Does negativity raise concerns? A study on the effect of the ECB's negative interest rate policy on bank profitability and risk-taking

Student: Victor Schipper

Student ID: 449180vs

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Thesis supervisor: Marshall X. Ma

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Abstract

This paper performs a difference-in-difference study on the effect of the ECB's negative interest rate policy (NIRP) on bank profitability and risk-taking. The panel dataset consists of 3154 banks in 11 countries. The treatment group consists of Belgium, France, Germany, Luxembourg, the Netherlands, and Spain. The control group includes Canada, Croatia, the Czech Republic, the UK, and the USA. Banks in NIRP-adopting countries experience a decrease of 3.7% in their net interest margin relative to banks subject to a positive policy rate. However, their total profitability does not decrease because non-interest income increases substantially. Concerning risk-taking, NIRP leads to an increase of 23.3% in loan loss provisions for banks subject to NIRP relative to those who are not. Small and liquid banks experience a relatively large decrease in NIM and take more risk. Also, the results show that banks with low margins take relatively more risk. Unfortunately, the results are not robust to changes in the sample and results should be interpreted carefully. In all, the large increase in risk-taking raises concerns about financial stability and calls for more research on the negative side-effects of NIRP.

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1 Introduction

Since the Global Financial Crisis (GFC), the European economy has struggled with weak economic growth, unemployment and deflation. The European Central Bank (ECB) implemented an accommodative monetary policy that led to interest rates close to zero to meet the inflation target. These extremely low interest rates did not lead to the intended spending and inflation. As a result, the central bank found itself left with unconventional monetary policy (UMP) measures (Blinder et al., 2017). Therefore, in June 2014, the ECB introduced a negative interest rate policy (NIRP) to stimulate the real economy[1].

NIRP aims to increase the supply of credit by increasing banks' costs of holding excess reserves at the central bank (Coeuré, 2016). This policy measure would decrease the financing costs for both banks and customers, increase supply and demand for loans to ultimately benefit the real economy (Jobst and Lin, 2016). A large strand of literature has researched the link between interest rate changes in positive territory and bank performance. However, the negative interest environment is a rather new phenomenon and differs from the low, positive environment in two ways (Molyneux et al., 2019). First, NIRP has an imperfect pass-through of deposit rates because banks are reluctant to charge negative rates to their depositors, fearing a large decrease in their funding base (Jobst and Lin, 2016; Demiralp et al., 2021). As the deposit rates hit the so-called zero lower bound (ZLB), the spread in lending and deposit rates decreases and profitability is negatively impacted. As a side-effect, the interest rate cut does not lead to lower deposit rates and limits the effectiveness of the monetary decision. The second difference is that a negative policy rate excessively lowers the expectation of future economic growth compared to rates in positive territory (Molyneux et al., 2019). Therefore, a negative interest rate is a rather new phenomenon and requires a re-assessment of the relationships found for positive rates.

Negative policy rates' novelty raises concerns about unintended effects on financial stability for two reasons. First, from a financial stability perspective and as stated above, negative policy rates could decrease bank margins and profits, reduce their equity capital and pressure banks' solvency. Second, negative rates may stimulate banks to search for yield if they experience a decrease in their profitability (Albertazzi and Gambacorta, 2009). A worsening of a bank's solvency and the increase in risk-taking would pose a threat to financial stability. Concerning the effectiveness of the monetary policy decision, one could argue that a decrease in banks' profitability and capital base could force banks to limit their credit supply. Hence, NIRP comes with concerns on financial stability and

[1]This paper uses the term interest rate, deposit facility rate, policy rate or simply rate interchangeably.

the effectiveness of the policy, which makes studying the effect of NIRP very relevant. Besides, literature is inconclusive on the effects and has not resolved the concerns (Tan, 2019). Therefore, this paper performs a difference-in-difference (DiD) study on the effect of NIRP on bank profitability and risk-taking from 2012 to 2016. The treatment group consists of banks in Belgium, France, Germany, Luxembourg, the Netherlands and Spain. The control group includes Canada, the Czech Republic, Croatia, the United Kingdom and the USA. This research aims to answer the following research question:

What is the effect of the ECB's negative interest rate policy on bank profitability and risk-taking?

This research has two main objectives. First, it aims to assess whether NIRP led to an improvement or worsening of bank profitability and an increase or decrease in risk-taking. Second, it analyzes the role of bank size, liquidity, deposit funding and NIMs on the outcome variables.

This research contributes to literature in three ways. First, the current literature lacks consensus on the effect of NIRP despite the policy's wide implementation. This paper provides insights on the impact of NIRP on banks and hence presents implications for central banks that consider employing or have employed negative rates. Second, this paper focuses on the effect of NIRP on both profitability and risk-taking for banks in 6 European countries. Most papers investigate the effect on either profitability or risk-taking. Also, most scholars either investigate all NIRP-adopting countries, the OECD countries with negative rates or only one country. The focus of the paper is intentionally on a few countries in one monetary system because Lopez et al. (2020) find that the effect of NIRP differs for various monetary regimes and supports the focus on one monetary regime. Third, this paper studies which bank-specific factors affect the impact of NIRP on banks to explain the variation in the effect of NIRP. Through these factors, this study provides insights on which banks are most negatively affected by NIRP.

The structure of the paper is as follows. Section 2 describes the institutional background and introduction of the negative policy rate. Section 3 discusses the literature on this topic and starts by explaining the transmission channels in case of an interest rate cut. Afterward, it reviews papers that study the effect of interest rate cuts on profitability and risk-taking, resulting in the formulation of the hypotheses. Section 4 elaborates on the data and methodology. Section 5 presents and discusses the results of the research. Section 6 lists the limitations and suggestions for future research. Lastly, section 7 summarizes the findings and the implications.

2 Institutional background

This section explains the institutional setup and discusses the evolvement of key interest rates. It aims to provide context and background information on the introduction of negative rates.

2.1 Deposit facility rate

Since the GFC of 2008, the ECB has performed an accommodative monetary policy that aims to enhance economic growth and inflation. This policy led to a substantial increase in the monetary base, which was more than banks' liquidity needs (Altavilla et al., 2018). Banks can deal with excess money in various ways. One commonly used possibility is to lend it to other banks for which banks receive an interbank rate such as the Euro Interbank Offered Rate (Euribor) rate. This is a commonly used interbank rate, benchmarking the market rate for short-term unsecured debt. Banks can also deposit their liquidity with the central bank overnight and receive the deposit facility (DF) rate. The interbank rate typically follows the evolution of the DF rate. The reason is that the interbank rate is determined by supply and demand between banks and competes with the DF rate. Therefore, the excess liquidity increases banks' exposure to the DF and interbank rate.

On June 11, 2014, the Governing Council of the ECB reduced the DF rate from 0.00% to -0.10% to provide monetary policy accommodation by increasing the supply of credit and enhancing the real economy (Praet, 2014). The central bank further decreased the rate to -0.20% in September 2014, to -0.30% in December 2015, and to -0,40% in March 2016. The introduction of NIRP was a rather unconventional action and was received with surprise (Tan, 2019). In light of the excess liquidity, a negative DF rate results in an additional expense for banks, which illustrates a negative effect of NIRP.

Figure 1 shows the evolvement of the ECB's DF rate, 3-month Euribor and the median of the overnight deposits rate on household and non-financial-corporation deposits for banks of the European Monetary Union (EMU) in the period between 2009 and 2016. Before introducing a negative DF rate, the three rates follow a similar path. After the policy announcement, the overnight deposit rate does not decrease to the same extent as the DF rate. This illustrates that the overnight deposit rate is truncated at zero and hits the ZLB. In other words, banks seem hesitant to charge households and non-financial-corporations a negative deposit rate. This is remarkable because storing excess liquidity is costly considering the negative rate DF and Euribor rate. Thus, there seem to be higher costs for banks because the deposit rates hit the ZLB.

Other monetary decisions complemented the rate changes in the DF rate by the ECB. Table 12 provides a timeline of the main ECB monetary decisions between June 2014 and December 2016. For instance, it shows that in June 2014, the rate cut to -0.10% was announced as well as preparations for an asset purchase program. This program aims to improve financing conditions to boost the economy. The complementary monetary programs are an identification challenge to this research.

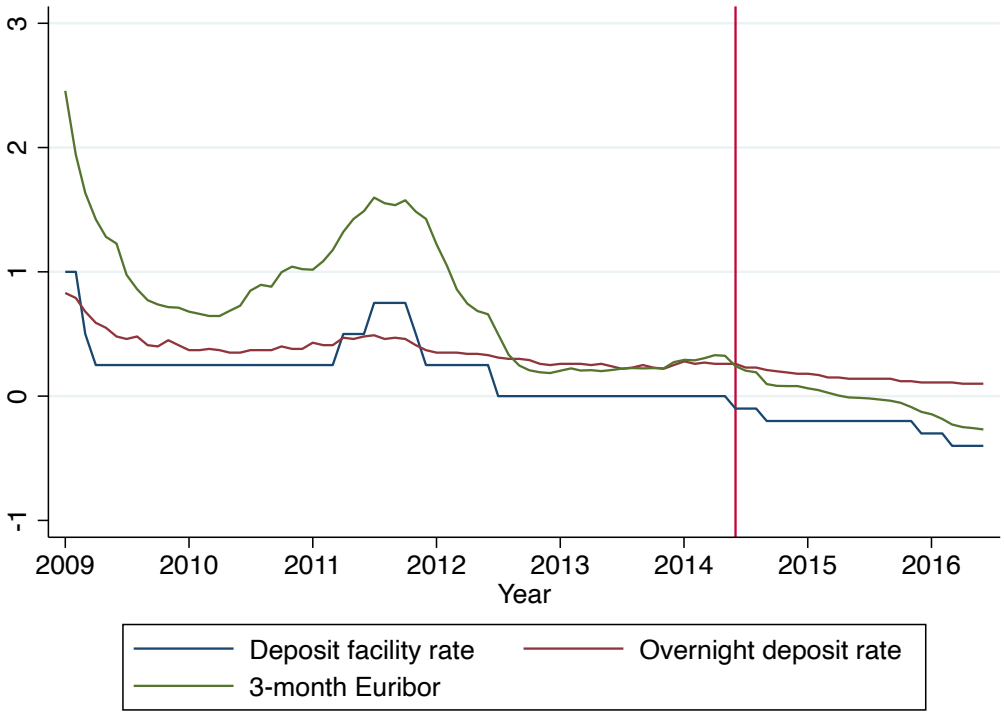


Figure 1: Deposit facility rate, overnight deposit rate and 3-month Euribor for European banks over time

This figure shows the movement of the deposit facility rate, overnight deposit rate and 3-month Euribor rate for Europe between January 2009 and June 2016. The overnight rate is the monthly, median overnight deposit rate for households and non-financial companies. The red vertical line highlights June 2014, when the negative deposit facility rate was announced.

2.2 Banking regulation

Also after the GFC, the regulation for banks increased substantially. The banking regulation aimed to strengthen the resilience of financial institutions by regulating their liquidity to assure that these institutions can absorb negative shocks in the economy (Boungou, 2019). For instance, central banks require banks to take provisions as reserves in anticipation of risky loans defaulting. In light of this study, the regulation plays an important role because provisions are a risk-taking measure and affect bank profitability as provisions are money that cannot be put to work.

3 Literature review and hypotheses

This section discusses the literature on interest rates, bank profitability and risk-taking. It starts with a discussion on transmission channels. Afterward, the section reviews the literature and presents reasons for a positive or negative NIRP-effect on profitability and risk-taking. Each section ends with formulating a hypothesis to answer the research question.

3.1 NIRP and bank profitability

3.1.1 Transmission channels: the impact of policy rate cuts

Bank profitability is subject to policy rate changes through various transmission channels. According to Altavilla et al. (2018), an interest rate cut could impact bank performance through the following channels, namely the 1) interest rate channel, 2) wealth channel, 3) equity constraint channel, 4) balance sheet channel and 5) credit channel. First, the interest rate channel argues that financing costs decrease when banks pass on the rate cut. Besides, a lower rate makes consumption and investments more attractive and increases the demand for bank loans. Second, a lower interest rate typically benefits asset prices. A rate cut could lead to a revaluation gain of fixed-income assets that add to profitability for banks. Third, as the revaluation gains improve banks' equity, banks can relax their equity constraints. The equity constraint channel argues that a lower equity constraint allows banks to increase their loan issuance. Fourth, also related to the improvement of assets prices, the balance sheet channel suggests that banks provide more loans when credit has higher valued collateral. Lastly, the credit channel argues that a lower rate improves the economic outlook and lowers the probability of default because both firms and households have lower funding costs or can roll over debt.

The impact of an interest rate cut on bank profitability can be attributed to a component of profit. Table 1 shows a bank's basic profit and loss statement that determines net income.

- The net interest income (A) is the difference between the interest income from loans and the interest expense of deposits. Typically, banks generate profit by borrowing short and lending long, and this is the driver of profitability (Altavilla et al., 2018). The interest rate channel argues that the net income can increase by increasing the interest margin, number of loans or the size of loans.

- Loan loss provisions (B) account for risky loans with a relatively high probability of late repayment or no repayment at all. As the credit channel suggests, the likelihood

of default decreases with lower interest rates. Therefore, the loan loss provisions should decrease after a rate cut and improve profitability.

- Third, the wealth channel suggests that an interest rate cut could lead to fixed-income asset revaluation gains. The realized and unrealized gains/losses on securities (D) account for these gains and contribute to bank profitability.

- The remaining variables, such as net fees and commission income (C), operating expenses (E) and other income/expenses (F), are unrelated to the transmission channels and interest rate cut. However, suppose banks experience a negative impact of a low or negative interest rate. They might respond to the adverse impact by shifting towards more non-interest income-generating activities or cutting costs. Therefore, an interest rate cut could indirectly affect these variables, depending on the trend in profitability.

Literature on interest rates and bank performance typically differentiates between interest and non-interest income. This distinction is vital to this research because the NIM may decrease, but total profitability could remain stable due to increased non-interest income. This paper primarily focuses on the NIM and total profitability but also studies the non-interest income when performing robustness tests.

Table 1: Profit and loss statement

Type	Effect	Variable
(A)	+	Net interest income
(B)	-	Loan loss provisions
(C)	+	Net fee and commission income
(D)	+/-	Realized and unrealized gains/losses on securities
	=	Operating income
(E)	-	Operating expenses
(F)	+/-	Other income/expenses
	=	Net income

3.1.2 Negative impact of NIRP on profitability

There are two reasons why an interest rate cut into negative territory hurts bank profits. First and as discussed in section 2.1, banks are reluctant to charge negative deposit rates because they fear losing their funding base. This reluctance could imply that the deposit rate decreases to a smaller extent than the loan rates, and hence the NIM decreases. For policy rates in positive territory, Borio et al. (2017) find that 109 large international banks in the period from 1995 to 2012 experienced a declining NIM due to ultra-low interest

rates. For negative rates, Bech and Malkhozov (2016) show that European banks that were subject to the negative interest rates since 2014 had a lower interest margin because banks were reluctant to charge negative deposit rates. Stráskỳ and Hwang (2019) confirm that banks in NIRP-adopting OECD countries experience a decline in their NIM.

The second reason for a negative impact of NIRP is that negative policy rates tax banks' excess reserves at the central bank. Banks are required to hold reserves at the central bank for risky assets but they could also store their excess liquidity at the central bank. Negative rates charge these reserves and excess liquidity, and consequently banks need to pay interest. Basten and Mariathasan (2018) examine a panel of 68 Swiss banks and find that banks with high excess reserves had a relatively large decrease in their interest income. Especially in the light of excess liquidity in the banking system after the GFC, banks' excess reserves are substantial and negative rates are likely to hurt profitability.

3.1.3 Positive impact of NIRP on profitability

On the other hand, the presented transmission channels show that bank profitability could improve by reducing funding costs, increasing credit growth, realizing revaluation gains and reducing capital constraints and provisions. Various scholars provide evidence for these channels and their effect on profitability. First, Molyneux et al. (2019) find that for 33 OECD countries from 2012 to 2016, banks that were subject to NIRP had substantially lower loan loss provisions. Second, Blot et al. (2016) find that European banks had a large increase in non-interest income because of revaluation gains in 2015. Third, literature has found contradicting results for the interest channel. Heider et al. (2019) and Tan (2019) find that European banks lend less and experience lower profitability, especially when banks are relying on deposit funding. However, Madaschi and Pablos Nuevo (2017) find that the supply of credit and NIM of Swedish and Danish banks remained stable. The main difference between these papers is that European banks are relatively more financed by deposits, whereas Swedish and Danish banks are wholesale funded. Overall, there seems to be evidence for improving profitability after NIRP but the capital funding matters.

As suggested, bank profitability can also increase with factors unrelated to the transmission channels. For instance, Dell'Ariccia et al. (2017) and Blot et al. (2016) find that banks raise non-interest income by increasing their fees and commissions. Scheiber et al. (2016) show that banks in Denmark, Sweden and Switzerland respond to low and negative policy rates by reducing their operating expenses and cost to income ratio in a low and negative interest rate environment.

3.1.4 Total impact of NIRP on profitability

A few papers investigate both interest and non-interest income to find whether the latter is able to outweigh the compressed interest margins. However, there is no consensus in the literature on the total effect. On the one hand, Florian (2018) and Molyneux et al. (2019) show that banks' profitability decreased after NIRP. The latter finds that banks' NIM and return on assets (ROA) in NIRP-adopting countries decreased by 16.41% and 3.06%, respectively. The non-interest income and cuts in expenses compensate for the decrease in NIM but cannot entirely compensate for the adverse impact. On the other hand, some papers point to an overall positive impact on profitability (see Scheiber et al., 2016; Madaschi and Pablos Nuevo, 2017; Altavilla et al., 2018). For example, Lopez et al. (2020) find that in European and Asian countries with negative policy rates, banks realized significant gains in non-interest income such as fees, capital gains, gains on securities and insurance income. These gains outweigh the negative impact on interest margins and provide evidence for a positive effect.

The following hypotheses test the impact of NIRP on profitability. As most papers point to a substantial decrease in NIMs and total profitability, the first hypotheses are as follows:

H1: NIRP hurts banks' net interest margin.

H2: NIRP hurts banks' total profitability.

3.2 NIRP and bank risk-taking

Interest rates changes could also affect banks' risk-taking and literature primarily studies this effect through the risk-taking channel as proposed by Borio and Zhu (2012). This channel suggests that a low interest rate could reduce the probability of default on outstanding loans in the short term and lower banks' risk profiles. However, in the medium and long term, banks might ease lending requirements or seek more risky assets in a low interest rate environment to maintain their profitability level. This could lead to a deterioration of credit quality and an increase in risk (Bikker and Vervliet, 2018). This theory comes from scholars that study the portfolio rebalancing channel as they argue that low interest rates stimulate banks to "search for yield" (Rostagno et al., 2019). In general, the risk-taking may temporarily decrease by a lower probability of default in the short term. However, it may increase in the medium term as banks reallocate money to riskier assets and loosen loan requirements.

3.2.1 Negative impact of NIRP on risk-taking

On the one hand, various papers investigate the risk-taking channel in the context of NIRP and find an increase in risk-taking after the introduction of NIRP. One key element of these papers is the theory that banks loosen loan conditions when monetary policy is accommodative (Paligorova and Santos, 2017). For instance, Ioannidou et al. (2015) show in a quasi-natural experiment that banks in ultra-low interest rate environments increase risk by lending to borrowers with bad credit histories, low internal ratings and weak performance. Schelling et al. (2020) find that Swiss banks took more risk by providing loans at looser conditions after the introduction of NIRP. Heider et al. (2019) and Bottero et al. (2020) both find evidence for the portfolio rebalancing theory. They show that European shift from low-yielding assets (e.g., short-term interbank claims or government bonds) towards higher-yielding assets (e.g., corporate loans). Bottero et al. (2020) also find that banks with relatively large excess reserves tend to increase their risk-taking substantially because of the high cost of holding liquid assets.

3.2.2 Positive impact of NIRP on risk-taking

On the other hand, scholars also support a decrease in risk during NIRP. Jobst and Lin (2016) study the Eurozone and find evidence for the short-term prediction of the risk-taking channel; low interest rates ease financial conditions and support credit and economic activity. As a result, NIRP improves borrowers' creditworthiness while reducing loan losses provisions. Boungou (2019) employs a dynamic panel data model for 28 European countries from 2011 to 2018 and measures risk using the loan loss provisions, non-performing loans (NPLs) and Z-score[2]. The results show that banks subject to a negative policy rate take less risk than banks in countries with a positive policy rate. Similarly, Bongiovanni et al. (2021) employ a DiD-methodology and study the Z-score for 33 OECD countries in the period of 2012 to 2016 and find that banks in NIRP-adopting countries experience a relative 10% decrease in risky assets compared to countries with positive rates.

Following the risk-taking channel, this paper expects to find a decrease in risk-taking because of the short sample period. Therefore, the third hypothesis is:

H3: NIRP decreases banks' risk-taking.

[2]The Z-score is a measure of a bank's risk-taking and is calculated as the sum of the return on assets and equity to total assets divided by the standard deviation the return on assets

3.3 The effect of NIRP across banks

According to literature, the impact on profitability and risk-taking potentially differs for three bank-level factors: bank size, liquidity and the degree of deposit funding. For each factor, this section first discusses its role for profitability, then its role for risk-taking and lastly, it provides a hypothesis. The last section reviews the effect of profitability on risk-taking.

3.3.1 Bank size

Negative policy rates are most likely to affect large banks less than small banks for two reasons. First, these banks have more diversified income streams than small banks. They are better able to mitigate the negative impact of NIRP on profitability (Altavilla et al., 2018). Molyneux et al. (2019) show that large banks have more non-interest activities. They have relatively higher fees and commissions and more fixed-income assets that experience revaluation gains in case of interest rate cuts. Second, large banks benefit from the low funding costs due to their economies of scope to a relatively large extent. Scheiber et al. (2016) find that large Danish, Swedish and Swiss banks were better capable of reducing funding costs and improving their cost to income ratio after the introduction of negative rates. In all, large banks seem better able to mitigate a potential adverse impact of negative policy rates.

Concerning risk-taking, large banks are generally more risk-averse than small banks (Bhagat et al., 2015). Nucera et al. (2017) show that the effect of negative rates on European banks' risk-taking depends on bank size: large banks take less risk relative to smaller banks because they are more diversified and have a lower incentive to increase risk. Bongiovanni et al. (2021) confirm that risk-taking decreases more for large banks than for small banks. They argue that NIRP has a stronger effect on small firms via the deposit channel and encourages them to search for yield. Boungou (2020) studies a relatively large dataset with 59 countries and obtains contradicting findings: he shows that smaller banks are better able at mitigating the effects of NIRP profitability and hence has lower risk-taking.

My hypothesis follows the majority of literature that argues that smaller banks' profitability is more adversely affected and that these banks take more risk compared to larger firms:

H4: NIRP affects small banks' profitability more negatively compared to large banks.

H5: NIRP stimulates smaller banks to take more risk compared to large banks.

3.3.2 Bank liquidity

As stated earlier, the negative policy rate charges excess reserves at the central bank and lending excess liquidity to other banks also yields negative returns (see the Euribor rate in figure 1). Therefore, banks with high liquidity, a high ratio of liquid securities over total assets, have a higher cost of funding. Bottero et al. (2020) show that Italian banks with high liquidity are relatively more adversely affected by the negative policy rate. Demiralp et al. (2017) obtain similar results for European banks and claim that especially banks with excess reserves at the central bank suffer from negative rates. Remarkably, Boungou (2019) has contradicting findings because he finds that liquid banks show a smaller decline in NIM compared to less liquid banks. Also, total profitability is higher for liquid banks. The difference in methodology and sample is the best explanation for the disparity in findings. Most scholars argue that NIRP affects liquid banks more negatively because of the high cost of holding liquidity.

Negative policy rates stimulate banks with high liquidity to put their money at work and take more risks. Basten and Mariathasan (2018) find that banks move their excess liquidity from the central bank account to riskier asset classes such as loans. Arce et al. (2019) find that banks with low liquidity take relatively less risk because they are limited in their capability to expand risk considering regulatory constraints. Bottero et al. (2020) find that liquid banks that experienced a decline in their profitability in 2014 and 2015 took more risk, as measured by the credit supply to ex-ante risky firms. In contrast, Boungou (2020) finds that the risk-taking decreased after the interest rate cut. The negative rates improved customers' creditworthiness and decreased the amount of NPLs. The difference in the risk-taking measure and methodology between these researches could potentially explain the difference in results. Overall, the majority of the literature finds an increase in risk-taking

Overall, most literature supports the view that liquid banks are less profitable and take more risk after NIRP. Therefore, the sixth and seventh hypotheses are as follows:

H6: NIRP affects profitability more negatively when banks have relatively high liquidity compared to less liquid banks.

H7: NIRP stimulates banks with high liquidity to take more risk compared to less liquid banks.

3.3.3 Deposit funding

The third factor for which the effect of negative rates appears to be different among subgroups is the type of bank funding. Banks generally fund themselves through (shareholder) equity, debt issuance, and deposits. Banks' net interest margins are typically determined by the deposit and loan rate difference. However, as discussed in 2.1, banks appear to be reluctant to charge negative rates to depositors. This reduces the NIM and subsequently hurts profitability. Eisenshmidt and Smets (2019) find that high-deposit banks have a relatively lower NIM. As an explanation, they argue that these banks obtain a lower reduction in their cost of funding compared to banks relying less on deposits.

Several scholars compare high-deposit to low-deposit banks in a DiD-study to study the variation in the NIRP-effect across banks. For instance, Heider et al. (2019) perform such a study in Europe and find that negative rates lead to more risk-taking by banks reliant on deposit funding. They argue that the introduction of negative rates is an adverse shock to high-deposit banks' net worth. A lower net worth increases agency problems, raises the external finance premium and incentivizes banks to screen and monitor risky borrowers less carefully. Support for this theory comes from Bittner et al. (2020): they examine confidential credit-registry data from Germany and Portugal between 2010 and 2016 and show that the NIM of high-deposit banks is squeezed. Besides, these banks take more risk as they screen and monitor new borrowers less carefully. Bubeck et al. (2020) show that high-deposit banks search for yield when realizing lower NIMs and therefore issue more risky loans.

In all, high-deposit banks appear more prone to compressed margins because of the higher cost of funding. As a result, banks reliant on deposits are likely to take relatively more risks.

H8: NIRP affects high-deposit banks more negatively compared to low-deposit banks.

H9: NIRP stimulates high-deposit banks to take more risk compared to low-deposit banks.

3.3.4 The role of profit on risk-taking

The assessment of profitability and risk-taking allows this paper to study the interaction between the two. Traditional literature argues that profitable banks take less risk because they have a lower incentive to do so (see Jensen and Meckling, 1976; Keeley, 1990). Therefore, one may argue that banks increase risk-taking to mitigate the negative effect of NIRP on profitability (Scheiber et al., 2016). Boungou (2019) seems to be the only paper that studies the effect of profitability on risk-taking in light of negative rates.

Boungou finds that a 1% decline in NIM after the introduction of NIRP results in a 5.44% decrease in NPLs and an increase in Z-score by 1.78%. This means that banks with lower profitability do not take more risk. The authors argue that Basel III allowed them to absorb the negative shock of NIRP, and hence banks were allowed to draw down their provisions. The contradicting findings and implications for the financial stability enlarge the contribution of the following hypothesis:

H10: The effect of net interest margins on risk-taking is positive.

4 Data and methodology

The first part of this section discusses the research data, from selecting the countries to describing the dataset and variables. The second part elaborates on the methodology by discussing the DiD-regression, its assumptions and the robustness tests.

4.1 Data

4.1.1 Selection of treatment and control group

The quality of the DiD-methodology depends on the selection of the treatment and control group and their characteristics. This research focuses on the effect of NIRP on a few but relatively strong economies from the EMU. The treatment group consists of large countries, such as Germany, and smaller countries like the Netherlands. The diversity in the sample contributes to the richness of the dataset. Eventually, the treatment group consists of Belgium, France, Germany, Luxembourg, the Netherlands and Spain. The control group should consist of similar countries that do not have a negative policy rate and therefore includes Canada, the United Kingdom (UK) and the United States of America (USA). Also, economies closely related to Europe are likely to be similar to the treatment group. Therefore, the Czech Republic and Croatia are also part of the control group.

This paper considers these countries to be similar in various aspects such as their fiscal policy, central bank supervision, corporate governance codes and more. To assure that both groups are similar in macroeconomic perspective, figure 2 in the appendix graphically shows the movement of inflation, unemployment and GDP growth of both groups in the time range of 2007 to 2016. This time window is larger than the sample period to capture short- and medium-term trends. Table 13 formally shows that the three macroeconomic factors are similar and that they correlate positively and significantly. These results show that the treatment and control groups are in similar economic situations.

Table 2: Overview of the treatment and control group and their macroeconomic and institutional variables

Treatment	N. of banks	Inflation	GDP growth	Unemployment	Credit-to-GDP	Yield curve	CB growth	Reserve	Taxes
Belgium	50	1.204	1.276	8.228	58.816	2.290	7.972	2.741	6.769
		(0.028)	(0.011)	(0.012)	(0.125)	(0.032)	(19.889)	(0.582)	(1.263)
France	404	0.626	0.845	10.040	92.671	2.001	7.972	2.378	8.452
		(0.008)	(0.004)	(0.004)	(0.005)	(0.008)	(19.889)	(0.210)	(0.447)
Germany	1249	0.941	1.503	4.786	78.271	1.354	7.972	1.817	8.706
		(0.003)	(0.003)	(0.002)	(0.012)	(0.002)	(19.889)	(0.051)	(0.088)
Luxembourg	80	1.102	3.453	5.995	89.971	1.349	7.972	5.852	6.310
		(0.014)	(0.034)	(0.008)	(0.053)	(0.009)	(19.889)	(0.520)	(0.746)
The Netherlands	75	1.309	0.992	6.721	118.316	1.515	7.972	6.750	6.485
		(0.014)	(0.025)	(0.011)	(0.100)	(0.009)	(19.889)	(0.600)	(1.492)
Spain	134	0.190	1.605	23.079	121.570	3.990	7.972	2.968	2.703
		(0.014)	(0.029)	(0.015)	(0.176)	(0.014)	(19.889)	(0.194)	(0.430)
Total	1992								
Mean treatment		0.997	1.263	7.349	86.262	1.585	7.972	2.415	8.254
		(0.007)	(0.012)	(0.048)	(0.153)	(0.009)	(19.889)	(0.041)	(0.058)

Control	N. of banks	Inflation	GDP growth	Unemploy ment	Credit-to-GDP	Yield curve	CB growth	Reserve	Taxes
Canada	112	1.372	1.698	7.025	94.485	1.945	10.486	2.645	7.143
		(0.003)	(0.012)	(0.003)	(0.067)	(0.006)	(0.124)	(0.499)	(0.740)
Czech Republic	42	0.867	2.314	5.613	49.953	2.056	25.828	5.060	5.939
		(0.039)	(0.050)	(0.022)	(0.011)	(0.024)	(0.311)	(0.781)	(0.797)
Croatia	50	0.504	0.890	15.911	49.951	5.176	5.665	8.990	1.741
		(0.090)	(0.113)	(0.055)	(0.024)	(0.054)	(0.236)	(0.988)	(0.594)
United Kingdom	329	1.394	2.174	6.105	89.316	2.134	9.011	10.520	5.360
		(0.010)	(0.005)	(0.016)	(0.045)	(0.003)	(0.175)	(0.741)	(0.580)
USA	989	1.304	2.232	6.346	49.841	1.711	9.790	3.613	6.976
		(0.001)	(0.001)	(0.003)	(0.002)	(0.001)	(0.027	(0.180)	(0.215)
Total	1522								
Mean control		1.342	2.101	6.698	61.797	1.926	10.441	4.833	6.849
		(0.009)	(0.009)	(0.024)	(0.216)	(0.009)	(0.160)	(0.098)	(0.111)
T-test		0.345***	0.838***	-0.651***	-24.465***	0.0342***	2.469***	2.418***	-1.405***

Note: This table shows the mean and standard deviation of macroeconomic and institutional factors from 2012 to 2016. Inflation is the annual growth in the Consumer Price Index. GDP growth is the annual growth rate of real GDP. Unemployment is the annual growth rate of unemployment. Credit-to-GDP is the ratio of gross loans to real GDP. Yield curve is the 10-year government bond return at the end of the year. CB growth is the growth rate of a central bank balance sheet size. Reserve is the ratio of cash and balances at the central bank to total assets. Taxes is the ratio of taxes to operating income. The table also reports a two-sample t-test that tests the difference in means between the treatment and control group for each variable. ***, **, * indicates a significance level of 1%, 5% and 10% respectively.

Table 3: Descriptive statistics of the treatment and control group before and during the NIRP period

Treatment	Before NIRP period					NIRP period					
group	Obs	Mean	Std. Dev.	Min	Max	Obs	Mean	Std. Dev.	Min	Max	Star
Panel A: Bank profitability and risk-taking											
NIM	2,800	2.177%	1.667%	-1.185%	11.066%	5,885	2.081%	1.556%	-1.185%	11.066%	*
ROA	2,831	0.438%	0.639%	-1.294%	3.962%	5,933	0.448%	0.0671%	-1.294%	3.962%	*
Z-score	2,553	2.324	0.6681	1.079	3.947	5,702	2.394	0.632	1.079	3.947	*
NPLs	2,046	5.406%	7.492%	0.041%	58.253%	4,874	4.566%	7.276%	0.041%	58.253%	*
Provisions	1,903	0.988%	2.550%	0.005%	20.275%	3,693	0.857%	2.543%	0.005%	20.275%	*
Panel B: Bank balance sheet											
Size	2,857	14.198	2.032	9.923	20.234	5,976	14.045	1.971	9.923	20.234	*
Liquidity	2,845	17.351%	19.259%	0.202%	97.282%	5,959	15.811%	1.003%	0.202%	97282%	*
Deposit funding	2,698	61.699%	24.646%	2.715%	87.975%	5,658	64.971%	23.401%	2.715%	87.189%	*
Capitalization	2,843	10.617%	11.906%	1.202%	86.975%	5,952	11.484%	12.122%	1.202%	86.975%	*
Loan growth	1,386	4.178%	9.013%	-10.134%	24.165%	5,885	4.663%	12.122%	1.202%	86.975%	
Efficiency	2,848	66.614%	23.244%	0.585%	145.373%	5,960	68.749%	22.202%	0.585%	145.373%	
Panel C: Institutional factors											
Reserve	2.608	2.145%	3.367%	0.000%	25.222%	5,566	2.542%	3.906%	0.000%	25.222%	*
Tax	2,159	8.187%	4.919%	-7.412%	23.548%	4,679	8.284%	4.671%	-7.412%	23.548%	*

Control	Before NIRP period					NIRP period					
group	Obs	Mean	Std. Dev.	Min	Max	Obs	Mean	Std. Dev.	Min	Max	Star
Panel D: Bank profitability and risk-taking											
NIM	2,754	2,922%	1.707%	-2.563%	12.492%	4,531	2.834%	1.778%	-2.563%	12.492%	*
ROA	2,752	0.983%	1.524%	-2.580%	10.918%	4,558	1.000%	1.643%	-2.580%	10.918%	*
Z-score	2,735	1.909	0.533	0.428	3.345	4,536	1.932	0.517	0.428	3.345	*
NPLs	2,077	2.964%	5.289%	0.007%	39.533%	2,453	2.705%	6.172%	0.007%	39.533%	*
Provisions	2,078	0.604%	1.059%	0.004%	7.921%	2,975	0.460%	1.005%	0.004%	7.921%	*
Panel E: Bank balance sheet											
Size	2,767	14.287	2.115	10.149	20.120	4,566	14.347	2.156	10.149	20.120	*
Liquidity	2,745	14.395%	17,422%	0.079%	93.758%	4,544	14.612%	19.417%	0.079%	93.758%	*
Deposit funding	2,553	70.402%	22.646%	9.129%	91.445%	4,142	69.691%	23.263%	9.129%	91.445%	*
Capitalization	2,753	13.718%	13.155%	1.625%	86.075%	4,542	14.642%	14.438%	1.625%	86.075%	*
Loan growth	2,026	6.500%	11.183%	-11.567%	32.779%	4,344	7.761%	10.938%	-11.567%	32.779%	
Efficiency	2,762	66.929%	22.469%	2.240%	142.91%	4,542	67.827%	22.339%	2.240%	142.910%	
Panel F: Institutional factors											
Reserve	2.645	4.446%	7.345%	0.002%	50.452%	4,357	5.069%	8.659%	0.002%	50.452%	*
Tax	1,897	6.445%	8.808%	-3.514%	27.634%	2,995	7.028%	7.492%	-35.142%	27.634%	*

Note: For a description of all variables see table 11. The treatment group consists of Belgium, France, Germany, Luxembourg, the Netherlands and Spain. The control group consists of Canada, Croatia, Czech Republic, the UK and the USA. The before NIRP period covers 2012 to 2013 and the NIRP period ranges from 2014 to 2016. The last column called 'Star' indicates the 5% significance level of a two-sample t-test on the difference in a variable's mean between the treatment and control group.

4.1.2 Data retrieval and cleaning

This paper examines a panel dataset to test the effect of NIRP on profitability and risk-taking over the period of 2012 to 2016. Orbis Bank Focus is the primary data source and provides annual bank-level data. Macroeconomic data comes from the World Bank Database and the DF rate, Euribor and deposit rate comes from the ECB Statistical Data Warehouse. The bank's balance sheet size comes from the respective central bank's websites.

The first step in selecting the data is differentiating between consolidated and unconsolidated banks. This paper uses consolidated data for banks that do not have an unconsolidated subsidiary and unconsolidated data to assure that the bank-level data only accounts for bank activity in one specific country. The risk with consolidated data is that it includes the statement of subsidiaries that may operate in countries where the negative policy rate does not apply. The second step is to only select banks that are active. Next, banks that show an asset growth of over 50% are not selected to reduce the potential bias of a merger or an acquisition. Besides, banks are either a bank holding company, commercial bank, cooperative bank, finance company, savings bank or a real estate and mortgage company to create similarity among the financial institutions. The last step is to keep banks that have at least two observations for the outcomes variables in the dataset.

After selecting the dataset, the entire dataset comprises of 3154 banks for 11 countries from 2012 to 2016. To reduce the effect of outliers, I winsorize the bank-level variables in both groups at a 1% and 99% level. Besides, invalid values, such as a capitalization larger than 100%, are dropped.

4.1.3 Descriptive statistics

Table 2 presents the mean and standard deviation of macroeconomic and institutional variables for all countries from 2012 to 2016, differentiating by the treatment and control group. The table shows that there are 1992 banks in the treatment and 1522 banks in the control group. Besides, it demonstrates that Germany and the USA dominate their respective groups because of their large number of banks. Interestingly, the mean of the treatment group's reserve ratio is half of the control group's mean, which is in line with the expectation that negative rates stimulate banks to have low reserves with the central bank. Furthermore, the t-tests in the table illustrate that the mean of each variable between the groups differs significantly.

Table 3 shows the descriptive statistics for the treatment and control group before and

after the introduction of NIRP. It shows that banks in the treatment and control group both experience a decline in their NIM, but their ROA remains fairly stable. Also, considering the increase in the Z-score and the decrease in the NPLs and Provisions, both groups seem to take less risk. Similar to table 2, the t-tests show that most variables are statistically different from each other. Lastly, the number of observations differs largely between the two periods because the period before NIRP only consists of two years, relative to three years for the NIRP period, and has many missing values.

The next section discusses the five outcome variables. The selection of these variables follows the literature on interest rates, profitability and risk-taking (see Menicucci and Paolucci, 2016; Bongiovanni et al., 2021; Boungou, 2019). Table 11 in the appendix lists all the variables with their respective definition.

4.1.4 Profitability and risk-taking measures

The variables of interest for profitability are the NIM and ROA. Following Claessens et al. (2018) and Molyneux et al. (2019), *NIM* represents the net interest margin and is the difference between the income from interest-earning assets and interest-bearing liabilities divided by the income from interest-earning assets. The return on assets, *ROA*, measures total profitability and is the ratio of bank income over total assets. The difference between the variables is that the *ROA* measures total profitability and the *NIM* only reflects interest income.

Following Boungou (2019), this study uses three variables that measure the level of risk-taking. The first measure is the *Z-score*, which is a measure of individual bank risk. The score can be interpreted as the probability that a bank will fail or go bankrupt (Beck et al., 2013). It is calculated by the sum of ROA and equity to total assets, divided by the standard deviation of ROA. A higher z-score implies a lower probability of default and a low level of risk-taking. This paper computes the standard deviation of ROA based on a three-year rolling window. The reason is that it is better to allow for time variation in the denominator and not fix the ROA (Beck et al., 2013). To reduce the skewness in the distribution of the z-score, this paper takes the natural logarithm of the score. The second variable is *NPLs*, which is the ratio of impaired loans to gross loans, and it reflects the quality of a banks' loan portfolio (Andries et al., 2016). A loan is considered non-performing or impaired once not paid in time or in full. A high ratio indicates that a bank has taken relatively more risk. The third risk-taking variable is *Provisions*, which is a measure of credit risk. *Provisions* is calculated as the ratio of loan loss provisions to gross loans. Banks are obligated to have provisions to anticipate expected loan losses. High provisions imply that a bank is relatively risky.

The reason for selecting three risk-taking measures is to evaluate them on their fit to the parallel trend assumption. The DiD-methodology requires that the variables show a similar movement before the event for the treatment and control group. Therefore, three risk-taking measures allow the research to select the variable(s) for which the assumption seems to hold optimally.

4.1.5 Bank level controls

The bank-level variables of interest are size, liquidity and the degree of deposit funding. *Size* is measured as the natural logarithm of total assets. *Liquidity* is calculated as the ratio of liquid assets, such as cash and accounts payable, to total assets. Lastly, *Deposit funding* is the ratio of customer deposits, both households and non-financial corporations, to total assets.

The baseline regression on profitability includes three control variables of which the first two also apply to the risk-taking regression: 1) bank capitalization, 2) efficiency and 3) loan growth.

First, the variable *Capitalization* is the ratio of total equity over total asset (E/TA). Well-capitalized banks (high E/TA) are able to lend more and increase profit because they have better access to debt funding and borrow at relatively favorable rates (Borio and Gambacorta, 2017). Concerning risk-taking, poorly capitalized banks are relatively more limited in increasing their risk due to capital constraints (Gambacorta and Shin, 2018). Therefore, *Capitalization* is expected to correlate positively with profitability and risk-taking.

Second, profitability and risk-taking may also depend on a bank's efficiency. The variable *Efficiency* is the ratio of operating expenses over operating income and shows how much it costs to generate one unit of income. Maudos and De Guevara (2004) argues that efficient banks with high-quality management are able to obtain high income at a low cost, meaning that a low ratio implies an efficient bank. Also, costs may be cut due to pressure on the NIM. The variable '*Efficiency* also controls for the changes in costs. Banks with high efficiency may have a low incentive for risk-taking. In general, the efficiency of banks is likely to correlate positively with profitability and negatively with risk-taking.

Third, banks may increase profit by increasing their margin or the number of loans. *Loan Growth*, the growth rate of gross loans, controls for any differences in the number of loans and is likely to correlate positively with profitability (Boungou, 2019). Risk-taking is unlikely to be affected by the loan growth because a bank's risk assessment should be independent of the number of loans.

4.1.6 Country level controls

Variation in the effect of NIRP on profitability and risk-taking may come from cross-sectional differences. There are four country control variables when studying profitability and risk-taking: 1) inflation, 2) GDP growth, 3) yield curve and 4) credit-to-GDP.

First, Menicucci and Paolucci (2016) and Forssbæck (2011) show that inflation correlates positively with interest margins and risk-taking. *Inflation* is measured as the annual change in a country's Consumer Price Index. Second, an increase in a country's real GDP growth (*GDP Growth*) reflects a growing economy that stimulates bank activity. According to Athanasoglou et al. (2008), high GDP growth is likely to increase bank profit because of the increase in bank activity. Third, economic activity also depends on economic expectations. Literature typically accounts for this by including a country's 10-year government bond (*Yield*) in the analysis. A high yield indicates good economic expectations and a positive impact on profitability. Overall, these three variables reflect a country's economic situation and business cycle that impact bank profitability and risk-taking.

Bank performance also depends on the importance of bank credit in a country: banks perform well if a country's economy is reliant on bank credit. In line with (Molyneux et al., 2019), the regression includes the variable *Credit-to-GDP*, measured as the ratio of gross loans to total GDP. Risk-taking is likely to be independent of the number of loans, and therefore the risk-taking regression does not include *Credit-to-GDP*.

4.1.7 Institutional controls

Institutional controls are variables that affect banks individually but depend on the institutional setting. This study includes 1) the amount of reserves at the central bank and 2) taxes. These variables only affect bank profitability.

First, banks with excess reserves (*Reserves*) at the central bank are charged by a negative rate and this hurts their profitability (Demiralp et al., 2017; Almarzoqi and Ben Naceur, 2015). The effect of bank reserves on profitability could be zero if banks charge the increase in the cost of funding to their customers. If they do not, the effect is likely to be negative. The risk-taking regressions do not include the amount of reserves because risk-taking should be independent of reserves and literature on risk-taking also does not include the variable. In all, reserves is only a control variable in the profitability analysis.

Second, banks subject to high tax rates have an incentive to tax their customers more heavily to generate profit (Demirguc-Kunt et al., 1998). *Taxes* is the ratio of total taxes

over operating income and controls for differences in tax rates. The tax rate is unlikely to affect risk-taking, and therefore only the regression on profitability includes it.

4.2 Methodology

To study the effect of NIRP on banks' profitability and risk-taking, this paper employs a DiD-methodology. The sample period ranges from 2012 to 2016 and provides two years of data prior and three years during NIRP. This time window is short because a larger window would increase the probability of confounding factors, resulting in omitted variable bias that threatens the model's validity. This research retrieves data for the period of 2011 to 2017 to calculate all variables and be able to perform robustness tests.

The DiD-methodology suits this research well because it is a quasi-experimental technique commonly used to understand the effect of a policy measure. The method identifies a treatment and control group. Both groups need to be similar, except that the treatment group is affected by the policy measure and the control group is not. In this research, NIRP affects banks in six European countries and the impact is measured relative to five non-European countries that do not have negative interest rates. The main advantages of the DiD-methodology are that it allows for a causal interpretation and controls for omitted variable bias as both groups should be similar except for the sign of the policy rate.

4.2.1 DiD-regression

The following formula presents the baseline regression and estimates the impact of negative rates:

$$Y_{i,j,t} = \alpha + \beta_1 Treatment_{i,j} + \beta_2 Post_{j,t} + \beta_3 (Treatment_{i,j} * Post_{j,t}) + \beta_4 X_{i,j,t} + \varphi_t + \gamma_j + \epsilon_{i,j,t} \quad (1)$$

Where $Y_{i,j,t}$ is the profitability or risk-taking measure of bank i in country j at time t. $Treatment_{i,j}$ is a dummy variable that equals 1 if NIRP affects bank i in country j and equals 0 otherwise. $Post_{j,t}$ is also a dummy variable. It equals 1 for the years in which the country's central bank j decided to activate NIRP, 0 otherwise. The ECB introduced NIRP in June 2014, meaning that this variable equals 1 for the treatment group from 2014 onwards. The third term is the interaction term and equals 1 for banks i subject to NIRP in country j from 2014 (t) onwards. The β_3 estimates the average difference in the outcome variable between NIRP-adopting countries, relative to those without NIRP. The results section also refers to the variable as the *NIRP-effect*. X_i is a vector of bank-

and country-specific control variables that controls for heterogeneity between banks and countries. Section 4.1 discussed the specific variables for each regression.

The regression also includes fixed effects to control for unobservable shocks or characteristics. First, the regression includes year-fixed effects because there are possible shocks impacting all banks in a specific year. For instance, a significant event in the economy could impact banks. The categorical variable φ_t is a year fixed effect and controls for such factors. Second, there are possibly country-specific factors that impact the outcome variables. For example, countries may differ in their financial regulation, demographics or technological innovation, impacting bank activity and performance. γ_j controls for such constant, unobservable country fixed effects. Both fixed-effects result in omitted variables for $Treatment_{i,j}$ and $Post_{j,t}$. The former drops because both the treatment group and country-fixed effects are constant over time. The post variable drops because is it is constant across banks. Therefore, the results only include the coefficient of the interaction term β_3.

Lastly, the standard errors, $\epsilon_{i,j,t}$, are clustered at the bank level. Bertrand et al. (2004) demonstrate that with a DiD-methodology, the treatment variable could lead to serial correlation in the standard error. Therefore, this paper clusters standard errors at the bank level. Besides, the standard errors are robust to deal with dependence and heteroskedasticity.

This research also runs percentile regressions on the size, liquidity, deposit funding and NIM to examine for which banks the effect of NIRP is strongest. Besides, these regressions could validate the results from the baseline regression. However, one important disadvantage is that the percentile regression is less likely to be normally distributed as it cuts the distribution in four. Therefore, the baseline regression provides the main result and the percentile regressions validate the results and provide additional insight on the effect on subgroups.

Three assumptions must hold for the DiD-methodology (Tan, 2019). The next section discusses the parallel trend assumption, whether the policy measure was exogenous and whether the introduction of NIRP was a surprise.

4.2.2 Assumption I: parallel trend

The first assumption is the parallel trend assumption, and it requires a similar trend in the outcome variable for the treatment and control groups during the pre-treatment period. In other words, the average change in the dependent variable should be the same for the treatment and control group in the absence of the introduction of NIRP. This assumption

cannot be proved because the policy measure is not random and the outcome without NIRP cannot be known. In an attempt to test the assumption, this paper examines the graphical movement of the outcome variables and their correlation.

Graph 3 and 4 show that the NIM and ROA of the treatment and control group move in a similar direction during the pre-NIRP period. However, the steepness of the fluctuations in both groups differs, especially for the ROA. Table 4 shows the correlation between the outcomes variables from 2011 to 2013 and 2014 to 2016. The correlation should be highly positive in the pre-NIRP period for the assumption to hold. The NIM seems to satisfy the assumption because it has a high positive correlation in the period before NIRP (0.996). For the ROA, the correlation is 0.849 in the pre-NIRP period. A downside of the ROA is that the ROA of the treatment group seems stable, whereas the control group shows an increase in the ROA towards 2014 and a decrease afterward. This downside is suboptimal for the assumption. Both variables show a negative correlation during NIRP, which hints at a NIRP-effect as the outcome variables move in the opposite direction. Overall, the correlations support the parallel trend assumption for the profitability measures.

Graph 5, 6 and 7 illustrate that the risk-taking of banks decreased substantially over time. This is confirmed in table 4 because the correlations differ among the three risk-taking measures. Figure 5 illustrates that the z-score differs substantially between the treatment and control group. Also, the correlation is negative before NIRP, implying that they move in opposite directions. Therefore, the z-score violates the parallel trend assumption. The regression will not include the z-score because it would yield invalid results. The NPLs and Provisions show a similar trend and a positive correlation for both groups. However, the NPLs show a larger difference in the trend and the correlation is weaker than Provisions. As these two variables aim to estimate the same effect, Provisions should be considered the main risk-taking variable because it satisfies the parallel trend assumption relatively best.

Table 4: The correlation between the treatment and control group's outcome variables for the period before and during NIRP.

Variables	Before NIRP period	NIRP period
NIM	0.996	-0.998
ROA	0.849	-0.069
Z-score	-0.669	-0.125
NPL	0.791	0.924
Provisions	0.955	-0.682

4.2.3 Assumption II: exogeneity

The second assumption requires the policy measure to be exogenous. This means that the decision of the ECB to introduce negative rates affects bank profitability and risk-taking and not the other way around. As mentioned earlier, NIRP aimed to increase the supply of credit by taxing banks' excess reserves with the central bank (Coeuré, 2016). This policy measure tries to align the inflation with the ECB's inflation goals (Jobst and Lin, 2016). Besides, the central bank is mandated for price stability, not bank performance. Therefore, the policy measure does not intend to affect bank profitability or risk-taking and is exogenous.

Additional evidence for exogeneity comes from the parallel trend assumption discussed in the prior section. Both profitability measures display a different direction after 2014. Also, the sign of the correlation differs for both periods. For the risk-taking measures, the change in the relationship between the group after 2014 is less evident. However, the main risk-taking variable, Provisions, does support the exogeneity assumption because the correlation reverses after NIRP.

4.2.4 Assumption III: surprise

Lastly, the third assumption is that the decision to introduce negative interest rates was a surprise. If it was not, banks could have acted on this expectation and changed their activities before the treatment. This would distort the 'pure' effect of the negative interest rate. As suggested with the first assumption, the figures on profitability and risk-taking indicate whether banks anticipated on possible negative policy rates (see figures 3 to 7). The NIM and ROA do not change significantly before the announcement of NIRP. Provisions seem to stabilize in 2013, indicating a change before the announcement. However, the movement in the profitability measures is most informative for the surprise factor as the policy directly increases costs on bank reserves. Risk-taking is likely to be less responsive than profitability. Hence, as these variables do not change significantly before the event, I believe the policy measure was a surprise.

Also, the surprise assumption finds support by news articles around the announcement of NIRP. Tan (2019) lists various papers that reflect the surprise by newspaper titles stating that the ECB took "bold measures" and "extraordinary steps" in its monetary policy[3]. In all, it seems that NIRP was a surprise and banks did not anticipate the policy

[3]For instance, The Guardian stated the "ECB launches bold measures including negative interest rate to boost eurozone" (Moneghan and Inman, 2014). Also, The Wall Street Journal wrote that "The European Central Bank took extraordinary steps ... to stave the threat of dangerously low inflation" (Blackstone, 2014).

measure.

4.2.5 Robustness tests

The DiD methodology is conditional upon various assumptions and requires several additional tests to validate the model and results. The first two tests examine explanatory factors underlying the results. The last three tests assess the robustness of the result.

First, the NIM is driven by interest income and interest expense. The interest income comes from loans and interest expense comes from deposits. The difference between the two is the interest margin. Running the regression on these variables validates the NIRP-effect on the NIM and provides additional evidence on the ZLB if the deposit rates show a smaller decrease than the loan rates.

Second, literature shows that some banks mitigate the negative impact on their NIM by increasing their non-interest income (NII) (Molyneux et al., 2019; Lopez et al., 2020). The paper reruns the regression on NII and net fees and commissions (NFCs) to explain potential differences in the NIRP-effect between NIM and ROA. Both measures are used because it provides insights on the role of, for example, fixed assets.

Third, a placebo test investigates whether the treatment and control group show a similar trend in the pre-NIRP period. The placebo test runs the baseline regression on a period of 2011 to 2014, where 2013 is the fake NIRP introduction. The results are validated if the fake treatment effect is insignificant. If not, banks may have anticipated the policy or the outcome variables already change significantly because of another trend, hurting the parallel trend assumption.

Fourth, German and American banks both account for more than 60% of all banks in their respective group (see table 2). Their dominance in the sample may drive the results. Therefore, the regression is run again without Germany and the USA in the sample. If the results are similar to the baseline regression, the results can be considered robust to changes in the group's constituents.

Fifth, there were various other UMPs introduced in the studied period (see table 12 for a timeline). These various monetary actions pose a challenge in disentangling the effect of NIRP from other policies. One of the largest confounding monetary action is the asset purchase program, which aims to stimulate lending and boost the economy by increasing the monetary base (Bernanke et al., 2004). A robustness test adds *CB Growth*, the natural logarithmic growth rate of a country's balance sheet, to the profitability regression to control for this program. The yield curve can also be considered as a control variable be-

cause monetary easing substantially decreases the yield curve (Lambert and Ueda, 2014). If the NIRP-effect remains similar, then the results show the 'pure' NIRP-effect without confounding factors from monetary decisions.

Studies that perform a DiD-analysis commonly employ Propensity Score Matching (PSM). This method pairs each treated with a non-treated bank based on the propensity score, which is the probability of being subject to NIRP. However, one necessary condition is the balancing hypothesis. This hypothesis states that for each score, treatment is random and the treatment and control group are largely similar (Havrylchyk and Jurzyk, 2011). However, table 2 and 3 shows that the mean for most variables differs significantly between groups. Therefore, the balancing hypothesis is not satisfied and PSM cannot be performed.

5 Empirical results

This section presents the empirical results from the DiD-regressions. First, it discusses the effect of NIRP on profitability and risk-taking, followed by reviewing the role of size, liquidity and deposit funding. Second, the section assesses the effect of NIM on risk-taking. This section ends by discussing the results of the robustness test.

5.1 Baseline results

The baseline results are shown in table 5. *NIRP-effect* measures the average difference in the change in the outcome variable between banks subject to NIRP and those who are not. The sign, size and significance level are important factors in determining the effect of NIRP.

5.1.1 Results on profitability

As shown in table 5, the NIM of banks in NIRP-adopting countries declines by 3.7%, relative to banks that were not subject to NIRP. The coefficient is significant at a 5%-level. The ROA did not show a significant decrease after NIRP. This implies that the adverse impact of NIRP on the NIM did not deteriorate the total profitability or other factors dampened the shock, such as fees and commissions or cost cuts. Remarkably, the presented decrease in NIM is substantially smaller than the decrease of 16.41% found by Molyneux et al. (2019). The difference in the sample may indicate that the negative impact is less severe for the studied European countries of this study compared to 33 OECD countries. Overall, the result is consistent with the first hypothesis because it finds a significant negative impact of NIRP on the NIM. However, the results do not

find evidence for the second hypothesis because NIRP has an insignificant effect on total profitability.

5.1.2 Results on risk-taking

According to column 4 of table 5, banks operating in countries with negative rates have increased their Provisions by 23.3%, compared to banks in countries without negative rates. The effect of NIRP on these banks' NPLs seems to support the increase in risk-taking (17.4%), but the effect is insignificant. Provisions focus on loan loss provisions and depend on the quality of the loans issued. This suggests that the risk-taking channel theory most likely explains the result; the ultra-low interest rates over the years incentivize banks to loosen their credit conditions, affecting the loan quality negatively. The result is not in line with Boungou (2020) and Bongiovanni et al. (2021) that find a decrease in risk-taking of 15.3% and around 10%, respectively. In all, the result show the opposite of the third hypothesis: NIRP has led to an increase risk-taking.

5.2 The role of size, liquidity, deposit funding and NIM

5.2.1 NIRP and bank size

The baseline regression (table 5) shows that a 1% increase in bank size implies a decrease in the NIM of 0.231%. Concerning the ROA, there is no significant effect. Panel A of table 6 shows that for the top three percentiles (group 2, 3 and 4), the effect on the NIM seems to be less negative for larger banks. However, the coefficients for the two groups with the largest banks are insignificant. The ROA shows a significant decrease in ROA for the group of smallest banks (-15.7% for group 1) and a significant increase in ROA for the second-largest group of banks (12.1% for group 3). In context to NIRP, this confirms the finding of Altavilla et al. (2018) that large banks are relatively better able to mitigate the total effect of NIRP on total profitability. To conclude, the result is consistent with the fourth hypothesis when considering the role of size on the NIM. However, it is inconsistent with respect to the role of size on total profitability.

When looking at the risk-taking measures, the results in table 5 provide evidence that large banks take relatively less risk compared to small banks. The coefficient of both NPLs and Provisions is negative, but it is only significant for NPLs. The percentile regressions in panel B of table 6 supports the baseline regression results: the NIRP-effect increases the risk-taking, measured by the Provisions, of small banks to a larger extent than of large banks (65.4% for group 1 and 31.6% for group 4). The result is in line with Nucera et al. (2017) who state that large banks are more diversified and have a lower

Table 5: The effect of NIRP on profitability and risk-taking

Variables	(1) NIM	(2) ROA	(3) NPLs	(4) Provisions
NIRP-effect	-0.037**	-0.004	0.174	0.233***
	(0.019)	(0.023)	(0.149)	(0.048)
Size	-0.232***	0.025	-2.031***	-0.261
	(0.075)	(0.079)	(0.546)	(0.239)
Liquidity	-0.010***	0.001	0.037***	0.010**
	(0.001)	(0.001)	(0.012)	(0.005)
Deposit funding	0.001	-0.003	-0.029*	-0.002
	(0.002)	(0.002)	(0.016)	(0.005)
Capitalization	-0.014*	0.092***	0.030	-0.052**
	(0.007)	(0.018)	(0.061)	(0.024)
Efficiency	-0.006***	-0.014***	-0.001	-0.007*
	(0.001)	(0.001)	(0.004)	(0.003)
Loan growth	0.000***	0.000		
	(0.000)	(0.000)		
Credit-to-GDP	-0.004**	0.001		
	(0.002)	(0.002)		
Inflation	-0.012	-0.000	-0.272**	0.027
	(0.010)	(0.018)	(0.125)	(0.042)
GDP growth	0.001	0.013	-0.296***	-0.006
	(0.007)	(0.011)	(0.060)	(0.033)
Yield curve	-0.076***	0.038**	-0.167*	-0.161***
	(0.010)	(0.015)	(0.098)	(0.039)
Reserve	0.017***	-0.001		
	(0.002)	(0.002)		
Taxes	0.127**	0.153		
	(0.053)	(0.142)		
Constant	6.849***	0.230	35.291***	5.578
	(1.193)	(1.256)	(8.257)	(3.791)
R-squared	0.129	0.231	0.071	0.031
Number of banks	2,949	2,950	2,848	2,964
Observations	11,352	11,340	12,121	10,334

Note: The NIRP-effect estimates the average difference in the change in the outcome variable between banks subject to NIRP and those who are not. NIM is the difference between income from interest earning assets and interest bearing liabilities divided by the income from interest earning assets. ROA is the ratio of a bank's net income to total assets. Non-performing loans is the ratio of impaired loans to gross loans. Provisions is the ratio of loan loss provisions to gross loans. Size is the natural logarithm of bank total assets. Liquidity is the ratio of bank liquid assets to total assets. Deposit Funding is the ratio of customer deposits to total assets. Capitalization is the ratio of bank equity to total assets. Efficiency is the ratio of operating expenses to operating income. Loan growth is the growth rate of gross loans. Reserve is the ratio of cash and balances at the central bank to total assets. Credit-to-GDP is the ratio of gross loans to real GDP. Inflation is the annual growth in the Consumer Price Index. GDP growth is the annual growth rate of real GDP. Yield curve is the 10-year government bond return at the end of the year. Reserve is the ratio of cash and balances at the central bank to total assets. Taxes is the ratio of taxes to operating income. The numbers in parenthesis are the robust clustered standard errors. ***, **, * indicates a significance level of 1%, 5% and 10% respectively.

incentive to take risks. Overall, this result confirms the fifth hypothesis: NIRP stimulates small banks to take more risk.

5.2.2 NIRP and bank liquidity

Table 5 shows that banks with a relatively high level of liquidity have a lower NIM compared to banks with less liquidity. If the liquidity ratio increases by one percentage point, the NIM decreases on average by 1.0%. The level of liquidity does not play a significant role in the effect of NIRP on total profitability. According to table 7, there is no significant trend in the role of liquidity on the NIM of the four groups. The NIRP-effect on the ROA does show some significance: the ROA increases 10.5% for illiquid banks (group 1) and -11.7% for the second most liquid group of banks (group 3) with

Table 6: The effect of NIRP on profitability and risk-taking by splitting the sample in four percentiles on bank size.

	Size $<$ 25th percentile (1)		Size $>$ 25th and $<$ 50th percentile (2)		Size $>$ 50th and $<$ 75th percentile (3)		Size $>$ 75th percentile (4)	
Panel A	NIM	ROA	NIM	ROA	NIM	ROA	NIM	ROA
NIRP-effect	-0.044	-0.157***	-0.112***	-0.065	-0.049	0.121**	0.034	0.012
	(0.040)	(0.038)	(0.035)	(0.044)	(0.037)	(0.048)	(0.033)	(0.030)
R-squared	0.289	0.354	0.263	0.199	0.139	0.231	0.141	0.204
N.Banks	813	811	879	880	773	775	751	751
N.Obs	2,674	2,667	2,806	2,807	2,722	2,724	3,150	3,142
Panel B	NPLs	Provisions	NPL	Provisions	NPLs	Provisions	NPLs	Provisions
NIRP-effect	0.061	0.654**	0.127	0.067	-0.222	-0.052	0.297*	0.316***
	(0.319)	(0.322)	(0.162)	(0.097)	(0.247)	(0.087)	(0.164)	(0.099)
R-squared	0.151	0.116	0.299	0.152	0.164	0.102	0.147	0.127
N.Banks	718	679	810	730	727	693	671	698
N.Obs	2,247	1,574	2,484	1,751	2,483	1,998	2,698	2,556

Note: This table shows the results for a DiD-regression that are obtained by splitting the sample on four percentiles. The percentiles consists of bank with a low (1) to large size (4), where size is measured as the natural logarithm of bank total assets. NIM is the difference between income from interest earning assets and interest bearing liabilities divided by the income from interest earning assets. ROA is the ratio of a bank's net income to total assets. Non-performing loans is the ratio of impaired loans to gross loans. Provisions is the ratio of loan loss provisions to gross loans. The NIRP-effect estimates the average difference in the change in the outcome variable between banks subject to NIRP and those who are not. The numbers in parenthesis are the robust clustered standard errors. ***, **, * indicates a significance level of 1%, 5% and 10%

a significance level of 10% and 5%-level, respectively. Although these coefficients are insignificant at the conventional level, they hint that more liquid banks have lower total profitability. The results would be in line with Bottero et al. (2020) and Demiralp et al. (2017) and could be explained by the theory that liquid banks have a higher cost of holding liquidity. However, these inferences are weak considering the significance level. Overall, the sixth hypothesis, stating that NIRP affects profitability more negatively when banks have relatively high liquidity, finds support when considering the NIM, but not when looking at the ROA.

Concerning risk-taking, table 5 shows that banks with high liquidity take more risk: on average, an increase of 1 percentage point in a bank's liquidity ratio significantly increases their NPLs by 3.7% and their Provisions by 1.0%. When comparing the most illiquid and

Table 7: The effect of NIRP on profitability and risk-taking by splitting the sample in four percentiles on bank liquidity.

	Liquidity < 25th percentile (1)		Liquidity > 25th and < 50th percentile (2)		Liquidity > 50th and < 75th percentile (3)		Liquidity > 75th percentile (4)	
Panel A	NIM	ROA	NIM	ROA	NIM	ROA	NIM	ROA
NIRP-effect	-0.040	0.105*	-0.075*	-0.072*	-0.063	-0.117**	-0.058	-0.046
	(0.055)	(0.055)	(0.038)	(0.040)	(0.047)	(0.046)	(0.041)	(0.043)
R-squared	0.140	0.164	0.182	0.136	0.182	0.177	0.154	0.413
N.Banks	971	973	1,379	1,379	1,358	1,359	968	965
N.Obs	2,636	2,644	2,869	2,868	2,937	2,933	2,910	2,895
Panel B	NPLs	Provisions	NPLs	Provisions	NPLs	Provisions	NPLs	Provisions
NIRP-effect	0.778***	0.055	0.592*	0.079	-0.214	0.018	0.025	0.112
	(0.234)	(0.061)	(0.311)	(0.088)	(0.337)	(0.092)	(0.303)	(0.167)
R-squared	0.206	0.432	0.336	0.289	0.103	0.191	0.198	0.142
N.Banks	918	790	1,300	1,102	1,239	1,105	804	785
N.Obs	2,470	1,969	2,626	1,953	2,620	2,062	2,196	1,895

Note: This table shows the results for a DiD-regression that are obtained by splitting the sample on four percentiles. The percentiles consists of bank with a low (1) to high liquidity (4), where liquidity is the ratio of bank liquid assets to total assets. NIM is the difference between income from interest earning assets and interest bearing liabilities divided by the income from interest earning assets. ROA is the ratio of a bank's net income to total assets. Non-performing loans is the ratio of impaired loans to gross loans. Provisions is the ratio of loan loss provisions to gross loans. The NIRP-effect estimates the average difference in the change in the outcome variable between banks subject to NIRP and those who are not. The numbers in parenthesis are the robust clustered standard errors. ***, **, * indicates a significance level of 1%, 5% and 10%.

liquid group of banks (group 1 and 4), table 7 yields contradicting findings for the effect of NIRP on NPLs; it finds that more liquidity relates to fewer Provisions. However, only the NIRP-effect on the NPLs is significant for group 1. Hence, the percentile regression neither confirms nor rejects the findings. As stated in the methodology section, the baseline regression is most valid. Overall, these results are in line with (Basten and Mariathasan, 2018) and imply that banks with high liquidity put their money at work and have more risky assets. Therefore, the result supports the seventh hypothesis.

Table 8: The effect of NIRP on profitability and risk-taking by splitting the sample in four percentiles on bank's degree of deposit funding.

	Dep. fun. < 25th percentile (1)		Dep. fun. > 25th and < 50th percentile (2)		Dep. fun. > 50th and < 75th percentile (3)		Dep. fun. > 75th percentile (4)	
Panel A	NIM	ROA	NIM	ROA	NIM	ROA	NIM	ROA
NIRP-effect	0.004	-0.142*	-0.101**	-0.046	-0.046	-0.017	-0.015	-0.024
	(0.071)	(0.079)	(0.048)	(0.041)	(0.030)	(0.032)	(0.033)	(0.039)
R-squared	0.190	0.418	0.217	0.256	0.228	0.187	0.168	0.224
N.Banks	674	678	1,118	1,115	1,230	1,226	984	983
N.Obs	2,206	2,218	3,042	3,034	3,138	3,132	2,966	2,956
Panel B	NPLs	Provisions	NPLs	Provisions	NPLs	Provisions	NPLs	Provisions
NIRP-effect	-0.707	-0.085	0.086	0.224***	-0.293	0.021	-0.428*	0.440
	(0.498)	(0.163)	(0.219)	(0.086)	(0.223)	(0.065)	(0.242)	(0.297)
R-squared	0.181	0.179	0.212	0.171	0.313	0.326	0.164	0.127
N.Banks	573	568	1,029	927	1,143	1,000	862	801
N.Obs	1,776	1,609	2,771	2,122	2,874	2,141	2,491	2,007

Note: This table shows the results for a DiD-regression that are obtained by splitting the sample on four percentiles. The percentiles consists of bank with a low (1) to high deposit funding (4), where deposit funding is the ratio of customer deposits to total assets. NIM is the difference between income from interest earning assets and interest bearing liabilities divided by the income from interest earning assets. ROA is the ratio of a bank's net income to total assets. Non-performing loans is the ratio of impaired loans to gross loans. Provisions is the ratio of loan loss provisions to gross loans. The NIRP-effect estimates the average difference in the change in the outcome variable between banks subject to NIRP and those who are not. The numbers in parenthesis are the robust clustered standard errors. ***, **, * indicates a significance level of 1%, 5% and 10%.

5.2.3 NIRP and deposit funding

According to the baseline results (table 5), the degree of deposit funding does not change bank margins and profitability significantly. The percentile regression hints towards a trend in the NIM and ROA when deposit funding increases. The NIM becomes less negative for relatively high-deposit funded banks (from group 2 to 4), and so does the ROA (from group 1 to 3). However, the results are insignificant. This finding is contrary to Eisenshmidt and Smets (2019) because it finds that high-deposit banks do not obtain a lower reduction in their cost of funding relative to banks less reliant on deposits. In all, the result lacks statistical significance and does not support the eighth hypothesis.

The risk-taking of high-deposit banks is also not necessarily higher than less deposit-funded banks. Table 5 shows very weak evidence of a decrease in risk-taking for banks with high deposit funding, as both coefficients for NPLs and Provisions are not significant at the 5%-level. Also, table 7 is inconclusive as both NPLs and Provisions lack a clear trend over the groups with more deposit funding. Therefore, there is no support for the papers that argue that high-deposit banks take more risk (see Heider et al., 2019; Bittner et al., 2020). An explation could be that if the degree of deposit funding does not impact profitability, the effect on risk-taking is also unlikely. Hence, there is no support for the ninth hypothesis that banks reliant on deposit funding take more risk.

5.2.4 The effect of NIM on risk-taking

The reduction in the NIM may stimulate banks to take more risk to enhance profitability (Keeley, 1990). Table 9 shows the results for regressing the NPLs and Provisions on the NIM and the earlier used control variables. The results show that a 1% percentage point increase in the NIM corresponds to a 26.4% and 40.2% increase in NPLs and Provisions, respectively. This implies that banks applying high margins tend to take more risk. Table 10 illustrates that banks with a low NIM (group 1) do not increase risk more significantly than banks with a high NIM (group 4). Even though group 4 only has significant coefficients, the increasing coefficient from low-NIM to high-NIM banks illustrates some of the correlation between the NIM and risk-taking measures. The result is in line with Martynova et al. (2015) that also find that more profitable banks take less risk. Hence, the results confirm the tenth hypothesis: the effect of NIM on risk-taking is positive.

Table 9: The effect of NIM on risk-taking

Variables	(1) NPLs	(2) Provisions
NIRP-effect	0.156	0.258***
	(0.148)	(0.049)
NIM	0.264***	0.402***
	(0.084)	(0.144)
Size	-1.879***	-0.168
	(0.547)	(0.227)
Liquidity	0.038***	0.014***
	(0.012)	(0.005)
Deposit funding	-0.018	-0.004
	(0.014)	(0.005)
Capitalization	0.039	-0.046*
	(0.062)	(0.024)
Efficiency	0.002	-0.002
	(0.004)	(0.003)
Inflation	-0.256**	0.029
	(0.124)	(0.042)
GDP growth	-0.297***	-0.007
	(0.059)	(0.032)
Yield curve	-0.157	-0.157***
	(0.098)	(0.038)
Constant	31.249***	2.861
	(8.138)	(3.546)
R-squared	0.072	0.062
Number of banks	2,832	2,958
Observations	12,051	10,310

Note: The NIRP-effect estimates the average difference in the change in the outcome variable between banks subject to NIRP and those who are not. NIM is the difference between income from interest earning assets and interest bearing liabilities divided by the income from interest earning assets. ROA is the ratio of a bank's net income to total assets. Non-performing loans is the ratio of impaired loans to gross loans. Provisions is the ratio of loan loss provisions to gross loans. Size is the natural logarithm of bank total assets. Liquidity is the ratio of bank liquid assets to total assets. Deposit Funding is the ratio of customer deposits to total assets. Capitalization is the ratio of bank equity to total assets. Efficiency is the ratio of operating expenses to operating income. Loan growth is the growth rate of gross loans. Reserve is the ratio of cash and balances at the central bank to total assets. Credit-to-GDP is the ratio of gross loans to real GDP. Inflation is the annual growth in the Consumer Price Index. GDP growth is the annual growth rate of real GDP. Yield curve is the 10-year government bond return at the end of the year. Reserve is the ratio of cash and balances at the central bank to total assets. Taxes is the ratio of taxes to operating income. The numbers in parenthesis are the robust clustered standard errors. ***, **, * indicates a significance level of 1%, 5% and 10% respectively.

Table 10: The effect of NIRP and NIM on bank's risk-taking.

	NIM < 25th percentile (1)		NIM > 25th and < 50th percentile (2)		NIM > 50th and < 75th percentile (3)		NIM > 75th percentile (4)	
Panel A	NPLs	Provisions	NPLs	Provisions	NPLs	Provisions	NPLs	Provisions
NIRP-effect	-0.555	0.096	-0.451***	0.058	-0.404	-0.038	0.351	0.148
	(1.185)	(0.208)	(0.169)	(0.081)	(0.366)	(0.100)	(0.448)	(0.193)
NIM	-0.438	-0.074	0.069	0.149	0.201	0.296**	0.465***	0.332**
	(0.467)	(0.290)	(0.202)	(0.106)	(0.370)	(0.127)	(0.144)	(0.138)
R-squared	0.127	0.128	0.308	0.284	0.234	0.223	0.263	0.212
N.Banks	420	400	1,044	873	964	802	665	636
N.Obs	1,089	955	2,450	1,659	2,292	1,671	2,457	2,018

Note: This table shows the results for a DiD-regression that are obtained by splitting the sample on four percentiles. The percentiles consists of bank with a low (1) to high NIM (4), where NIM is the difference between income from interest earning assets and interest bearing liabilities divided by the income from interest earning assets. NPLs is the ratio of impaired loans to gross loans. Provisions is the ratio of loan loss provisions to gross loans. The NIRP-effect estimates the average difference in the change in the outcome variable between banks subject to NIRP and those who are not. The numbers in parenthesis are the robust clustered standard errors. ***, **, * indicates a significance level of 1%, 5% and 10%.

5.3 Robustness tests

5.3.1 Decomposition of NIM

Panel A of table 14 shows that the introduction of NIRP resulted in a decrease in the interest income of 21.6% and 14.7% for interest expenses. These results confirm that deposit rates are relatively sticky compared to loan rates. Hence, it supports the theory of a ZLB because banks are reluctant to decrease the deposit rates to the same extent as loan rates. Overall, the decomposition of NIM verifies the negative impact of NIRP on interest margins and confirms the existence of a ZLB.

5.3.2 Non-interest income

The baseline regression is run on NII and NFCs to explain the difference in the NIRP-effect on the NIM and ROA. Panel A of table 14 shows that the NII and NFCs increase significantly with 8.6% and 2.8% respectively after the introduction of NIRP. This provides further evidence that banks can mitigate the compressed NIM by increasing non-interest income. Also, the difference in magnitude of the coefficients suggests that the increase in realized gains outweighs the increase in fees and commissions. In all, non-interest income

increases significantly after NIRP with an increase in NFCs.

5.3.3 Placebo test

A placebo test is run to verify that both treatment and control group experience a similar trend before introducing NIRP, more specifically in 2013. Panel A of table 15 shows that NIRP has a significant positive effect on NIM, NPLs and Provisions. This outcome hurts the validity of the DiD-analysis because these variables change significantly before the event and subsequently violate the parallel trend assumption. This implies that the results should be reviewed carefully when making strong inferences.

5.3.4 Different groups

Panel B of table 15 re-estimates the NIRP-effect on the treatment and control group without the countries that dominate the sample, namely Germany and the USA. The results show higher coefficients for most outcome variables, implying a stronger effect, but the effect of NIRP on NIM becomes insignificant. Therefore, the results depend on the group's constituents and implications should be made carefully.

5.3.5 Control for asset purchase programs

The last robustness test includes an additional control variable for asset purchase programs to the regression. The results remain similar to the baseline regression, except for a stronger NIRP-effect on NIM and a significant effect on the NPLs. The latter shows that NIRP leads to an increase in risk-taking by the treatment group of 67.4% relative to the control group. This is a substantial increase. Overall, the results do not seem to be confounded by asset purchase programs and capture the real NIRP-effect.

6 Limitations and further research

The empirical results presented should be considered in light of some limitations. First, the evidence on fully satisfying the parallel trend assumption is suboptimal. The graphical movement and correlation between the treatment and control group's outcome variables indicate a similar trend. However, the placebo test shows that the outcome variables already change significantly before the event. This research intentionally chose a small treatment group to focus on a few similar countries and limit possible outliers and confounding factors. However, the sample lacks the characteristics that fit the DiD-methodology well.

Second, this study explains its results by the most likely reasons that have been documented in the literature. However, it does not test on the underlying mechanisms and therefore the explanation for these results lacks formal proof from the sample. Therefore, the interpretation is valuable but the explanation should be considered with care. For instance, this research finds a substantial increase in risk-taking and suggests that the increase in risky loans is the main reason. However, it is unclear whether the increase comes from, for example, looser credit conditions or a general deterioration of borrowers' creditworthiness. Further research should study the exact mechanisms at play to deepen our understanding of NIRP.

Third, many factors could affect the studied bank-level variables and macroeconomic development during the sample period. In light of the first limitation, if the groups do not show a similar trend or are not exact counterfactuals, then the DiD-analysis does not fully control for omitted variable bias. Also, the fixed effects in the regression may not correct the biases. Consequently, the regression requires more control variables. However, not all variables that could affect an outcome variable were available. In all, the research cannot assure to have any omitted variable bias, partly due to the possible dissimilarity between the groups and unavailable data.

The suggestions for further research primarily follow the limitations of this research. As mentioned earlier, this study has a broad scope and discusses various mechanisms that could explain the results. However, some results lack an in-depth understanding of what factors determine the effect. Especially considering the lack of consensus in the literature and the relevance of this topic for the financial stability, research on the underlying mechanisms is important. Besides, scholars should further research which factors play a role on the effect of NIRP on profitability and risk-taking. This paper shows that size and liquidity play an important role but maybe there be more factors that are at play. Besides, understanding which factors affect the profitability and risk-taking, reduces the possibility of omitted variable bias. Therefore, extending the research on specific factors could provide central bankers the knowledge to identify and monitor banks that are most likely to be hit negatively by the policy measure.

7 Conclusion

In 2014, the ECB introduced the NIRP to increase the credit supply and stimulate the real economy by charging negative interest rates on bank reserves. Various scholars point to the negative side-effects of the policy and argue that it poses a threat to financial stability. One potential adverse side-effect of the policy is a negative impact on banks' NIM

that subsequently leads to lower profits, a decrease in banks' equity base and solvency rate. Besides, negative rates may encourage banks to seek yield and increase their risk once their profitability is under pressure. Therefore, from a financial stability perspective, it is highly relevant to understand the effect of NIRP on profitability and risk-taking.

This paper performs a difference-in-difference study on the effect of NIRP on profitability and risk-taking between 2012 to 2016. The panel data consists of 3154 banks from 11 countries where Belgium, France, Germany, Luxembourg, the Netherlands and Spain are in the treatment group and Canada, Croatia, Czech Republic, the UK and the USA are in the control group. The results show that NIRP leads to a decrease of 3.7% in the NIM of banks subject to negative policy rates compared to those not. However, total profitability does not decrease significantly because the NII increases substantially by 8.6%. This suggests that banks on average mitigate the negative effect of compressed margins. Banks in NIRP-adopting countries experience a relative increase in provisions by 23.3%, indicating that these banks take more risk than banks in countries with a positive policy rate.

This research also studies the role of bank size, liquidity and deposit funding, and the relationship between the NIM and risk-taking. First, large banks seem better able to mitigate the adverse impact of NIRP on their NIM and take less risk than small banks. These findings support the view that large banks are typically more diversified and obtain a lower cost of funding (Nucera et al., 2017). Second, banks with low liquidity experience a less negative NIRP-effect on their profitability and take less risk than liquid banks. Liquid banks seem to have a higher cost of holding their excess liquidity. Subsequently, they have a higher incentive to put their money at work and increase their risk-taking (Basten and Mariathasan, 2018). Third, this paper finds no significant effect of the degree of deposit funding on the effect of NIRP. This is inconsistent with several scholars that argue that high-deposit banks increase their risk-taking due to the adverse shock of NIRP on their net worth (Heider et al., 2019). Lastly, and in contrast to traditional theory (see Jensen and Meckling, 1976; Keeley, 1990), the results show that banks with a high NIM also take more risk.

The robustness test shows that the NIM is most likely to decrease because of the ZLB: deposit rates decrease less than loan rates. Also, even though the NIM decreases on average, banks' total profitability remains stable as the NII and NFCs increase with 8.6% and 2.8% respectively. In addition, the robustness tests show that the results remain similar when adding an additional control for the ECB's asset purchase programs. However, a placebo test shows that the NIM, NPLs and provisions changed significantly with a fake NIRP announcement in 2013. This violates the parallel trend assumption and hurts the

validity of the results. Also, Germany and the USA dominate the sample and excluding them results in an insignificant decrease in NIM. Hence, the results are not robust to a change in the group and inferences should be made carefully.

To conclude, NIRP led to a lower NIM, although this did not decrease total profitability. The increase in risk-taking after NIRP raises concerns about the negative side-effect of the policy. Especially, small and liquid banks fare worse after NIRP. This paper calls for interest from academics and policymakers to assure a strong financial stability.

Appendix

Table 11: Definition of variables

Variable	Units	Description
Panel A: Bank profitability and risk-taking variables		
Net interest margin (NIM)	ratio	Net interest margin is the difference between income from interest earning assets and interest bearing liabilities divided by the income from interest earning assets.
Return on assets (ROA)	ratio	Return on assets is the ratio of a bank's net income to total assets.
Z-score	ratio	Z-score is the natural logarithm of the sum of the return on assets and equity to total assets, divided by the standard deviation of the return on assets.
NPLs	ratio	Non-performing loans is the ratio of impaired loans to gross loans.
Provisions	ratio	Provisions is the ratio of loan loss provisions to gross loans.
Interest income	ratio	Interest income is the the ratio of interest income on total assets.
Interest expenses	ratio	Interest expenses is the ratio of interest expenses to total assets.
Non-interest income	logarithm	Non-interest income is natural logarithm of the ratio of non-interest income to total operating revenue.
Net fees and commissions	ratio	Net fees and commissions is the ratio of net fees and commissions to total assets.
Panel B: Dummy variables		
NIRP-effect	dummy	NIRP-effect is a dummy variable that takes value 1 if bank i in country j is subject to NIRP and NIRP was active.
Treated	dummy	Treated is a dummy variable that takes value 1 if bank i in country j is subject to NIRP and 0 otherwise.

Post	dummy	Post is a dummy variable that take the value 1 for the years in which NIRP was active and 0 otherwise.
Panel C: Bank balance sheet variables		
Size	logarithm	Size is the natural logarithm of bank total assets.
Liquidity	ratio	Liquidity is the ratio of bank liquid assets to total assets.
Deposit funding	ratio	Deposit funding is the ratio of customer deposits to total assets.
Capitalization	ratio	Capitalization is the ratio of bank equity to total assets.
Efficiency	ratio	Efficiency is the ratio of operating expenses to operating income.
Loan growth	percentage	Loan growth is the growth rate of gross loans.
Panel D: Macroeconomic variables		
GDP growth	percentage	GDP growth is the annual growth rate of real GDP.
Inflation	percentage	Inflation is the annual growth in the Consumer Price Index.
Unemployment	percentage	Unemployment is the annual growth rate of unemployment.
Yield curve	percentage	Yield curve is the 10-year government bond return at the end of the year.
Credit-to-GDP	ratio	Credit-to-GDP is the ratio of gross loans to real GDP.
Growth CB BS	percentage	Growth CB BS is the growth rate of a central bank balance sheet size.
Panel E: Institutional variables		
Reserve	ratio	Reserve is the ratio of cash and balances at the central bank to total assets.
Taxes	ratio	is the ratio of taxes to operating income.

Table 12: Timeline of the main ECB monetary policy decisions between 2014 and 2016.

Date	Deposit Facility rate	Marginal lending rate	Main refinancing rate	Complementary policies announced
June 2014	-0.10	0.40	0.15	1) Targeted Longer-Term Refinancing Operations program with 2-year maturity 2) Preparations for an Asset Back Securities Purchase Program
September 2014	-0.20	0.30	0.05	1) Initiation of Asset Back Securities Purchase Program
December 2015	-0.30	0.30	0.05	1) 6-month extension of asset purchase programs 2) Eligible assets for purchase expanded
March 2016	-0.40	0.25	0.00	1) Quantative Easing program expanded from €60 billion to €80 billion per month untill March 2017 2) Non-financial corporate bonds are added to list of assets eligible for purchases 3) New Targeted Longer-Term Refinance Operations program with four year maturity

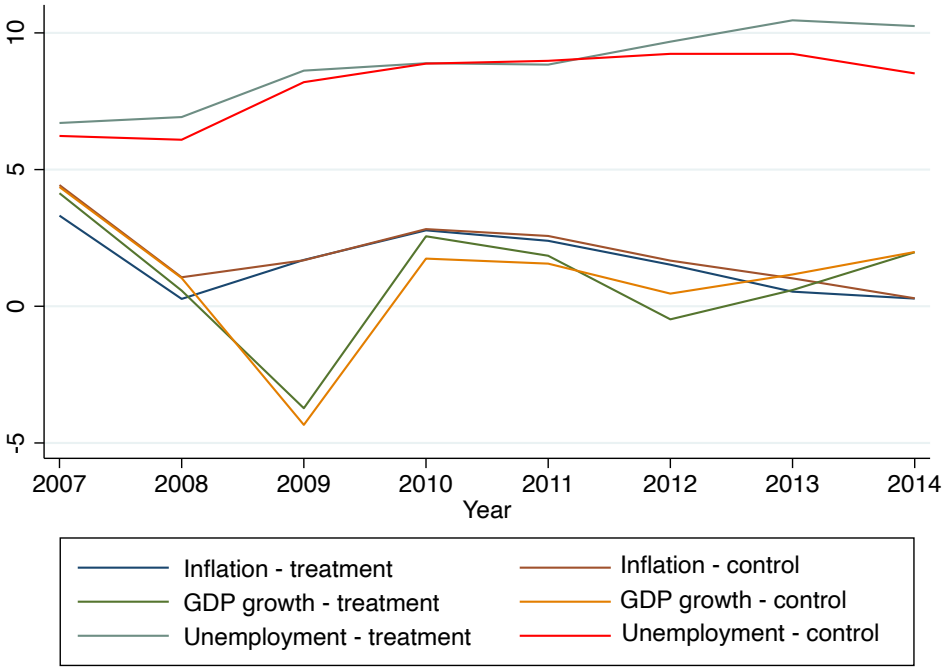
Note: The timeline is based on papers from Arteta et al. (2016) and Van Riet (2017).

Table 13: Pearson correlation

Variables	Mean treatment	Mean control	Pearson	P-value
Inflation	1.599	1.944	0.949***	0.000
	(1.219)	(1.505)		
GDP growth	0.935	0.997	0.969***	0.000
	(2.643)	(2.756)		
Unemployment	8.796	8.170	0.896***	0.002
	(5.587)	(3.068)		

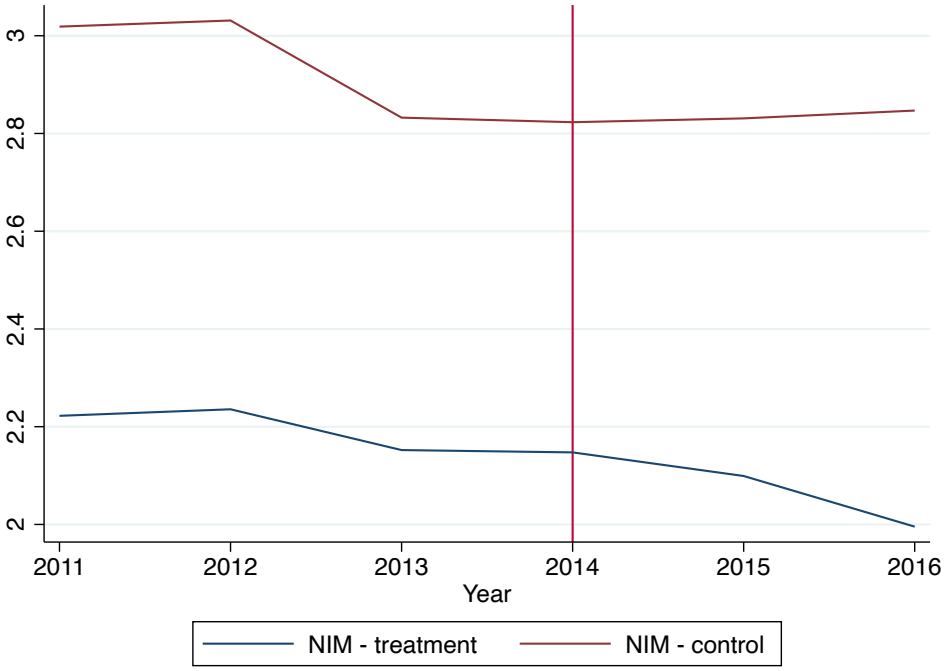
Note: Inflation is the annual percentage growth in the Customer Price Index. GDP growth is the annual growth rate of GDP. Unemployment is the annual level of unemployment in percentage. * indicates statistical significance at a 1%-level.

Figure 2: Macroeconomic trends of treatment and control group



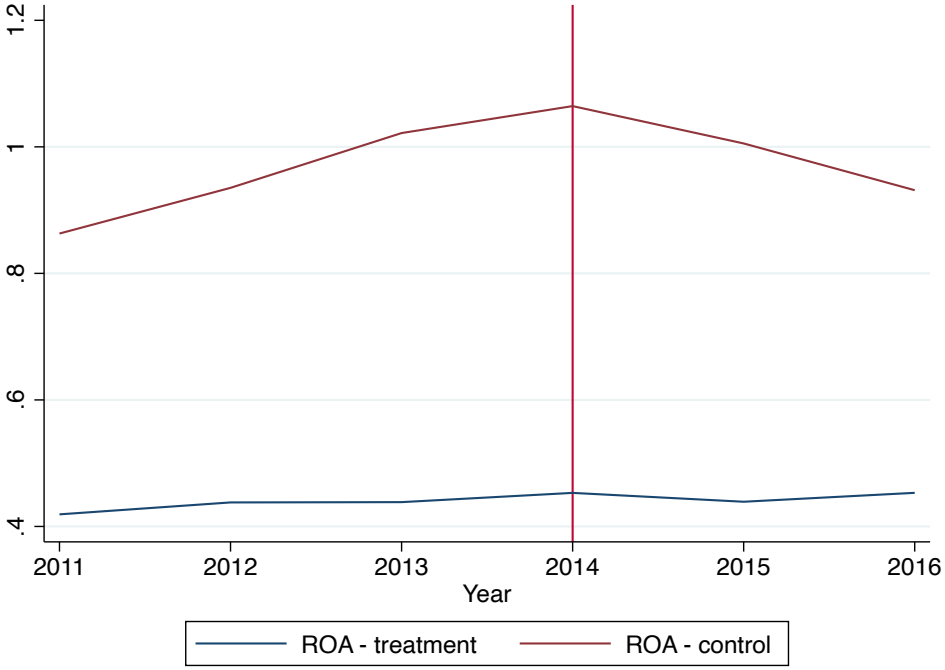
This figure shows the movement of GDP growth, inflation and unemployment for the treatment (Belgium, France, Germany, Luxembourg, the Netherlands and Spain) and control group (Canada, Czech Republic, Croatia, United Kingdom and the United States of America) between 2007 and 2016. All variables are determined annually and measured in percentage.

Figure 3: Net interest margin before and after NIRP



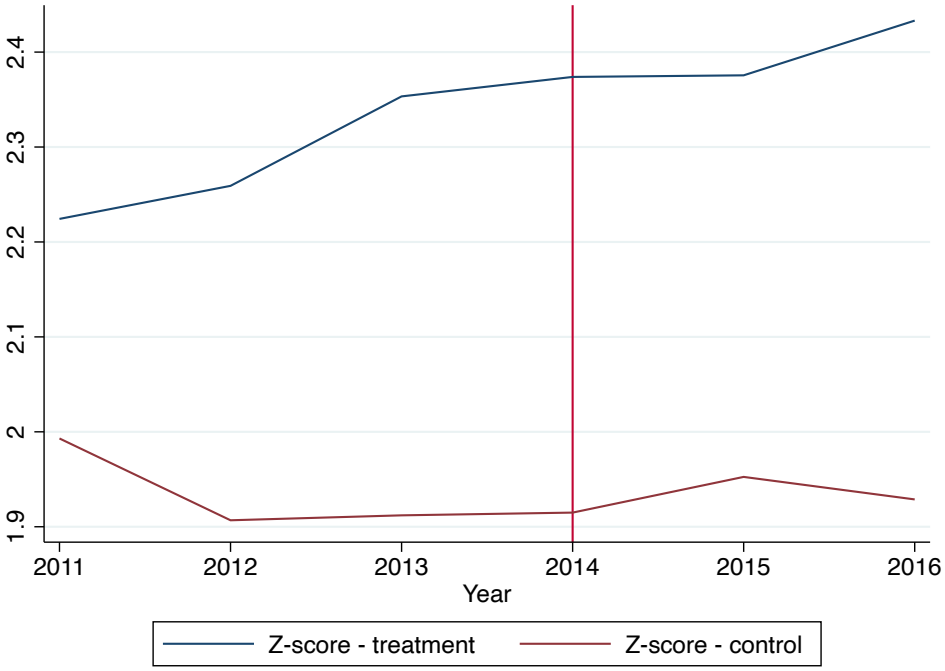
This figure shows the movement of the net interest margin (NIM) for both treatment and control group over time. NIM is the annual difference between income from interest earning assets and interest bearing liabilities divided by the income from interest earning assets.. The red vertical line indicates the introduction of the negative interest rate policy.

Figure 4: Return on assets before and after NIRP



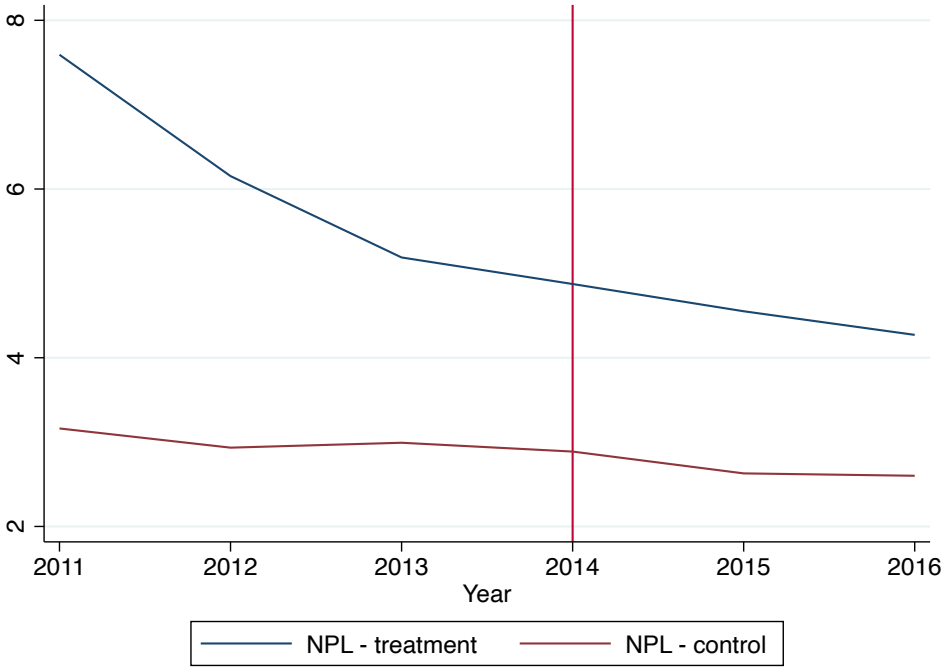
This figure shows the movement of the return of assets (ROA) for both treatment and control group over time. The ROA is the annual ratio of bank's net income to total assets. The red vertical line indicates the introduction of the negative interest rate policy.

Figure 5: Z-score before and after NIRP



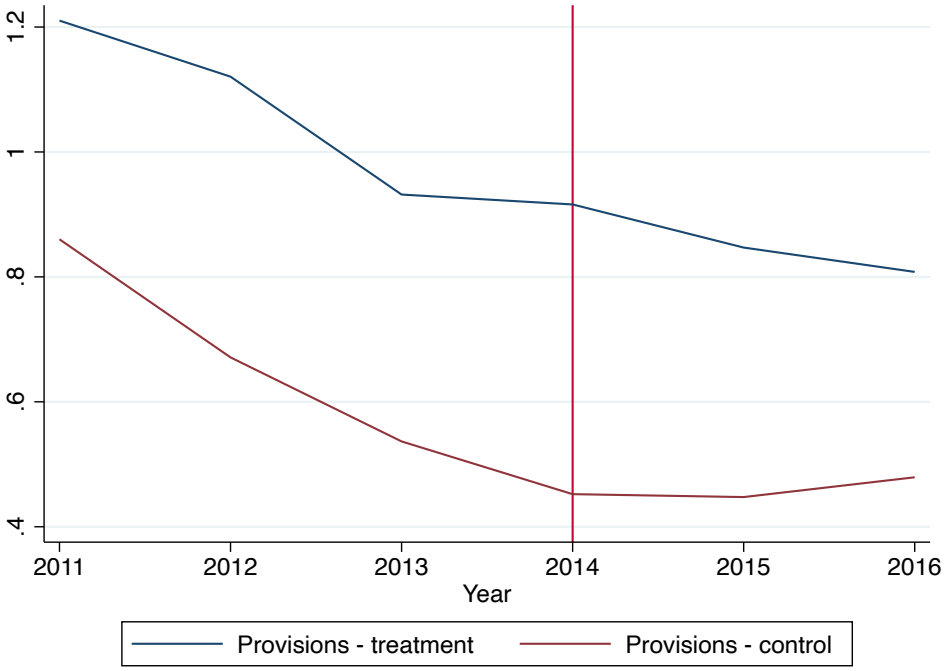
This figure shows the movement of the z-score for both treatment and control group over time. Z-score is the natural logarithm of the sum of the return on assets and equity to total assets, divided by the standard deviation of the return on assets. The red vertical line indicates the introduction of the negative interest rate policy.

Figure 6: Non-performing loans before and after NIRP



This figure shows the movement of the non-performing loans (NPLs) for both treatment and control group over time. NPLs is the ratio of impaired loans to gross loans. The red vertical line indicates the introduction of the negative interest rate policy.

Figure 7: Loan loss provisions before and after NIRP



This figure shows the movement of the loan loss provisions (Provisions) for both treatment and control group over time. Provisions is the ratio of loan loss provisions to gross loans. The red vertical line indicates the introduction of the negative interest rate policy.

Table 14: Robustness tests on explanatory factors

Panel A: Decomposition of the NIM	Interest income	Interest expense
NIRP-effect	-0.216***	-0.147***
	(0.026)	(0.015)
R-squared	0.281	0.512
Number of banks	3,059	3,059
Observations	11,752	11,761
Panel B: Non-interest income	Non-interest income	Net fees and commissions
NIRP-effect	0.086***	0.028**
	(0.022)	(0.015)
R-squared	0.120	0.096
Number of banks	2,389	2,292
Observations	9,052	8,720

Note: This table shows the results for robustness tests. Panel A shows the results for regressing the baseline regression on interest income and interest expense. Panel B presents the results for regressing the non-interest income and net fees and commissions. Interest income is the the ratio of interest income on total assets. Interest expenses is the ratio of interest expenses to total assets. Non-interest income is the ratio of non-interest income to total operating revenue. Net fees and commissions is the ratio of net fees and commissions to total assets. The NIRP-effect estimates the average difference in the change in the outcome variable between banks subject to NIRP and those who are not. The numbers in parenthesis are the robust clustered standard errors. ***, **, * indicates a significance level of 1%, 5% and 10%

Table 15: Robustness tests on the validity of the model

Panel A: Placebo test	NIM	ROA	NPLs	Provisions
NIRP-effect	0.103***	0.019	0.651***	0.248***
	(0.025)	(0.036)	(0.122)	(0.091)
R-squared	0.137	0.166	0.065	0.033
Number of banks	2,902	2,903	2,774	2,755
Observations	6,592	6,576	7,635	6,911
Panel B: Different groups	NIM	ROA	NPLs	Provisions
NIRP-effect	-0.055	0.005	0.461	0.509***
	(0.044)	(0.046)	(0.518)	(0.137)
R-squared	0.143	0.363	0.051	0.044
Number of banks	964	970	878	929
Observations	3,760	3,772	3,646	3,561
Panel C: Control for asset purchase programs	NIM	ROA	NPLs	Provisions
NIRP-effect	-0.062***	0.039	0.674***	0.269***
	(0.024)	(0.028)	(0.172)	(0.064)
Growth CB BS	-0.003***	-0.001**	-0.012***	-0.001
	(0.000)	(0.000)	(0.002)	(0.001)
R-squared	0.138	0.232	0.075	0.031
Number of banks	2,949	2,950	2,848	2,964
Observations	11,352	11,340	12,121	10,334

Note: This table shows the results for robustness tests. Panel A shows the results for a placebo test that assesses the NIRP-effect with a fake introduction in 2013 in the period of 2011 to 2014. Panel B shows the regression results for the treatment and control group without Germany and the USA. Panel C shows the regression that includes a control variable for the growth rate of the central bank's balance sheet. NIM is the difference between income from interest earning assets and interest bearing liabilities divided by the income from interest earning assets. ROA is the ratio of a bank's net income to total assets. NPLs is the ratio of impaired loans to gross loans. Provisions is the ratio of loan loss provisions to gross loans. Growth CB BS is the growth rate of a central bank balance sheet size. The NIRP-effect estimates the average difference in the change in the outcome variable between banks subject to NIRP and those who are not. The numbers in parenthesis are the robust clustered standard errors. ***, **, * indicates a significance level of 1%, 5% and 10%

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