) are clustered at the bank level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

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De Nederlandsche Bank N.V.
Postbus 98, 1000 AB Amsterdam
020 524 91 11
dnb.nl