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Making a virtue out of necessity: the effect of negative interest rates on bank cost efficiency

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Abstract

Do negative interest rates affect banks' cost efficiency? We exploit the unprecedented introduction of negative policy interest rates in the euro area to investigate whether banks *make a virtue out of necessity* in reacting to negative interest rates by adjusting their cost efficiency. We find that banks most affected by negative interest rates responded by enhancing their cost efficiency. We also show that improvements in cost efficiency are more pronounced for banks that are larger, less profitable, with lower asset quality and that operate in more competitive banking sectors. In addition, we document that enhancements in cost efficiency are statistically significant only when breaching the zero lower bound (ZLB), indicating that the pass-through of interest rates to cost efficiency is not effective when policy rates are positive. These findings hold important policy implications as they provide evidence on a beneficial second-order effect of negative interest rates on bank efficiency.

JEL classification: E43; E44; E52; G21; F34

Keywords: NIRP; Difference-in-differences; Stochastic frontier approach; Bank cost efficiency

Non-technical summary

In June 2014, the European Central Bank (ECB) was the first major central bank to undertake the unprecedented decision to cut its deposit facility rate (DFR) into negative territory. With the primary aim of providing additional monetary stimulus, thereby contributing to price stability and supporting economic growth, the ECB's adoption of negative policy rates (NIRP) has been part of a wider credit-easing strategy to counter off substantial deflationary risk. NIRP effectiveness remains potentially controversial for several reasons. One of the main criticisms is associated with the negative effects of NIRP on bank margins and profits as banks may be reluctant to impose negative rates on deposits because of the fear of losing their deposit base. Lower bank profitability can lead, in turn, to a contraction in lending supply and therefore impair the transmission mechanism of monetary policy under negative rates as well as the expansionary aim of central banks. Further unintended consequences associated with NIRP, such as asset overvaluation and banks' tendency to assume excessive risk, can pose a risk to financial stability.

Banks may offset the potentially negative effects of NIRP on bank profitability in several ways. First, they could offset the contraction in net interest margins by increasing loan volumes, i.e. one of the intended aims of the policy. Second, they could boost non-interest income via raising fees and commissions and/or gains from holding a sizeable amount of held-for-trading fixed-income securities. Third, they may react to NIRP by increasing their holdings of riskier, higher yielding assets. A growing strand of the literature has already focused on the different channels through which NIRP impacts the supply of bank credit to the real economy and bank profitability. Other studies explored the way negative interest rates affect banks' risk-taking and the "reach-for-yield" behaviour and the usage of cash.

In this paper, we investigate a previously unexplored channel and put forward the hypothesis that NIRP-affected banks - i.e. banks with a greater reliance on retail deposits as a source of funding – strategically react to the detrimental repercussions of NIRP on their performance by improving their cost efficiency. We conjecture that negative rates have strengthened euro area high-deposit banks' incentives to improve their efficiency to mitigate the adverse impact on their profitability. Furthermore, we explore whether the heterogeneity in balance sheet and market conditions, before the introduction of NIRP in 2014, influenced banks' incentives to enhance their cost structure. We fill the gap in the existing literature by analysing the impact of negative interest rates on bank cost efficiency, defined as the ability to generate the highest levels of desirable outputs (e.g. loans and other earning assets) with the lowest use of input (e.g. deposits and labour).

In the analysis, we exploit the ECB implementation of NIRP in mid-2014 and a comprehensive dataset of bank balance-sheet and profit and loss characteristics to investigate whether and to what extent euro area banks had to make a virtue out of necessity, therefore enhancing cost efficiency. To test this hypothesis, we employ a difference-in-differences (DiD) econometric identification strategy where we compare the behaviour of banks with different retail deposit ratios around the introduction of policy rates below the zero lower bound (ZLB). In our empirical settings, we consider high (low)-deposit banks those institutions with a retail deposit to total asset ratio above (below) the median value of the related distribution, pre-NIRP.

Our evidence suggests that NIRP-affected banks responded to the introduction of NIRP via improvements in their cost efficiency. We document greater incentives to enhance cost efficiency for NIRP-affected banks that are larger, less profitable, with lower asset quality, weaker pre-NIRP lending growth and that operate in competitive banking sectors. Therefore, based on our findings, we can infer that (i) high-deposit large banks have more room for manoeuvres on operating costs than smaller banks; (ii) high-deposit banks that are less profitable, with lower asset quality and limited lending capacity face additional pressures to react to the negative effects of NIRP on profits by improving their cost efficiency; and (iii) competitive market conditions further compress banks' margins and profits in a negative interest rate environment, thereby pushing high-deposit banks to enhance their cost efficiency. In addition, we document that enhancements in cost efficiency are statistically significant only when breaching the ZLB, indicating that the pass-through of interest rates to cost efficiency is not effective when policy rates are positive. These findings hold relevant implications for both financial stability and the transmission of the monetary policy. If NIRP-affected banks improve their cost efficiency, this may lead to higher profits with beneficial effects in terms of financial stability and monetary policy transmission as banks' lending decisions largely depend on retained earnings as a source of funding.

1 Introduction

In June 2014, the European Central Bank (ECB) was the first major central bank to undertake the unprecedented decision to cut its deposit facility rate (DFR) into negative territory.[1] Further cuts followed in September 2014, December 2015, and March 2016, each by 10 basis points (bps), until the DFR reached -0.5% in September 2019. With the primary aim of providing additional monetary stimulus, thereby contributing to price stability and supporting economic growth, the ECB's adoption of negative policy rates (NPRs) has been part of a wider credit-easing strategy to counter off substantial deflationary risk.[2]

Besides the ECB, since 2012 the central banks of several European countries outside the euro area (Denmark, Hungary, Norway, Sweden and Switzerland) and Japan introduced the Negative Interest Rate Policy (NIRP). However, NIRP effectiveness remains potentially controversial for several reasons (Ball et al., 2016; Bech and Malkhozov, 2016; Jobst and Lin, 2016). One of the main criticism is associated with the negative effects of NIRP on bank margins and profits as banks may be reluctant to impose negative rates on deposits because of the fear of losing their deposit base (Heider et al., 2019). Lower bank profitability can lead, in turn, to a contraction in lending supply and therefore impair the transmission mechanism of monetary policy under negative rates as well as the expansionary aim of central banks (Brunnermeier and Koby, 2018). Further unintended consequences associated with NIRP, such as asset over-valuation and banks' tendency to assume excessive risk, can pose a risk to financial stability (Hong and Kandrac, 2021).

Banks may offset the potentially negative effects of NIRP on bank profitability in several ways. First, they could offset the contraction in net interest margins by increasing loan volumes, i.e. one of the intended aims of the policy. Second, they could boost non-interest income via raising fees and commissions and/or gains from holding a sizeable amount of held-for-trading fixed-income securities. Third, they may react to NIRP by increasing their holdings of riskier, higher yielding assets. A growing strand of the literature has already focused on the different

[1] The DFR is the interest rate that banks receive for depositing money with the Eurosystem overnight. Together with the interest rate on the main refinancing operations (MRO) and the rate on the marginal lending facility (MLF), the DFR represents a key interest rate set by the ECB Governing Council.

[2] In response to the severe effects of the 2008-2009 global financial crisis, many central banks worldwide, began to experiment with a range of unconventional monetary policies, (i) including large-scale asset purchases (LSAPs) to increase asset prices and money supply; (ii) targeted asset purchases to impact the relative prices of selected assets; and (iii) forward guidance which aims at reducing the uncertainty about future policy rate paths.

channels through which NIRP impacts the supply of bank credit to the real economy (Arce et al., 2018; Bottero et al., 2019; Heider et al., 2019; Eggertsson et al., 2019; Demiralp et al., 2021) and bank profitability (Molyneux et al., 2019; Klein, 2020; Lopez et al., 2020; Altavilla et al., 2021). Other studies explored the way negative interest rates affect banks' risk-taking and the "reach-for-yield" behaviour (Bubeck et al., 2020; Bongiovanni et al., 2021; Hong and Kandrac, 2021), systemic risk (Nucera et al., 2017) and the usage of cash (Liñares-Zegarra and Willesson, 2021).

In this paper, we investigate a previously unexplored channel and put forward the hypothesis that NIRP-affected banks - i.e. banks with a greater reliance on retail deposits ("high-deposit banks" thereafter) as a source of funding - strategically react to the detrimental repercussions of NIRP on their performance by improving their cost efficiency. In the spirit of Heider et al. (2019), by assuming that the behaviour of low-deposit banks offers the counterfactual for the behaviour of high-deposit banks, we compare the cost efficiency of euro area banks with different retail deposit to total asset ratios, before and after the ECB's adoption of NIRP.[3] Indeed, Figure 1 reveals that high-deposit banks experienced greater contractions in margins and profits in comparison to banks less reliant on retail deposits. Therefore, we conjecture that negative rates have strengthened euro area high-deposit banks' incentives to improve their efficiency to mitigate the adverse impact on their profitability in comparison to low-deposit banks. Furthermore, we explore whether the heterogeneity in both balance sheet and market conditions, before the introduction of NIRP in 2014, influenced banks' incentives to enhance their cost structure.

We fill the gap in the existing literature by analysing the impact of negative interest rates on bank cost efficiency, defined as the ability to generate the highest levels of desirable outputs (e.g. loans and other earning assets) with the lowest use of input (e.g. deposits and labour). We exploit the ECB implementation of NIRP in mid-2014 and a comprehensive dataset of bank balance-sheet and profit and loss characteristics to investigate whether and to what extent euro area banks had to make a virtue out of necessity, therefore enhancing cost efficiency. We employ stochastic frontier analysis (SFA) to estimate banks' cost efficiency and a panel dataset of 1,130 banks from 17 euro area countries between 2011 and 2018. To test the hypothesis central to our

[3] In our empirical settings, we consider as high (low)-deposit banks those banks with a retail deposit to total asset ratio above (below) the median value of the related distribution, pre-NIRP.

study, we employ a difference-in-differences (DiD) econometric identification strategy where we compare the behaviour of banks with different retail deposit ratios around the introduction of policy rates below the zero lower bound (ZLB).

Our evidence suggests that NIRP-affected banks responded to the introduction of NIRP via improvements in their cost efficiency. We document greater incentives to enhance cost efficiency for NIRP-affected banks that are larger, less profitable, with lower asset quality, weaker pre-NIRP lending growth and that operate in competitive banking sectors. Therefore, based on our findings, we can infer that (i) large high-deposit banks have more room for *manoeuvres* on operating costs than smaller high-deposit banks; (ii) high-deposit banks that are less profitable, with lower asset quality and limited lending capacity face additional pressures to react to the negative effects of NIRP on profits via an enhancement in cost efficiency; and (iii) competitive market conditions further compress banks' margins and profits in a negative interest rate environment, thereby pushing high-deposit banks to enhance their cost efficiency. In addition, we document that improvements in cost efficiency are statistically significant only when breaching the ZLB, indicating that the pass-through of interest rates to cost efficiency is not effective when policy rates are positive. These findings hold relevant implications for both financial stability and the transmission of the monetary policy. If NIRP-affected banks improve their cost efficiency, this may lead to higher profits with beneficial effects in terms of financial stability and monetary policy transmission as banks' lending decisions largely depends on retained earnings as a source of funding (Shin, 2016).

Our paper contributes to the existing literature in two main ways. First, we add to the growing strand of literature that analyses the impact of NIRP on the euro area banking sector and its specific transmission channels (Heider et al., 2019; Molyneux et al., 2019; Bubeck et al., 2020; Demiralp et al., 2021). In particular, to the best of our knowledge, we are the first to explore the effect of negative interest rates on banks' cost efficiency. Our evidence informs the ongoing debate on the implications of monetary policies below the ZLB. Second, we extend prior literature on efficiency in European banking (Maudos et al., 2002; Vander Vennet, 2002; Casu and Girardone, 2004; Bos and Schmiedel, 2007; Fend and Wang, 2018; Huljak et al., 2019), adding to the relatively limited evidence from recent years.

The remainder of the paper is organized as follows. Section 2 discusses the relevant literature.

Section 3 provides the identification strategy and empirical methodology. Section 4 describes the sample and data. Sections 5 and 6 present the results and the robustness checks, respectively. Section 7 concludes and offers relevant policy implications.

2 NIRP, transmission channels and bank cost efficiency

The adoption of a NIRP implies charging banks for holding excess reserves at the central bank and therefore it strengthens their incentives to expand lending in an attempt to reduce their reserve holdings. This is intended to produce positive effects for the real economy, in terms of greater loan supply and demand, as a result of reduced funding costs for both banks and borrowers.

While a standard reduction in policy rates has the potential to lower banks' funding costs and consequently results in higher bank net worth (due to the core maturity transformation performed by banks) and increased capability to lend (Arnould et al., 2022), rate cuts leading to negative territory may produce different effects.[4] In particular, the pass-through of negative rates to customers might be limited for a number of reasons, especially in the short-term. For small-size retail deposits, banks might be reluctant to charge negative rates to avoid losing long-term customers, who could opt for holding cash or sovereign bonds and/or switching banks. Moreover, there could be legal and/or political constraints hindering the possibility to apply negative rates to retail deposits (Bubeck et al., 2020; Altavilla et al., 2021). Therefore, as discussed in several contributions (Eggertsson and Woodford, 2003; Correia et al., 2013), the doubts cast on the effectiveness of monetary policies below the ZLB.

Banks' ability to transfer negative rates to wholesale customers is somehow different. As demonstrated in Altavilla et al. (2021), sound banks that rely more on the wholesale market for funding, as opposed to high-deposit banks, tend to pass on negative rates to their corporate deposits and the degree of pass-through assumes greater strength as policy rates become more negative. Therefore, while a ZLB may exist for retail deposits, a different mechanism works in the case of corporate deposits when central banks move into negative territory, with the potential to generate a heterogeneous impact on high and low retail deposit banks.[5] In this

[4]Reduced (albeit positive) policy rates also tend to increase the franchise value of banks with higher net worth, thereby limiting the incentives to assume extra risk (Heider et al., 2019).

[5]Compared to corporate customers, retail (households) clients can easily withdraw their deposits, substituting

respect, with policy rates turning negative, Eggertsson et al. (2019) document a reduced credit growth for Swedish banks relying more on deposit financing. Heider et al. (2019) find that euro area banks with more retail deposits reduce their lending and increase risk-taking. Molyneux et al. (2019) argue that banks in NIRP-adopter countries, that are more reliant on deposit funding, less capitalized and more interest income-oriented, reveal weaker lending.

Negative interest rates are transmitted via different channels, impacting both the asset and liability side of banks' balance sheets. The overall effect of NIRP on banks' performance and, therefore, the balance between costs and benefits is uncertain and still subject to ongoing debate and research.[6] Negative rates may erode banks' profitability, mostly by compressing their net interest margin, given the difficulty to pass them to retail deposits. As discussed in the relevant literature (Nucera et al., 2017; Arce et al., 2018; Molyneux et al., 2019; Bubeck et al., 2020; amongst others), banks can compensate for the effects of negative rates by (i) increasing lending volumes; (ii) boosting fees and commissions (non-interest income); and (iii) taking extra risks.[7] However, the possibility to leverage these strategies strongly depends on specific features at the bank level, as well as factors characterising the overall banking sector and, more in general, the country where banks operate. In case of limited possibilities to enhance the non-interest income and if banks do not have a sufficient risk-bearing capacity (i.e. bank capital), also functional to extend the loan supply, it is then likely to observe a fall in profits under negative policy rates.[8] In addition, and specific to the euro area banking context, the high levels of non-performing loans (NPLs) as a legacy of the global financial and sovereign debt crises weighted on banks' profitability, dragging on capital resources and further restricting the ability to grant new loans. As per Arce et al. (2018), less profitable banks, with lower capital strength, are left with fewer options to tackle the adverse effects of low (negative) interest rates. Also, while NIRP may induce bank balance-sheet (re)adjustments, there could exist points beyond which banks can no longer tolerate the squeeze of margins, especially for a prolonged period (Bech and Malkhozov, 2016).

them with cash (Eisenschmidt and Smets, 2019). Moreover, in the case of small deposits, usually, banks tend to charge additional fees rather than change interest rates (Altavilla et al., 2021)

[6] A recent strand of the literature explores the impact of a "negative-for-long" scenario on banks' key functions and behaviour (Arce et al., 2018; Stráský and Hwang, 2019; Brandão-Marques et al., 2021).

[7] Furthermore, beneficial effects in terms of reduced loan-loss provisions, as a result of improved borrowers' capability to meet their obligations, can help to sustain profits.

[8] Especially in the case of less capitalized institutions, bank capital regulation can limit greater risk-taking in response to negative interest rates (Bongiovanni et al., 2021).

In this paper, we aim to understand whether an unexplored strategy that euro area banks exploited to mitigate the effects of negative rates has been that of enhancing their cost efficiency. Given the squeeze in profit margins for retail deposit-based banks stemming from NIRP, we can reasonably expect, *ceteris paribus*, that NIRP-affected banks might have pursued the route of efficiency improvements to sustain profits. Unlike existing contributions, we focus on a different channel of monetary policy transmission to euro area banks, seeking to shed the light on unexplored impacts of NIRP. Thus, the first hypothesis is as follows:

H1.*Ceteris paribus, did high-deposits euro area banks enhance their cost efficiency in response to the introduction of NIRP in June 2014?*

The need for NIRP-affected banks to improve their cost efficiency following the introduction of NIRP depends also on banks' balance sheet and market conditions prior to NIRP. For instance, smaller high-deposit banks engaging in relationship lending may incur higher monitoring costs, given that the "soft" information is the result of costly long-term relationships (Petersen and Rajan, 1994; Uchida et al., 2012; Bolton et al. 2016). Consequently, for smaller retail-oriented banks it may be more difficult to react to NIRP by improving costs, for instance, via closing up branches. In addition, high-deposits banks that are less profitable may face additional pressure to improve their cost efficiency in comparison to more profitable institutions as low profitability impairs banks' ability to increase lending and risk-taking (Bongiovanni et al., 2021). Furthermore, NIRP-affected banks with poorer asset quality may struggle to maintain profits via boosting their lending in a negative interest rate environment, hence being forced to adopt different strategies, including that of improving their cost structure. High-deposit banks with an already weaker credit growth prior to NIRP may face additional pressures to enhance their cost efficiency as negative rates may further limit their ability to increase loan volumes (Molyneux et al. 2020). Finally, in a negative interest rate environment, the degree of competition in the banking sector could represent an additional key factor in encouraging banks to work on their cost efficiency, given that a higher bank competition level can *de facto* amplify the contraction of the net interest margins (Molyneux et al., 2019). Our second hypothesis is accordingly as follows:

H2.*Do higher/lower incentives to enhance cost efficiency for high-deposit banks depend on both balance sheet and market conditions in place before the introduction of NIRP in June 2014?*

3 Identification strategy

3.1 Cost efficiency estimation

This study employs the SFA to generate cost efficiency scores for each bank in the sample under investigation, over the sample period between 2011-2018.[9] Specifically, we adopt a two-step procedure based on which the initially estimated efficiency scores obtained from the stochastic frontier are regressed, in a second step, on a selected set of explanatory variables. This approach enables us to examine the impact of NIRP on euro area banks' efficiency, while controlling for a number of bank-specific and country-level factors. As widely recognized in prior literature on cross-country samples (Beccalli, 2004; Gaganis and Pasiouras, 2013; Luo et al., 2016), there is the need to assume a common frontier as a benchmark necessary for the comparison of banks located in different countries. To this end, data across countries are pooled together and a common frontier is estimated.

3.2 Selection of inputs and outputs

The selection of input and output variables for the cost frontier is based on the standard intermediation approach (e.g. Sealey and Lindley, 1977; Maudos et al., 2002; Gaganis and Pasiouras, 2013; Chortareas et al., 2013), which considers banks as financial intermediaries that collect *funds*, use *labour* and *physical capital*, i.e. the inputs, and transform them into *loans* and *other earning assets*, i.e. the outputs. Therefore, we specify three input prices: (i) the cost of borrowed funds (W1), proxied by the ratio of interest expenses to total deposits; (ii) the cost of physical capital (W2), measured as the ratio of overhead expenses, net of personnel expenses, to the book value of fixed assets; and (iii) the cost of labour (W3), defined as personnel expenses over the number of employees.

For the output prices, we employ: (i) the ratio of interest income to loans (P1); and (ii) the ratio of non-interest income to other earning assets (P2). Moreover, in line with Mester (1996), Altunbas et al. (2000) and Fiordelisi et al. (2011), amongst others, the equity (EQ) is included as a quasi-fixed input in the efficiency function in order to control for different banks' risk profiles. In this respect, Berger and Mester (1997) suggest that failing to control for equity might lead to a scale bias in the estimation of inefficiency given that equity is a further key

[9] For a recent review on the importance of efficiency and different approaches to measure it, see e.g., Hughes and Mester (2019).

funding source for loans and, in some cases, the cost of raising equity may be higher than that of collecting deposits. Linear homogeneity restrictions are imposed by using the third input price (W3) to normalize the dependent variables and all the input prices. In addition, a time trend (T = 1 for 2011 to T = 8 for 2018), with both linear and quadratic terms (T and T^2), is included to account for the effect of changes in technology over time (Lensink et al., 2008; Lozano-Vivas and Pasiouras, 2010).

3.3 Stochastic Frontier Analysis (SFA)

We employ a multi-product translog function to estimate the cost efficiency of banks (Vander Vennet, 2002; Bos and Kool, 2006; Berger et al., 2009; Williams, 2012; Shamshur and Weill, 2019). The function is represented by a second-order Taylor expansion that is commonly employed in previous studies (Luo et al., 2016) since the translog functional form allows for greater flexibility when evaluating the efficiency frontier. Using the discussed input and output prices, the cost function is specified as:

$$
\begin{aligned}
Ln(\frac{Y_{it}}{W_3}) = \alpha &+ \beta_1 ln(Q_1) + \beta_2 ln(Q_2) + \beta_3 Ln(\frac{W_1}{W_3}) + \beta_4 Ln(\frac{W_2}{W_3}) + \beta_5 ln(EQUITY) + \\
&\beta_6 \frac{1}{2}(ln(Q_1))^2 + \beta_7 ln(Q_1) ln(Q_2) + \beta_8 \frac{1}{2}(ln(Q_2))^2 + \beta_9 \frac{1}{2} Ln(\frac{W_1}{W_3})^2 + \\
&\beta_{10} Ln(\frac{W_1}{W_3}) Ln(\frac{W_2}{W_3}) + \beta_{11} \frac{1}{2}(Ln(\frac{W_2}{W_3}))^2 + \beta_{12} \frac{1}{2}(ln(EQUITY))^2 + \\
&\beta_{13} ln(Q_1) Ln(\frac{W_1}{W_3}) + \beta_{14} ln(Q_1) Ln(\frac{W_2}{W_3}) + \beta_{15} ln(Q_2) Ln(\frac{W_1}{W_3}) + \\
&\beta_{16} ln(Q_2) Ln(\frac{W_2}{W_3}) + \beta_{17} ln(EQUITY) ln(Q_1) + \beta_{18} ln(EQUITY) ln(Q_2) + \\
&\beta_{19} ln(EQUITY) Ln(\frac{W_1}{W_3}) + \beta_{20} ln(EQUITY) Ln(\frac{W_2}{W_3}) + \beta_{21} Trend + \\
&\beta_{22} \frac{1}{2} Trend^2 + \beta_{23} Trend ln(Q_1) + \beta_{24} Trend ln(Q_2) + \beta_{25} Trend Ln(\frac{W_1}{W_3}) + \\
&\beta_{26} Trend Ln(\frac{W_2}{W_3}) + \epsilon_{it} \qquad (1)
\end{aligned}
$$

where Y represents the total cost (TC) of production of bank i at time t. The estimated input-oriented efficiency score ($Costeff_i$) ranges between 0 and 1 for bank i. Following the SFA method, the closer the bank is to the theoretical best practice frontier representing full efficiency (100%), the more efficient it is, in the sense that its outputs cannot be further expanded without increasing its inputs. A bank with an efficiency score below 100% is relatively inefficient, suggesting that it can attain its current output level by employing fewer inputs.

3.4 Econometric framework

In the second stage of our analysis, we use a DiD specification to explore the effect of NIRP on bank efficiency scores. In the spirit of Heider et al. (2019), our identification strategy relies on comparing bank efficiency scores of euro area banks with different retail deposit to total assets ratios, after the introduction of NIRP in June 2014. Equation (2) presents our baseline model:

$$Costeff_{ijt} = \alpha_i + \beta(High - deposits_i * Post_t) + \sigma K_{ijt-1} + \tau_t + \epsilon_{it} \quad (2)$$

$Costeff_{ijt}$ are the estimated cost efficiency scores for bank i in country j at time t.[10] α_i indicates bank-fixed effects employed to gauge time-invariant unobservable bank characteristics. $High - deposits_{ij}$ is a dummy variable that takes the value 1 if in 2013 (i.e. before NIRP), the average ratio of retail deposits to total assets of bank i located in a NIRP-affected country j was above the median, and 0 otherwise.[11] $Post_t$ is a dummy variable that assumes the value 1 after the introduction of NIRP, and 0 otherwise. Since NIRP was introduced on 5 June 2014, the related dummy variable ($Post_t$) assumes the value 1 from 2014 year-end onwards. β is our coefficient of interest, which represents the average difference in cost efficiency between banks with different retail deposit ratios after the introduction of NIRP. K_{ijt-1} is a vector of lagged bank- and country-specific control variables used to capture cross-bank and cross-country heterogeneity over time. Specifically, we include the ratio of gross loans to total assets (LOANS), the logarithm of total assets (SIZE), the net income to total asset ratio (ROA), the total regulatory capital ratio (TOTCAP), the ratio of net interest income to operating income (INT_OP) and the ratio of loan loss provisions to net interest income (LLP). Among the country-specific characteristics, we control for the inflation rate (INFLATION) and the GDP growth (GDP_g). Control variables are lagged by one period in order to overcome possible endogeneity and simultaneity concerns.[12] τ_t indicates year fixed-effects employed to control for

[10] In a robustness check, we also use the cost-to-income ratio as an alternative dependent variable.

[11] For robustness purposes, we provide variation to the baseline specification by either performing a DiD with a continuous treatment or using quartiles, instead of the median, for the definition of the treated group (refer to Section 6 for further details).

[12] A correlation matrix provided in Table A in the appendix suggests that correlation coefficients are relatively low. Multicollinearity issues should not impact our regression results.

time-variant shocks on bank efficiency, over the sample period, hence limiting the potential bias in estimates of β. Robust standard errors (ϵ_{it}) are clustered at the bank-level.

The DiD method must satisfy suitability requirements if we apply it to determine the effect of NIRP on bank cost efficiencies. First, treatment assignment has to be exogenous with respect to bank efficiency. In our empirical setting, meeting this assumption seems reasonable as the implementation of NIRP is driven by the need to fuel below-target inflation and tackle weak aggregate demand (IMF, 2017). Thus, influencing bank efficiency does not represent a policy aim. Second, according to Betrand et al. (2004) and Imbens and Wooldridge (2009), the DiD approach is only valid under the restrictive assumption (i.e. the parallel trend assumption), whereby changes in the outcome variables in the timespan before the application of the treatment are similar for both the treatment (i.e. banks with an above-median level of retail deposit ratio) and the control group (i.e. banks with a below-median level of retail deposit ratio). Figure 2 depicts the development of the outcome variable from 2011 to 2018, for both the treated and control groups. As evident, the level of bank cost efficiency for the two groups shares a comparable trend prior to the NIRP introduction, suggesting that the parallel assumption holds and, therefore, the validity of our empirical setting.

4 Sample and Data

The dataset used in this analysis is a balanced bank-level panel data comprising 1,130 banks located in 17 euro area countries.[13] We consider banks with different institutional forms, namely bank-holding and commercial banks, cooperative banks and saving banks.[14] The data employed in the empirical analysis are gathered from multiple sources. With the aim of maximising the sample size, bank balance sheet and performance data are collected both from Moody's BankFocus and SNL Financial. This also allows ensuring greater consistency of the information provided and thereby minimising the impact of potential misreporting and outliers. The macroeconomic series are obtained from the World Bank (World Development Indicators) and the ECB Statistical Data Warehouse.[15] Bank specific characteristics, sampled on an annual basis, are winsorized

[13]We excluded Latvia and Lithuania as they joined the euro area in 2014 and 2015, respectively.

[14]We follow the classification provided by BankFocus. Table B in the Appendix provides detail on the sample composition, both regarding the country where banks are located, as well as the bank specialization.

[15]BankFocus and SNL Financial cover financial statement data both at the consolidated and unconsolidated level. In our dataset, in order to avoid duplicate observations, we either include the unconsolidated data or the consolidated one, but without unconsolidated subsidiaries.

at the 1% and 99% levels to mitigate the influence of outliers.

Descriptive statistics for bank cost efficiency scores, bank balance sheet variables and macroeconomic variables related to both the treatment and control groups, prior to and after the introduction of NIRP, are reported in Table 1. Panels A and D of Table 1 present the summary statistics for our dependent variables. It clearly shows that high-deposit banks (i.e. the treatment group), as compared to low-deposit banks (i.e. the control group) appear to have improved their cost efficiency in the years after the introduction of NIRP. In particular, the related average score moves from 0.65 in 2011-2014 to 0.66 in 2015-2018, while the same figure for the control group declines from 0.69 to 0.68. Both groups experienced an increase in the cost-to-income ratio after the introduction of NIRP. However, while the increase for the control group is 2.95 percentage points (from 65.11% to 68.07%), the same figure for the treatment group is more modest, i.e. 1.48 percentage points (from 69.65% to 71.15%).

Panels B and E of Table 1 report the summary statistics for the bank balance sheet information. We consider the ratio of gross loans to total assets (LOANS) to measure the loan intensity of banks' balance sheets (Williams, 2012). On the one hand, given that loan production is relatively more costly than holding other assets (e.g. securities), due to costs associated with effective screening and monitoring, it is reasonable to expect an inverse relationship between bank asset structure and efficiency. On the other hand, banks with a greater share of loans in their balance sheets may face additional management pressure to deal with credit risk, hence improving bank efficiency. Bank size (SIZE) is computed as the natural logarithm of bank total assets. The relationship between bank size and efficiency is not straightforward. Some studies (Berger et al., 1993; Miller and Noulas, 1996) document a positive relationship between the two variables, while other authors (Deyoung and Nolle, 1996; Girardone et al. 2004) find an inverse association. Other studies do not observe any significant efficiency advantage for large banks (Berger and Mester, 1997; Pi and Timme, 1993). Bank profitability is captured by the ratio of net income to total assets (ROA). More profitable banks usually tend to be more efficient (Casu and Girardone, 2004). We account for the level of bank capitalization, by using the total regulatory capital ratio (TOTCAP). We predict a positive relationship between the level of the capital ratio and our variables of interest as a higher capitalization mitigates agency problems between managers and shareholders, thereby improving bank efficiency (Mester, 1996). We include a measure of income stream (INT_OP), defined as the ratio of interest income to operating income, to control for banks' business models. Roengpitya et al. (2017) find that banks with a more retailed-oriented business model exhibit lower cost-to-income ratios in comparison to banks that generate most of their revenues from trading activities. Finally, we introduce a measure of bank credit risk, calculated as the ratio of loan loss provisions to net interest income (LLP). Fiordelisi et al., (2011) show that cost efficiency declines as credit risk increases.

As country-level controls (Panels C and F of Table 1), we employ (i) the inflation rate (INFLATION); and (ii) the growth of gross domestic product (GDP_g). According to Barth et al. (2013) a country's inflation is inversely linked to bank efficiency, suggesting that a lower inflationary environment is associated with more efficient bank operations. Moreover, Fries and Taci (2005) document that costs may decrease with overall economic growth because of corresponding improvements in the quality of public institutions.[16]

5 Empirical Results

5.1 Baseline results

Table 2 presents the results of the baseline analysis performed to test our first hypothesis on bank cost efficiency. The dependent variable is the estimated bank cost efficiency score, ranging between 0, which indicates an entity with structural inefficiency, and 1 which identifies the theoretical best practice frontier. In order to capture the effect of NIRP on bank cost efficiency, we control for a number of relevant bank-level factors, commonly used in banking studies, as well as for two macroeconomic variables. Specifically, the first column of Table 2 shows the impact of the introduction of NIRP in 2014 (our intervention) on the treated group (high-deposit banks) as compared to the untreated group (low-deposit banks) without the inclusion of bank- and country-specific controls. In the second and the third columns of Table 2, we progressively introduce bank-specific control variables (column 2) and macroeconomic controls (column 3). All regressions include bank and year fixed effects. Robust standard errors are clustered at the bank-level.

The interaction coefficient ($High - deposits*Post$) is positive and statistically significant at the 1% level in all specifications. This suggests that the move of policy rates into negative territory has pushed high-deposit banks, which are more materially affected by the NIRP, to

[16]Table C in the appendix provides a detailed definition of the variables and the associated sources.

substantially enhance their cost structure compared to low-deposit banks, most likely to offset the potential contraction on the profit side. The corresponding coefficient is also economically meaningful. Specifically, high-deposit banks improve their cost efficiency by about 0.0162 points after NIRP in comparison to low-deposit banks. We assert that profitability pressure may force high-deposit banks to consolidate and strengthen their operational (cost) efficiency. Indeed, Jobst and Lin, 2016 argue that "pressure on profitability [...] may explain why some banks have already announced significant cuts in operating costs (closing of branches and reduction in staffing)." Also, other studies (Scheiber et al., 2016 and Madaschi and Nuevo, 2017) assessing the development in the cost-to-income ratio in the immediate pre- and post- NIRP periods, confirm improvements in bank cost expenses. This result is particularly important for policymakers as it indicates that negative interest rates can orientate banks' incentives towards strategies intended to improve their performance.

In Figure 3, we also plot the time-varying coefficients (based on column 1 of Table 2) on the treatment prior to and after NIRP to investigate more in detail the dynamics of the effect. From a policymaker's perspective, it is relevant to appreciate if high-deposit banks enhance their cost efficiency immediately after the introduction of NIRP or whether this response was delayed. In addition, the dynamic DiD informs about the suitability of the DiD econometric identification strategy. We do not find statistically significant differences between the treatment and the control group prior to the introduction of NIRP as the two confidence intervals largely overlap suggesting that the parallel trend assumption holds and the DiD framework is valid. However, after the introduction of NIRP, high-deposit banks improved progressively their cost efficiency (the only exception being the slight decline recorded in 2018) in comparison to low-deposit banks, which after NIRP showcased a downward trend. Small but steady improvements in cost efficiencies as a reaction to the negative interest rate environment are reasonable as they require strategic reconfiguration of processes, branches, employees and technologies.

Results hold up well when we add bank-specific variables (column 2) and macroeconomic factors (column 3). The coefficient on the NIRP-effect retains its sign and significance, suggesting robustness in our inference. Several bank-level characteristics are also significantly related to cost efficiency. Specifically, bank size and the degree of capitalization appear to be positively related to cost efficiency. The coefficient on the variable SIZE is positive and statistically significant at the 10% level in both model specifications (columns 2 and 3), suggesting that larger banks are better equipped for improvements on the costs side, benefiting from efficiency gains (Berger et al., 1993; Miller and Noulas, 1996; Barth et al. 2013). In line with prior literature (Casu and Girardone, 2004; Carvallo and Kasman, 2005), we document a beneficial effect of bank capital in terms of cost efficiency, indicating that higher levels of capital mitigate potential agency problems existing between managers and shareholders. More capitalized banks, compared to their peers, are more likely to adopt cost-reducing practices (Fiordelisi et al., 2011). In this respect, positive coefficients on the TOTCAP variable, although with marginal statistical significance, are shown both in columns 2 and 3 of Table 2. Turning to the macroeconomic controls, we find an inverse and highly statistically significant relationship between GDP growth and our variable of interest.

5.2 NIRP and cost efficiency: the role of bank-specific characteristics and market competition

In this section, we deepen our understanding of the relationship between NIRP and cost efficiency by analysing whether the heterogeneity in bank-specific characteristics matters for the banks' response to negative interest rates. Specifically, in order to test our second hypothesis, we perform a set of additional regressions where we account for banks' balance sheet and market conditions in place prior to the introduction of NIRP.

First, we aim to appreciate whether NIRP has a stronger effect on the cost efficiency of high-deposit banks depending on their size. Smaller high-deposit banks engaging in relationship lending incur higher monitoring costs, given that the "soft" information are gathered and updated through costly long-term lending relationships (Petersen and Rajan, 1994; Uchida et al., 2012; Bolton et al. 2016). Consequently, for smaller retail-oriented banks may be more difficult to react to NIRP by improving costs via closing up branches, for instance. In addition, large banks due to greater international reach, potential to expand lending abroad and more diversified portfolios are better equipped to mitigate the detrimental effects of NIRP on margins and profits (Molyneux et al., 2019). They can effectively exploit interest rate cuts and generate gains on held-for-trading fixed income securities, as well as raise fees and commissions income more easily than smaller banks (Molyneux et al., 2021). We should, therefore, expect greater improvements in cost efficiencies for large, high-deposit banks. To test this hypothesis, we triple-interact our treatment dummy ($High - deposits * Post$) with a dummy variable labelled $Quartile\_Size$ which is equal to 1 if a bank prior to NIRP (2013) has total assets below the first quartile of the bank total asset distribution, and 0 otherwise. The results are displayed in column 1 of Table 3 and are interesting for two main reasons. First, the coefficient on the interaction term $High - deposits * Post$ is positive and statistically significant at the 1% level, indicating that post-NIRP improvements in cost efficiencies for high-deposit banks are driven by larger banks. Second, the coefficient on the triple interaction $High - deposits * Post * Quartile\_Size$ is negative and statistically significant at the 1% level, suggesting that smaller high-deposit banks appear to have a lower capacity for manoeuvre to enhance their cost efficiency.

Second, we investigate whether high-deposit banks that are less profitable face additional pressure to improve their cost efficiency in comparison to more profitable institutions. Indeed, high-deposit, less profitable banks are left with fewer options to tackle negative interest rates. First, low profitability impairs capital accumulation via retained earnings and, consequently, the ability of banks to increase lending volumes (Molyneux et al. 2020). In addition, less profitable banks may try to avoid *"gambling for resurrection"* via an increase in risk-taking behaviour to boost profitability under negative rates. According to Bongiovanni et al. (2021), in a negative interest rate environment, low profitable banks prefer to invest in safer and more liquid assets such as government bonds rather than increase risky assets. Therefore, we expect a stronger reaction to NIRP in terms of cost enhancements stemming from high-deposit less profitable banks. To test this hypothesis, we triple-interact our treatment dummy ($High - deposits * Post$) with a dummy variable labelled $Quartile\_ROA$ which takes the value 1 if a bank prior to NIRP (2013) has a ROA below the first quartile of the corresponding distribution, and 0 otherwise. The results are reported in column 2 of Table 3. In line with our expectations, the coefficient on the triple interaction term ($High - deposits * Post * Quartile\_ROA$) is positive and highly statistically significant, reflecting a more pronounced reaction to NIRP of high-deposit less profitable banks.

Third, we explore whether enhancements in cost efficiency following the implementation of NIRP depend on bank asset quality. Indeed, banks with deteriorated asset quality may face additional impediments to react to NIRP for several reasons. On the one hand, lower asset quality reduces bank profitability, thus limiting banks' ability to expand lending volumes. On the other hand, banks carrying sizeable amounts of *legacy assets* cannot exploit in full the beneficial implications of negative interest rates on bank funding costs as investors expect a higher premium for lending to institutions with impaired asset quality. Based on these considerations, we predict greater improvements in cost efficiency for those high-deposit banks with riskier loan portfolios. For this exercise, we triple-interact our treatment dummy ($High{-}deposits{*}Post$) with a dummy variable labelled $Quartile\_LLP$ which takes the value 1 if a bank prior to NIRP (2013) has a LLP ratio below the first quartile of the related distribution, and 0 otherwise. The results are reported in column 3 of Table 3. The coefficient on the double interaction $High{-}deposits{*}Post$ is positive and highly statistically significant, confirming our hypothesis that high-deposit banks with deteriorated asset quality (i.e. those banks with greater provisioning) improve their cost efficiency after NIRP. In contrast, the coefficient on the triple interaction $High - deposits * Post * Quartile\_LLP$ is negative and statistically significant at the 1% level, suggesting that high-deposit banks with lower levels of provisioning did not face the same urgency, given that a better asset quality helps sustaining profits, also when policy interest rates are negative.

Fourth, we look at whether high-deposit banks with weaker lending growth before NIRP have stronger incentives to improve their cost efficiency in response to NIRP because of the limited capacity to further boost lending volumes in a negative interest rate environment. For this test, we triple-interact our treatment dummy ($High - deposits * Post$) with a dummy variable labelled $Quartile\_Loan\_g$ which is equal to 1 if a bank prior to NIRP (2013) has a lending growth below the first quartile of the lending growth distribution, and 0 otherwise. The results are reported in column 5 of Table 3. The coefficient on the triple interaction term $High - deposits * Post * Quartile\_Loan\_g$ is positive and statistically significant at the 10% level, reflecting the difficulty of high-deposit banks with an already limited lending growth prior to NIRP to counter off the detrimental effects of NIRP on margins and profits. Consequently, these banks appear to react to NIRP by improving their cost efficiency.

Lastly, we assess the impact of NIRP on bank cost efficiency in the context of competitive banking sectors. For this exercise, we use the Lerner index at the country level as a proxy for competitive conditions.[17] Kok Sorensen and Werner (2006) argue that banks operating in less competitive environments undertake slower adjustments to interest rates, which slows the transmission of monetary policy (Avignone et al., 2021) and contributes to sustain banks' net interest margins. In addition, Brunnermeier and Koby (2016) present a "reversal interest rate" hypothesis, according to which there is a rate of interest at which an accommodative monetary

[17] Alternatively, we also use the Boone index and a measure of banking market concentration such as the Herfindahl-Hirschman Index (HHI). The results, unreported but available upon request, are consistent with those obtained by using the Lerner index.

policy ”reverses” its effect and becomes contractionary. They show that a low interest rate policy is likely to have a more limited effect on bank lending in competitive markets because of the associated pressure on net interest margins. Consequently, we argue that high-deposit banks operating in less competitive banking sectors may not have the same incentives to improve their cost efficiency, compared to high-deposit banks operating in more competitive markets, due to the weaker adverse effects of negative rates on margins. To test for this possibility, we triple-interact our treatment dummy ($High-deposits*Post$) with a dummy variable labelled $Quartile\_Lerner$ which takes the value 1 if a bank prior to NIRP (2013) operates in a market with a Lerner index below the first quartile of the corresponding distribution, and 0 otherwise. The results reported in column 4 of Table 3 largely support our intuition. Indeed, the coefficient on the triple interaction term $High-deposits*Post*Quartile\_Lerner$ is positive, statistically significant (at the 1% level) and sizeable in magnitude, confirming that high-deposit banks operating in more competitive banking sectors face additional pressure to improve their cost efficiency likely because of the stronger compression on the net interest margins under NIRP.

6 Robustness Checks

6.1 Placebo test and the ZLB

When using a DiD estimation approach it is fundamental to remove the possibility that the identified behaviour of the variable of interest, in our case the efficiency scores, might have already manifested prior to the shock. In practice, we need to ensure that bank cost efficiency for the treatment group had not already diverged prior to the adoption of NIRP in comparison to the control group - for instance, as result of the anticipation of the adverse effects of NIRP, or for some non-identified bank-specific reasons. This would invalidate our empirical strategy and, therefore, the choice of the DiD estimation. To deal with this aspect, a *placebo* exercise can be set up, based on which the data is tricked so that the considered shock occurs at an earlier date, compared to the real one. If the estimated coefficient on a ”false” NIRP-adoption-date lacks statistically significance, we can reasonably infer that our baseline coefficient is effectively capturing a genuine shock (the introduction of NIRP, in our case).

In addition, a *placebo* test informs on the differences between interest rates at the ZLB (or above) and negative interest rates. Indeed, statistically significant differences in bank cost efficiency between the treatment and the control group prior to NIRP would suggest, *ceteris paribus*, enhancements in cost efficiency for high-deposit banks also in positive interest rates territory.

In Table 4, we report the results from the estimation in which we limit our time dimension to the pre-NIRP period (2011-14) and set a "false" introduction of NIRP in 2013.[18] The interaction coefficient ($High - deposits$*"$false$"$Post$) retains its positive sign, but it is smaller in magnitude and lacks statistical significance, thereby adding further robustness to the validity of our baseline estimation. Moreover, this evidence informs on the pass-through of interest rates on bank cost efficiency. Low, but still positive interest rates are shown not to be effective in pushing banks to enhance cost efficiency. This seems to confirm the hypothesis advanced in other studies (Eggertsson and Woodford, 2003; Heider et al., 2019) according to which, by squeezing the net interest margins and the profitability due to the stickiness of retail deposits, the adoption of NIRP appears to drive banks to engage in different off-setting strategies. Specifically, in our paper, we identify a pro-active behaviour towards the enhancement of bank cost efficiency.

6.2 Alternative definition of the treatment variable

In the baseline specification, we defined as *treated* those banks with a retail deposit to total asset ratio above the median value pre-NIRP (2013). In this section, we provide a variation to the baseline specification by redefining the treatment dummy in two additional ways. First, rather than focusing on the median value, we consider as treated those banks with a pre-NIRP (2013) retail deposit to total asset ratio above the top-tercile of the related distribution, while the control group considers the bottom-tercile retail deposit ratio. Second, we replace our treatment dummy variable with the lagged value of the retail deposit to total asset ratio, expressed as a continuous variable, that captures the intensity of the treatment effect. Using a continuous variable, rather than a dummy indicator, has the potential to allow for a more accurate estimation of the intensity of the effect (when employing a dummy variable, entities are grouped based on a specified threshold). However, in our empirical settings, the dummy variable retains the advantage of allowing for non-linearity in the estimation of NIRP on bank cost efficiency. The use of both approaches, therefore, further validates our findings.

[18]In an unreported test, we perform an additional DiD estimation limiting the time dimension to 2011-2013 and setting a "false" introduction of NIRP in 2012. The results are consistent with those discussed in this section and available upon request.

Evidence reported in Table 5 (columns 1 to 6) suggests that our results are overall robust to a different definition of the treatment variable. The definition of the treatment variable based on the tercile of the retail deposit to asset ratio distribution produces results qualitatively consistent with those discussed for the baseline specification. In addition, we document a positive and highly statistically significant coefficient on the continuous variable, suggesting that the higher the retail deposit to total asset ratio the larger the improvements achieved in terms of cost efficiency, post NIRP. As a graphical illustration of this relationship, we plot in Figure 4 the estimated coefficients of $Costeff$ at different levels of the retail deposit to total asset ratio (the employed coefficients are from the estimation performed in column 4 of Table 5). We find that, at around 60% of the retail deposit to total asset ratio, banks increased their cost efficiency in comparison to the pre-NIRP period, further corroborating the core hypothesis of this study based on which high-deposit euro area banks reacted to the negative interest rate environment by improving their cost efficiency.

6.3 Accounting-based measure: Cost-to-income ratio

As a final robustness check, we replace our original dependent variable (i.e. cost efficiency scores estimated through the SFA method), with an accounting-based measure. For this exercise, we employ the cost-to-income ratio, a typical measure of banks' efficiency and productivity, calculated as the ratio of operating expenses to operating income.

Table 6 reports the related results. The interaction coefficients ($High - deposits * Post$) are negative and overall statistically significant at the 1% level (except for the univariate model in column 1), indicating that high-deposit banks managed to lower their cost-to-income ratio after the introduction of NIRP, compared to banks in the control group. Specifically, high-deposit banks reduced their cost-to-income ratio by 2.18-2.57% - depending on the econometric specification - following the intervention, with respect to the group of low-deposit banks. This evidence adds further robustness to our baseline findings and appears to be in line with the existing literature (Scheiber et al., 2016 and Madaschi and Nuevo, 2017) that documents improvements in bank cost expenses in the immediate pre- and post- NIRP periods.

7 Conclusions

This paper investigates the impact of NIRP on euro banks' cost efficiency. To the best of our knowledge, we are the first to consider this unexplored channel and test whether banks responded to negative policy rates by enhancing efficiency with respect to costs. Existing studies (Arce et al., 2018; Bottero et al., 2019; Heider et al., 2019; Bubeck et al., 2020; Bongiovanni et al., 2021; Demiralp et al., 2021; amongst others) focused on other levers that banks exploited, since mid-2014, to tackle the detrimental effects of NIRP on interest margins and profitability. We fill the gap in the literature and provide empirical evidence of the way banks *made a virtue out of necessity* reacting to the unprecedented introduction of negative interest rates in the euro area.

Our identification strategy relies on the use of standard Standard Frontier Analysis (SFA), to estimate cost score efficiencies, and a robust difference-in-differences (DiD) setting, which enables us to compare the cost efficiency-related behavior of banks with different retail deposit to assets ratios (namely, high-deposits and low-deposits banks), prior and after the adoption of NIRP. We also account for a comprehensive set of bank-specific characteristics, as well as two macroeconomic factors. Our analysis is based on a sample of 1,130 banks from 17 euro area countries for the period 2011-2018.

Our findings overall suggest that treated banks reacted to NIRP by improving their cost efficiency. We provide evidence of greater incentives to improve cost efficiency stemming from larger and less profitable banks. Moreover, banks with an already constrained lending growth tend to enhance their cost efficiency following the implementation of the NIRP by the ECB. In addition, we find that asset quality issues affect the channel through which negative rates impact banks' efficiency, as institutions with better loan portfolios have not faced the same urgency to cut costs as their peers with weaker asset quality. On the other hand, banks operating in more competitive banking sectors are subject to additional pressure to improve their cost efficiency. Our results are robust to a number of additional tests, such as the use of ”false” treatment dates, as well as alternative definitions of both the treatment and dependent variables.

In addition to the gains from building on existing empirical evidence on cost efficiency in the euro area banking sector, our findings advance the ongoing debate on the effectiveness and implications of NIRP. We believe our results to be, therefore, of primary interest to academics, policymakers and supervisors. Albeit outside the policy scope of the ECB, the enhanced cost efficiency of euro area banks in response to negative interest rates represents a favourable ”side effect” with the potential to benefit the overall banking sector and financial stability.

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Figure 1. Trends in banks' net interest margins and return on assets before and after NIRP. This figure displays the trends in net interest margins and return on assets over the period 2012-2018 for high-deposit banks (blue solid line), i.e. banks relying mostly on retail deposits as a funding source, and low-deposit banks (dashed yellow line), i.e. banks holding fewer retail deposits. High-deposit and low-deposit ratios identify those banks that prior to the introduction of NIRP (2013) had a ratio of retail deposits to total assets above and below the median, respectively. The vertical dashed red line indicates the year of the introduction of NIRP (2014).

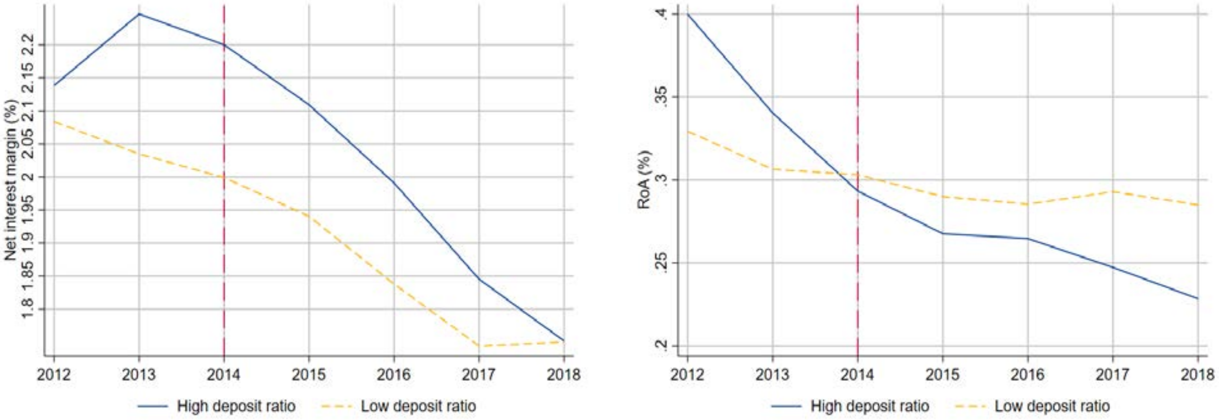

Figure 2. Cost efficiency evolution before and after NIRP.
This figure shows the normalised trends (year 2014=100 index) of the average bank cost efficiency estimates for the group of banks that have a retail deposit to total asset ratio in 2013 above the median (our treatment group) and the control group over the period 2011-2018. High- deposit and low-deposit ratio identify those banks that prior to the introduction of NIRP (2013) had a ratio of retail deposits to total assets above (blue solid line) and below (yellow dashed line) the median, respectively. Trends are normalised such that both variables take value 100 in 2014. The red solid vertical line indicates the introduction of NIRP in 2014.

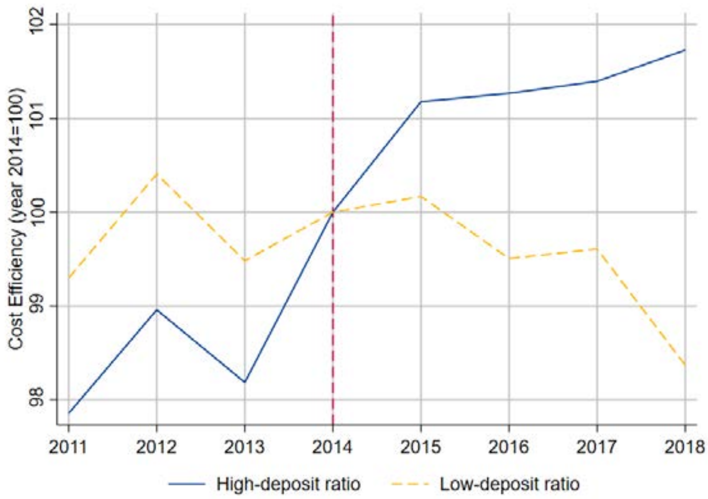

Figure 3. Difference-in-differences dynamic coefficients plot

This figure plots the dynamic coefficients of the DiD estimation over the sample period. The solid blue line represents the estimated DiD coefficients for the control group (i.e. low-deposit banks) whilst the yellow dashed line the estimated DiD coefficients for the treatment group (i.e. high-deposit banks). Low deposits are those banks with an above median level of retail deposits to total assets, vice versa for high deposit banks. The vertical dashed red line indicates the implementation of NIRP. The shaded grey areas indicate 90% confidence interval.

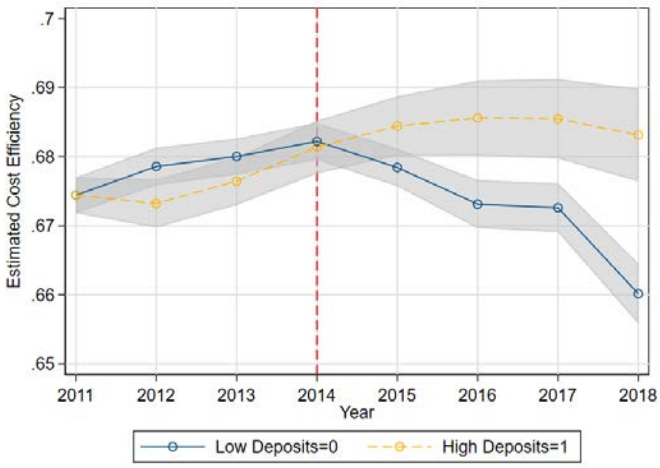

Figure 4. Estimated relationship between bank cost efficiency and retail deposit to total assets

This figure shows the estimated bank cost efficiency coefficients at different levels of the main variable of interest (DEP_TA). The blue solid line represents the marginal effects, while the grey shaded area represents the confidence interval at the 95% level. The horizontal red solid line indicates whether the estimated bank cost efficiency coefficient is positive or negative.

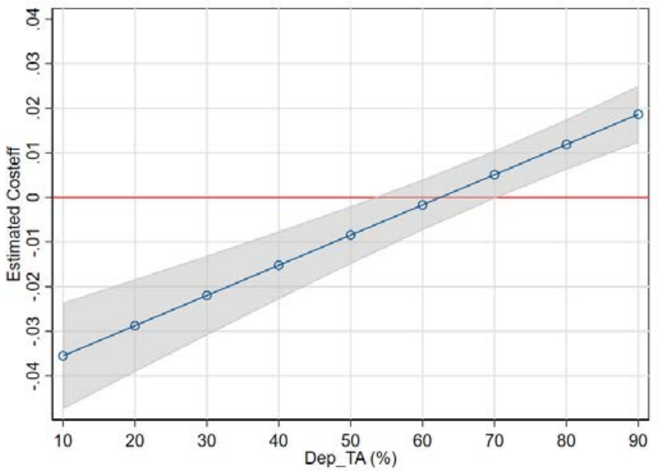

Table 1. Descriptive statistics for control and treatment groups before and after NIRP

	Treatment (High-deposit banks - retail deposit to total asset ratio > 67.61%)											
	Pre-NIRP (2011-2014)						NIRP period (2015-2018)					
	Obs	Avg	Std.	p25	Med	p75	Obs	Avg	Std.	p25	Med	p75
Panel A : Dependent variables												
Costeff (Score)	1498	0.65***	0.12	0.61	0.67	0.72	1639	0.66***	0.12	0.62	0.69	0.73
Cost-to-income (%)	1459	69.70***	11.10	63.50	69.20	75.70	1602	71.10***	11.00	64.90	70.70	76.80
Panel B : Bank specific variables												
LOANS (%)	1496	55.99***	16.10	46.84	57.63	66.94	1638	58.22***	15.48	49.11	60.63	69.37
SIZE (log)	1498	6.37***	1.71	5.03	6.24	7.62	1639	6.53***	1.66	5.21	6.43	7.68
ROA (%)	1475	0.39	0.46	0.19	0.33	0.53	1639	0.37**	0.38	0.16	0.28	0.52
TOTCAP (%)	1399	18.37	7.13	14.15	17.47	21.12	1561	19.89	7.03	15.81	18.20	22.21
INT_OP (%)	1498	102.17***	22.93	89.32	102.20	114.24	1639	81.76***	17.91	72.20	80.81	89.79
LLP (%)	1477	8.99***	22.95	1.47	6.32	14.45	1632	7.71***	15.29	1.37	4.98	11.03
DEP_TA (%)	1498	79.97***	5.44	76.37	80.12	83.69	1639	81.13***	5.57	78.08	81.60	84.98
LOAN_g (%)	1183	4.00***	12.20	1.30	3.80	6.70	1638	5.60**	12.70	2.10	4.90	8.00
Panel C : Macroeconomic variables												
INFLATION (%)	1498	1.73***	0.53	1.50	1.86	1.97	1639	1.42***	0.46	1.13	1.51	1.70
GDP_g (%)	1498	1.16***	1.45	0.42	0.66	2.23	1639	2.06***	0.86	1.53	2.08	2.47
	Control (Low-deposit banks - retail deposit to total asset ratio <= 67.61%)											
	Pre-NIRP (2011-2014)						NIRP period (2015-2018)					
	Obs	Avg	Std.	p25	Med	p75	Obs	Avg	Std.	p25	Med	p75
Panel D : Dependent variables												
Costeff (Score)	2676	0.69***	0.12	0.65	0.71	0.77	2800	0.68***	0.13	0.63	0.71	0.77
Cost-to-income (%)	2440	65.10***	15.30	56.90	64.80	72.20	2620	68.10***	15.00	59.90	67.80	74.80
Panel E : Bank specific variables												
LOANS (%)	2672	62.22***	18.03	53.01	65.14	75.48	2799	63.61***	16.80	54.86	66.62	75.95
SIZE (log)	2676	7.64***	2.27	5.92	7.36	9.25	2800	7.73***	2.18	6.08	7.46	9.22
ROA (%)	2551	0.38	0.68	0.17	0.32	0.58	2800	0.40**	0.58	0.17	0.33	0.57
TOTCAP (%)	2458	18.04	9.05	13.39	15.66	19.42	2635	19.56	8.61	15.00	17.06	20.93
INT_OP (%)	2676	110.03***	28.17	93.01	109.10	128.39	2800	88.02***	24.68	72.74	84.76	98.56
LLP (%)	2608	27.58***	34.84	7.38	17.77	37.93	2771	22.12***	29.47	4.76	12.74	30.38
DEP_TA (%)	2676	51.68***	16.35	41.55	53.69	65.18	2800	59.36***	16.05	51.70	63.15	71.09
LOAN_g (%)	2068	1.80***	17.30	-2.30	1.50	5.50	2799	2.90***	76.30	0.50	4.20	8.40
Panel F : Macroeconomic variables												
INFLATION (%)	2676	1.33***	0.67	0.91	1.45	1.61	2800	1.09***	0.55	0.90	1.05	1.18
GDP_g (%)	2676	0.11***	1.90	-1.03	0.42	0.74	2800	1.75***	1.43	1.10	1.67	2.23

Note: The table presents summary statistics for the variables employed in the analysis. The table is divided in six panels: Panels A, B and C report the statistics for the dependent, bank-specific and macroeconomic variables for the treatment group prior and after the introduction of NIRP in June 2014. Panels D, E and C report the statistics for the dependent, bank-specific and macroeconomic variables for the control group prior and after the introduction of NIRP. Control group banks are those that have a retail deposit to total asset ratio in 2013 below the median (67.61%), while banks in the treated group have a retail deposit to total asset ratio in 2013 above the median (67.61%). Costeff is the estimated cost efficiency score. Cost-to-income is the ratio of operating expenses to operating income. LOANS is the ratio of gross loans-to-total assets. SIZE is the logarithm of bank total assets. ROA is the ratio of net income-to-total assets. TOTCAP is the total capital ratio. INT_OP is the ratio of interest income-to-operating income. LLP is the ratio of loan loss provisions-to-net interest income. DEP_TA is the ratio retail deposit divided by total assets. LOAN_g is the annual growth rate of loans. INFLATION is the growth rate of the Consumer Price Index (CPI). GDP_g is the annual growth in the gross domestic product (GDP). T-test difference in means between Mean treatment and Mean control prior and after NIRP is also reported. ***, **, * indicate statistical significance at 1%, 5% and 10% respectively.

Table 2. Baseline results

This table shows the results of the baseline specification performed on the bank-level panel dataset. Costeff is the estimated cost efficiency score. High-deposits is a dummy variable that takes the value 1 if in 2013 (i.e. before NIRP), the average ratio of retail deposits to total assets of bank i located in a NIRP-affected country j was above the median, and 0 otherwise. Post is a dummy variable that assumes the value 1 after the introduction of NIRP, and 0 otherwise. LOANS is the ratio of gross loans to total assets. SIZE is the logarithm of bank total assets. ROA is the ratio of net income to total assets. TOTCAP is the total capital ratio. INT_OP is the ratio of interest income to operating income. LLP is the ratio of loan loss provisions to net interest income. INFLATION is the growth rate of the Consumer Price Index (CPI). GDP_g is the annual growth in the gross domestic product (GDP). Robust standard errors are clustered at bank-level. *, **, *** indicate statistical significance of 10%, 5% and 1%, respectively.

	(1)	(2)	(3)
VARIABLES	costeff	costeff	costeff
High-deposits*Post	0.0162***	0.0147***	0.0104***
	(0.0041)	(0.0038)	(0.0040)
L.LOANS		0.0004	0.0003
		(0.0003)	(0.0003)
L.SIZE		0.0316*	0.0304*
		(0.0179)	(0.0178)
L.ROA		0.0032	0.0044
		(0.0030)	(0.0029)
L.TOTCAP		0.0008*	0.0007*
		(0.0004)	(0.0004)
L.INT_OP		-0.0002	-0.0002
		(0.0002)	(0.0002)
L.LLP		0.0000	-0.0000
		(0.0001)	(0.0001)
L.INFLATION			0.0020
			(0.0021)
L.GDP_g			-0.0045***
			(0.0011)
Observations	8,743	6,856	6,856
R-squared	0.0134	0.0357	0.0448
Number of banks	1,130	1,073	1,073
Bank FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
Cluster	Bank	Bank	Bank

Table 3. NIRP and cost efficiency: the role of bank-specific characteristics and market competition

This table shows the results of the triple interaction regressions performed on the bank-level panel dataset. Costeff is the estimated cost efficiency score. LOANS is the ratio of gross loans-to-total assets. SIZE is the logarithm of bank total assets. ROA is the ratio of net income to total assets. TOTCAP is the total capital ratio. INT_OP is the ratio of interest income to operating income. LLP is the ratio of loan loss provisions to net interest income. INFLATION is the growth rate of the Consumer Price Index (CPI). GDP_g is the annual growth in the gross domestic product (GDP). Loan_g is the growth rate of gross loans. Lerner is the difference between output prices and marginal costs (relative to prices). Robust standard errors are clustered at bank-level. *, **, *** indicate statistical significance of 10%, 5% and 1%, respectively.

VARIABLES	(1) costeff	(2) costeff	(3) costeff	(4) costeff	(5) costeff
High-deposits*Post	0.0206***	0.0001	0.0187***	-0.0129**	-0.0026
	(0.0048)	(0.0050)	(0.0071)	(0.0058)	(0.0062)
Post*Quartile_Size	0.0014				
	(0.0067)				
High-deposits*Post*Quartile_Size	-0.0275***				
	(0.0090)				
L.LOANS	0.0001	0.0003	0.0004*	0.0004	
	(0.0002)	(0.0003)	(0.0003)	(0.0003)	
L.SIZE		0.0284	0.0344**	0.0319*	0.0226
		(0.0173)	(0.0159)	(0.0179)	(0.0167)
L.ROA	0.0012		0.0009	0.0022	0.0012
	(0.0038)		(0.0033)	(0.0038)	(0.0037)
L.TOTCAP	0.0006	0.0008*	0.0005	0.0011**	0.0007*
	(0.0004)	(0.0004)	(0.0005)	(0.0004)	(0.0004)
L.INT_OP	-0.0001	-0.0002	-0.0002*	-0.0002	-0.0002
	(0.0002)	(0.0001)	(0.0001)	(0.0002)	(0.0001)
L.LLP	-0.0000	-0.0000		-0.0001	-0.0000
	(0.0001)	(0.0001)		(0.0001)	(0.0001)
L.INFLATION	0.0015	0.0018	0.0025	0.0023	0.0015
	(0.0022)	(0.0021)	(0.0021)	(0.0021)	(0.0021)
L.GDP_g	-0.0048***	-0.0041***	-0.0037***	-0.0047***	-0.0039***
	(0.0011)	(0.0011)	(0.0010)	(0.0011)	(0.0010)
Post*Quartile_ROA		-0.0122***			
		(0.0046)			
High-deposits*Post*Quartile_ROA		0.0205***			
		(0.0079)			
Post*Quartile_LLP			0.0247***		
			(0.0050)		
High-deposits*Post*Quartile_LLP			-0.0198**		
			(0.0087)		
Post*Quartile_Loan_g					-0.0301***
					(0.0055)
High-deposits*Post*Quartile_Loan_g					0.0143*
					(0.0080)
Post*Quartile_Lerner				0.0016	
				(0.0054)	
High-deposits*Post*Quartile_Lerner				0.0404***	
				(0.0074)	
Observations	6,858	6,982	7,129	6,858	6,858
R-squared	0.0395	0.0455	0.0532	0.0626	0.0562
Number of banks	1,073	1,073	1,079	1,073	1,073
Bank FE	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes
Cluster	Bank	Bank	Bank	Bank	Bank

Table 4. Placebo test

This table shows the results of the placebo test performed on the bank-level panel dataset. A "false" introduction of NIRP is set in 2013. Costeff is the estimated cost efficiency score. LOANS is the ratio of gross loans to total assets. SIZE is the logarithm of bank total assets. ROA is the ratio of net income to total assets. TOTCAP is the total capital ratio. INT_OP is the ratio of interest income to operating income. LLP is the ratio of loan loss provisions to net interest income. INFLATION is the growth rate of the Consumer Price Index (CPI). GDP_g is the annual growth in the gross domestic product (GDP). Robust standard errors are clustered at the bank-level. *, **, *** indicate statistical significance of 10%, 5% and 1%, respectively.

VARIABLES	(1) costeff	(2) costeff	(3) costeff
High-deposits*"false"Post	0.0019	0.0008	0.0010
	(0.0026)	(0.0035)	(0.0036)
L.LOANS		0.0005*	0.0004
		(0.0003)	(0.0003)
L.SIZE		0.0106	0.0064
		(0.0168)	(0.0165)
L.ROA		-0.0011	0.0010
		(0.0036)	(0.0030)
L.TOTCAP		0.0005	0.0006
		(0.0005)	(0.0005)
L.INT_OP		-0.0001	0.0000
		(0.0001)	(0.0001)
L.LLP		-0.0001**	-0.0001*
		(0.0001)	(0.0001)
L.INFLATION			0.0053*
			(0.0028)
L.GDP_g			-0.0042**
			(0.0021)
Observations	4,230	2,641	2,641
R-squared	0.0199	0.0216	0.0444
Number of banks	1,130	1,051	1,051
Bank FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
Cluster	Bank	Bank	Bank

Table 5. Results using alternative definitions of the treatment variable
This table shows the results of the robustness check performed on the bank-level panel dataset. Costeff is the estimated cost efficiency score. LOANS is the ratio of gross loans to total assets. SIZE is the logarithm of bank total assets. ROA is the ratio of net income to total assets. TOTCAP is the total capital ratio. INT_OP is the ratio of interest income to operating income. LLP is the ratio of loan loss provisions to net interest income. INFLATION is the growth rate of the Consumer Price Index (CPI). GDP_g is the annual growth in the gross domestic product (GDP). Robust standard errors are clustered at the bank-level. *, **, *** indicate statistical significance of 10%, 5% and 1%, respectively.

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	costeff	costeff	costeff	costeff	costeff	costeff
High-deposits(tercile)*Post	0.0243***	0.0221***	0.0191***			
	(0.0045)	(0.0045)	(0.0047)			
L.LOANS		0.0001	0.0001		0.0005*	0.0004
		(0.0003)	(0.0003)		(0.0003)	(0.0003)
L.SIZE		0.0237	0.0230		0.0266*	0.0261
		(0.0204)	(0.0203)		(0.0161)	(0.0159)
L.ROA		-0.0011	0.0000		-0.0023	-0.0011
		(0.0041)	(0.0040)		(0.0036)	(0.0036)
L.TOTCAP		0.0008	0.0008		0.0005	0.0005
		(0.0005)	(0.0005)		(0.0004)	(0.0004)
L.INT_OP		-0.0002	-0.0002		-0.0002	-0.0002
		(0.0002)	(0.0002)		(0.0001)	(0.0001)
L.LLP		-0.0001	-0.0001		-0.0001	-0.0001*
		(0.0001)	(0.0001)		(0.0000)	(0.0000)
L.INFLATION			0.0002			-0.0000
			(0.0024)			(0.0021)
L.GDP_g			-0.0028**			-0.0028***
			(0.0011)			(0.0010)
L.DEP_TA				-0.0015***	-0.0017***	-0.0016***
				(0.0002)	(0.0003)	(0.0003)
High-deposits*Post (cont. treatment)				0.0007***	0.0006***	0.0005***
				(0.0001)	(0.0001)	(0.0001)
Observations	6,391	5,044	5,044	7,798	6,828	6,828
R-squared	0.0360	0.0653	0.0693	0.0481	0.0697	0.0735
Number of banks	822	787	787	1,127	1,072	1,072
Bank FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Cluster	Bank	Bank	Bank	Bank	Bank	Bank

Table 6. Results using an alternative dependent variable
This table shows the results of the baseline specification performed on the bank-level panel dataset. Cost-to-income is the ratio of operating expenses to operating income. is the estimated cost efficiency score. LOANS is the ratio of gross loans to total assets. SIZE is the logarithm of bank total assets. ROA is the ratio of net income to total assets. TOTCAP is the total capital ratio. INT_OP is the ratio of interest income to operating income. LLP is the ratio of loan loss provisions to net interest income. INFLATION is the annual growth rate of the Consumer Price Index (CPI). GDP_g is the annual growth in the gross domestic product (GDP). Robust standard errors are clustered at the bank-level. *, **, *** indicate statistical significance of 10%, 5% and 1%, respectively.

	(1)	(2)	(3)
VARIABLES	cost-to-income	cost-to-income	cost-to-income
High-deposits*Post	-0.8495	-2.5703***	-2.1838***
	(0.5216)	(0.5704)	(0.6007)
L.LOANS		-0.0737*	-0.0637
		(0.0434)	(0.0447)
L.SIZE		-2.8951*	-2.6386
		(1.7358)	(1.7158)
L.ROA		-1.8657***	-1.9568***
		(0.5947)	(0.6040)
L.TOTCAP		0.1166**	0.1187**
		(0.0580)	(0.0578)
L.INT_OP		-0.0348	-0.0352
		(0.0274)	(0.0278)
LLP		0.0049	0.0076
		(0.0103)	(0.0103)
L.INFLATION			0.6265*
			(0.3592)
L.GDP_g			0.5302*
			(0.2840)
Observations	8,392	6,564	6,564
R-squared	0.0368	0.0821	0.0879
Number of banks	1,070	1,029	1,029
Bank FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
Cluster	Bank	Bank	Bank

Appendix A

Table A. Correlation Matrix
This table represents the correlation matrix for the variables included in the baseline regression. Correlations that are statistically significant at least at the 5% level are reported in bold italics. The number on the horizontal axis indicates the variables on the vertical axis. Each horizontal number matches the variable's position in the vertical.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) LOAN		**0.08**	**-0.08**	**-0.36**	**0.15**	**0.04**	**-0.10**	**-0.04**
(2) SIZE	**0.08**		**-0.04**	**-0.18**	**0.30**	**0.07**	**-0.20**	**0.10**
(3) ROA	**-0.07**	**-0.04**		**0.13**	**-0.14**	**-0.34**	**0.06**	**0.11**
(4) TOTCAP	**-0.36**	**-0.18**	**0.13**		**-0.19**	**-0.12**	0.01	**0.03**
(5) INT_OP	**0.15**	**0.30**	**-0.14**	**-0.19**		**-0.03**	**0.02**	**-0.11**
(6) LLP	**0.04**	**0.07**	**-0.34**	**-0.12**	**-0.03**		**-0.25**	-0.30
(7) INFLATION	**-0.10**	**-0.20**	**0.06**	0.01	**0.02**	**-0.25**		**-0.30**
(8) GDP_g	**-0.04**	**0.10**	**0.11**	**0.03**	**-0.11**	-0.30	**0.14**	

Note: LOANS is the ratio of gross loans to total assets. SIZE is the logarithm of bank total assets. ROA is the ratio of net income to total assets. TOTCAP is the total capital ratio. INT_OP is the ratio of interest income to operating income. LLP is the ratio of loan loss provisions to net interest income. INFLATION is the annual growth rate of the Consumer Price Index (CPI). GDP_g is the annual growth in the gross domestic product (GDP).

Table B. Number of banks by country and specialisation

	N.Banks	BHCs	Commercial	Cooperative	Savings
Austria	178	2	15	144	17
Belgium	17	1	12	1	3
Cyprus	4	0	4	0	0
Germany	375	6	21	226	122
Estonia	2	0	2	0	0
Finland	6	0	4	2	0
France	134	5	66	50	13
Greece	7	1	5	1	0
Ireland	6	1	5	0	0
Italy	308	5	47	245	11
Luxembourg	30	1	25	2	2
Malta	5	1	4	0	0
Netherlands	21	6	14	1	0
Portugal	8	2	5	1	0
Slovenia	5	0	3	1	1
Slovakia	8	0	7	0	1
Spain	16	0	12	1	3
Total	1130	31	251	675	173

Table C. Variables, labels, definitions and sources

Variable	Label	Definition	Source
Dependent variables			
Cost efficiency	Costeff	The estimated cost efficiency scores based on the Stochastic Frontier Analysis	Authors' calculation
Cost Efficiency	Cost-to-income	The ratio of operating expenses to operating income	Moody's BankFocus & SNL Financial
Variables of interest			
Treated	High-deposit banks	A dummy variable equal to 1 if a bank has a retail deposit to total asset ratio in 2013 above the median, 0 otherwise	Authors' calculation
Post	Post	A dummy variable equal to 1 after the introduction of NIRP, 0 otherwise	Authors' calculation
Treatment	NIRP-effect	The interaction between the dummy Treated and the dummy Post	Authors' calculation
Funding structure	DEP_TA	The ratio of retail deposits to total assets	Moody's BankFocus & SNL Financial
Asset structure	LOAN	The ratio of gross loans to total assets	Moody's BankFocus & SNL Financial
Bank size	SIZE	The logarithm of bank total assets	Moody's BankFocus & SNL Financial
Profitability	ROA	The ratio of net income to total assets	Moody's BankFocus & SNL Financial
Capitalisation	TOTCAP	The total regulatory capital ratio (TIER1 + TIER2)	Moody's BankFocus & SNL Financial
Business model	INT_OP	The ratio of interest income to operating income	Moody's BankFocus & SNL Financial
Asset quality	LLP	The ratio of loan loss provisions to net interest income	Moody's BankFocus & SNL Financial
Loan growth	Loan_g	The growth rate of gross loans	Moody's BankFocus & SNL Financial
Country control variables			
Inflation	INFLATION	The annual growth rate of the Consumer Price Index (CPI)	World Bank
Economic growth	GDP_g	The annual growth rate of the gross domestic product (GDP)	World Bank
Market competition	Lerner Index	The difference between output prices and marginal costs (relative to prices)	World Bank

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