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Effects of a negative interest rate policy in bank profitability and risk taking: Evidence from European banks

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ABSTRACT

This paper analyses the effect of a negative interest rate policy (NIRP) on profitability and risk taking in the European banking sector and whether this effect is differentiated according to the bank business model. Using a dataset of 2596 banks from 29 European countries over the period 2011–2019 and applying a static modelling approach, we conclude that the implementation of NIRPs lowers the net interest margin and the return on assets of a representative bank by 14.5 basis points and 18.5 basis points, respectively. We also conclude that a decrease in the short-term interest rate lowers the net interest margin when interest rates are already negative. In an environment of negative interest rates, we do not find that European banks take on more risk and conclude that the effects of the implementation of NIRPs influence banks' profitability and risk taking differently, depending on the business model adopted.

1. Introduction

In the last decade, some central banks around the world, in an attempt to avoid low inflation rates and stimulate economic growth, resorted to a set of unconventional monetary policy instruments, such as large-scale asset purchases in the form of quantitative easing, the implementation of negative interest rate policies (NIRPs), as well as policy rate forward guidance. In July 2012, Danmarks Nationalbank lowered its policy rate to negative values for the first time. Several central banks from other countries (the euro area, Hungary, Norway, Sweden, Switzerland, Bulgaria, and Japan) adopted the same behaviour.

The implementation of NIRP means that central banks are now charging (instead of paying) interest on the excess reserves that commercial banks have deposited there, encouraging them to take them back on the balance sheet. This is expected to have positive effects on economic activity through the increased supply and demand for loans due to the decline in funding costs for both banks and borrowers (Cœuré, 2016). However, the effect that NIRPs can have on a bank's profitability is not so clear (Boungou, 2019).

Low or negative interest rates help to improve banks' balance sheets and performance, leading to capital gains and a reduction in loan loss provisions. However, low or negative interest rates can also mean lower net interest margins. This is because bank intermediation is a spread business, based on the difference between interest rates on loans and deposits. When market interest rates fall, becoming low or even negative, banks may need to drop loan interest rates but are very reluctant to lower deposit rates to negative levels, especially for retail depositors, compressing the net interest margin (Claessens et al., 2018). Banks know that a negative deposit interest rate would lead their customers to withdraw their deposits and take them elsewhere. Refusing to pass negative interest rates

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onto customer deposits, banks' profitability related to maturity transformation will be negatively affected, eroding their equity capital and deteriorating their financial stability (Zimmermann, 2019). Banks can compensate for the margin decline by increasing fees and commissions and reducing operating expenses (Scheiber et al., 2016).

The implementation of NIRPs also impacts bank risk taking. First, a decline in the reference interest rate affects banks' perceptions of and/or tolerance to risk. Lowering interest rates drives up the value of assets and collateral and, subsequently, banks' income, thus raising their risk taking capacity (Borio and Zhu, 2008). If interest rates remain low or negative for long periods, a credit boom will be highly likely, leading banks to loosen their lending standards and increase credit to riskier clients (Chen et al., 2017). In a context of lower or negative interest rates, if a bank's return target is sticky, it will induce the bank's managers to hold an increasing amount of risky assets in the search for yield (Rajan, 2005)(Rajan, 2005). Several authors also advocate that the NIRP effect on bank profitability and risk taking depends on bank-specific characteristics such as size, funding structure, assets repricing, and product line specialization and that banks adjust their business models in response to this new environment (Boungou, 2019; Molyneux et al., 2019).

Considering the above scenario, the objective of this research is to study the impact of negative interest rates on the profitability and risk taking of European banks. In particular, the intention is to investigate i) the effects of negative interest rates on banks' net interest margin and the remaining items of bank profitability, ii) the effects of negative interest rates on banks' risk taking, and iii) lastly, whether these effects are differentiated according to the bank's business model.

The contribution of this study is threefold. First, there are still very few studies, some of them with contradictory results, that analyse the impact of some countries' central banks' adoption of NIRPs on bank profitability and risk taking. Second, we verify whether the impacts of changes in interest rates on bank profitability and risk taking are differentiated when interest rates are positive or negative. Third and, to our best knowledge, for the first time, we investigate whether the impact on bank profitability and risk taking resulting from the implementation of NIRPs is differentiated according to the business model adopted by the bank.

Banks' margins and overall profitability are proxied by their net interest margin and return on assets (ROA), respectively. We used three measures for bank risk taking: the Z-score, as a measure of overall bank risk, the ratio of nonperforming loans (NPLs) as a measure of credit risk, and, finally, the ratio of risk-weighted assets (RWA) to total assets as a measure of the risk associated with the bank's investment strategy. To characterize the interest rate environment, we consider a short-term interest rate, proxied by a three-month interbank money market interest rate, and the slope of the yield curve measured by the difference between the 10-year Treasury yield and the three-month interbank money market interest rate.

We used an unbalanced panel data dataset of 2596 banks, with 15119 bank–year observations, operating in 29 European countries over the period 2011–2019. In the sample period considered, six central banks adopted NIRPs. To investigate the effects of NIRP adoption on bank profitability and risk taking, two equations are estimated using a fixed effect estimator, and, to mitigate a possible endogeneity bias and potential omitted variables, explanatory variables are lagged one period and bank and time fixed effects are included. To identify banks' business models in European banking and investigate the effects of NIRP adoption on bank profitability and risk taking, we used k-median clustering to assign each bank to a specific banking business model, given its asset and funding structure. Based on cluster analysis, we identify four different business models: investment-oriented banks (type I), retail-oriented banks, investment-oriented banks (type II), and interbank lending–oriented banks.

The main findings indicate that NIRP implementation lowered the net interest margin and overall profitability of European banks that were affected by that policy. We also find evidence that a decrease in short-term interest rates lowered net interest margins when interest rates were already negative. The same evidence is not found for the ROA variable. Considering the whole sample, we find no evidence that European banks increase risk taking with NIRP adoption. The results also allow us to conclude that the effects of the implementation of NIRPs affect bank profitability and risk taking differently, depending on the business model adopted by the banks. The net interest margins of banks' business models whose main source of finance is retail deposits are more negatively affected by NIRP implementation. Banks' financial stability and credit risk, across different bank business models, are not shown to be affected by negative interest rates. Lastly, we conclude that investment-oriented banks (type I) and interbank lending–oriented banks adopt riskier investment strategies, while retail-oriented banks adopt less risky investment strategies.

The remainder of the paper is organized as follows. Section 2 reviews the literature on the relation between a low or negative interest rate environment and bank profitability and risk taking. Section 3 describes the econometric methodology and the data used in the econometric tests. The results are reported and discussed in Sections 4 to 6. Finally, Section 7 concludes the paper and highlights political implications.

2. Literature review and research hypothesis

In this section, we briefly review the literature on the relationship between a low or negative interest rate environment and bank behaviour. In the first subsection, we present the literature that analyses the relationship between interest rates and bank profitability. In the next section, we focus on the relationship between low or negative interest rates and bank risk taking.

2.1. Negative interest rates and bank profitability

How changes in interest rates affect bank performance is a subject that has recently received increased attention, from both a practical and an academic point of view. The literature argues that the effect of interest rates on banks' profits will vary by bank, depending on their interest rate exposure, which, in turn, is a function of their degree of maturity transformation and the use of risk management techniques, including derivatives (Claessens et al., 2018). According to Borio et al. (2017), changes in the levels of interest rates and the slope of the yield curve affect the various items of bank profitability, that is, the net interest margin, non-interest

income, and loan loss provisions.

Most theoretical and empirical studies suggest that banks' net interest margins are lower when interest rates are low. According to Claessens et al. (2018), this is because, for many types of deposits and other liabilities, banks are reluctant to lower interest rates below a certain level, since depositors and other creditors can switch to cash forms of savings. When short-term interest rates become negative, there is a reduction in banks' net interest margins, since they are unable to pass these interest rates onto their clients' applications, given the possibility and even the high probability that clients will invest their savings in alternative financial instruments. With deposit rates facing a floor, as interest rates decline, bank margins will compress if banks must still pass lower rates onto the asset side of their balance sheet (Claessens et al., 2018). This market imperfection leads banks to compensate for those losses by selling complementary products and services in a cross-selling policy and with increased commissions, together with a reduction in costs and an increase in credit volume.

The slope of the yield curve can also influence the net interest margin (Borio et al., 2017). Specifically, a flat yield curve has a negative effect on a bank's net interest margin. Typically, a bank is financed with short-term liabilities in its maturity transformation activity and invests in assets with longer maturities. If the term premium is close to zero or even negative, the net interest margin will be compressed. Changes in the slope of the yield curve will also have quantity effects, notably influencing the volume of banks' fixed-rate mortgages.

Low or negative interest rates can also impact non-interest income and loan loss provisions. Borio et al. (2017) argue a negative relationship between interest rates and non-interest income through two effects: valuation effects on securities and fees and commissions. As interest rates rise, a bank's ability to generate profits from the net interest margin between loans and applications increases and, as interest rates decrease, the need for banks to generate profits from non-interest income rises. The relationship between interest rates and loan loss provision is presented by a concave shape: higher rates induce variable-rate loans, increasing stock and debt service burdens; nevertheless, this relationship is attenuated as rates increase.

As noted by Boungou (2019), there is currently no consensus on the interest rate effects on bank profitability. On the one hand, several studies show that low-interest rates have a negative effect on banks' net margins and overall profitability. Borio et al. (2017) analyse the influence of monetary policy on bank profitability through the influence on the interest rate structure. The authors found a concave relationship between the level of interest rates and the slope of the yield curve, associated with higher net income. This relationship is particularly strong at very low levels of nominal rates. The authors also find a negative relationship between interest rates and non-interest income, which seems to indicate a search for alternative channels that ensure bank profitability. Claessens et al. (2018), using a sample of 3385 banks from 47 countries between 2005 and 2013, find that low interest rates have a significantly greater impact on banks' net interest margins than high interest rates. The impact is greater on interest income than on interest expense, and banks with short maturity balance sheets are more affected than those with long maturity balance sheets. The effects on bank profitability are not so pronounced, because banks mitigate the negative effect of low interest rates on net interest margin by cutting costs and generating more non-interest income, such as fees and commissions and valuation gains. Similar conclusions are drawn by Genay and Podjasek (2014); Busch and Memmel (2017), and Bikker and Vervliet (2018).

On the other hand, some authors find opposite effects of low (negative) interest rates on bank profitability. Scheiber et al. (2016), in an investigation of the profitability of banks in three European countries (Denmark, Sweden, and Switzerland) during a period of very low and negative interest rates (2010–2015), conclude that negative interest rates have thus far not resulted in a significant reduction in bank profitability or, particularly, net interest margins. Similar results are found by Madaschi and Pablos Nuevo (2017) for Swedish and Danish banks. Altavilla et al. (2017) analyse eurozone banks over the period 2000–2016 and conclude that monetary policy easing – a decrease in short-term interest rates and/or a flattening of the yield curve – is not associated with lower bank profits. Their analysis indicates that the main items of bank profitability are asymmetrically affected by accommodative monetary conditions, with a positive impact on loan loss provisions and non-interest income largely offsetting the negative impact on net interest income. Finally, we reference the study of Lopez et al. (2020), who, using data on 5200 banks from 27 advanced European and Asian countries over the period 2010–2017, conclude that banks offset interest income losses under negative rates with lower deposit expenses and gains in non-interest income, including fees and capital gains. However, the authors emphasize that there is no guarantee that the gains to non-interest bank income are sustainable over long periods.

Some authors emphasize the fact that the impact of low (negative) interest rates on profitability varies depending on a set of bank characteristics. Molyneux et al. (2020) reinforce the existence of specific characteristics that significantly influence the relationship between negative interest rates and bank margins, as follows: bank size, banks' funding structure and business model, including assets repricing, and product line specialization. Bank size could explain the reduced elasticity of net interest margins to interest rate volatility. The funding structure is important, because, when policy rates turn negative, banks that rely on deposit funding are reluctant to reduce deposit rates, trying to keep their funding base, avoiding passing negative rates onto depositors. The business model can provide different degrees of sensitivity to interest rate risk. This risk is different for a real estate mortgage specialist bank, compared to a bank that holds mostly floating interest rate loans.

Considering the difficulty that banks have in obtaining non-interest income that compensates for interest income losses under a negative interest rate scenario, the following hypotheses are formulated.

Hypothesis I. *An NIRP leads to a drop in banks' net interest margins and profitability*.

Hypothesis II. *The effects of a change in interest rates on banks' net interest margins and profitability are differentiated when an NIRP is implemented*.

Because the evidence shows that the effect of adopting an NIRP can be differentiated depending on the bank's business model, we

still formulate the following hypothesis.

Hypothesis III. *The effect of an NIRP on profitability depends on the bank's business model.*

2.2. Negative interest rates and bank risk taking

Unconventional monetary policies, including quantitative easing, as well as policy rate guidance promoted by central banks to provide economic stimulus in an economic stagnation environment, have led to negative interest rates with impacts on bank risk taking.

The relationship between low interest rates and bank risk taking has been presented in the literature within a risk taking channel that shows the way that changes in monetary policy affect the risk perceptions or risk tolerance of finance intermediaries (Rajan, 2005; Borio and Zhu, 2008; Adrian et al., 2010). The risk taking channel can operate i) through the way banks measure risk, through their impact on valuations, incomes, and cash flows (Borio and Zhu, 2008; Adrian and Shin, 2009), and ii) through an increase in the search for yield (Rajan, 2005). Analysing the way banks measure risk, we find that low interest rates provide an increase in asset and collateral values, decreasing risk perception by reducing asset price volatility. Adrian and Shin (2009) emphasize that, after an unusually long period of low interest rates, in which leveraged positions may have built up, small changes in the monetary policy stance will have an amplified impact on the repricing of risk and on liquidity conditions. Search for yield is related to the commitment to produce certain levels of nominal rates of return that cannot be ensured by an environment of low or even negative interest rates and low returns on government bonds.

Rajan (2005) justifies the willingness of asset managers to take on more risks with three reasons: contractual, behavioural, and institutional. The author states that, when interest rates are low, the yields on risk-free assets are also low and banks tend to invest in risky assets, providing a higher yield. This behaviour is reinforced by the replication of investment decisions by peers, a phenomenon known as herding. This phenomenon is complemented by the so-called money illusion, according to which investors may ignore the fact that nominal interest rates can decline to compensate for lower inflation.

Andries et al. (2015) emphasize the dual effect of monetary policy on the credit supply of banks, the credit channel presented by Arteta et al. (2016), namely, i) the increase in the collateral and cash flows of borrowers provided by low interest rates through the balance sheet channel, which allows increases on supply loans, and ii) the search for other financing sources by banks in response to the threat of deposit withdrawals under low interest rates. The higher costs related to these other financing sources implies an extra cost that ends up reducing the credit supply.

Altunbas et al. (2014) state, in addition, that bank risk can also be influenced by communication policies, with a moral hazard problem. Monetary policy easing perceptions of bad economic outcomes can lower the expectations of large downside risks and encourage liquidity risk taking. This leads to the low interest rate paradox introduced by Maddaloni and Peydró (2011), according to which, when interest rates are low, credit risk and liquidity risk increase, as does the likelihood of a financial crisis. The interaction between finance, behavioural finance, and macroeconomics associated with the risk taking channel of monetary policy has been justified because it captures the measurement and management of risk, as well as the effects of monetary policy on banks' risk perceptions and incentives, and because excessive bank risk taking has effects on the general equilibrium, respectively (Andries et al., 2015). Complementing the moral hazard problem, monetary policy will have an impact on the adverse selection problem, considering the decreasing incentive of weakening banks to screen and monitor loan applicants (Dell'Ariccia et al., 2014).

In terms of empirical studies, Jiménez et al. (2014) test for the existence of a risk taking channel for Spain. According to the authors, low interest rates affect the risk of Spanish banks' loan portfolio as follows: i) in the short term, low interest rates reduce the probability of default of outstanding loans and ii) in the medium term, banks tend to take on more risk, loosening their lending standards and lending to borrowers with bad credit history. Ioannidou et al. (2009) reach the same conclusion in investigating the impact of changes in monetary policy rates on loan pricing in Bolivia. They note a negative relationship between the interest rate and loan risk. They also conclude that banks increase the number of new risky loans and reduce the rates they charge to riskier borrowers relative to less risky ones.

Several studies in the risk taking literature explain how the interest rate structure encourages excessive risk taking by banks. For some authors, the effects of interest rates on risk taking depend on the profitability level of banks (Repullo, 2004; Martynova et al., 2019), and for others on banks' capitalization levels (Jiménez et al., 2014; Dell'Ariccia et al., 2017). Studies that investigate the effects of NIRPs on bank risk taking are still limited, with contradictory results.

Heider et al. (2018), using loan-level information for Europe over the period from January 2013 to December 2015, conclude that the introduction of negative policy rates by the European Central Bank in mid-2014 led to more risk taking and less lending by euro area banks, potentially posing a risk to financial stability with lending by high-deposit banks. Basten and Mariathasan (2018) analyse the effect of negative monetary policy rates on banks, using detailed supervisory information from Switzerland, namely, comparing changes in the behaviour of banks that had different fractions of their central bank reserves exempt from negative rates. They conclude that more affected banks reduced costly reserves and bond financing while maintaining non-negative deposit rates and larger deposit ratios. With higher fees and interest income, banks compensate for squeezed liability margins, but increase credit and interest rate risk. Boungou (2020) analyse – to the best of our knowledge for the first time – the effects of negative rates on the risk taking of banks operating in the 28 member countries of the European Union. The author concludes that negative interest rates contributed to a reduction in bank risk taking. During the implementation period of negative rates, banks took on less risk, particularly by reducing the share of NPLs. Boungou (2019) finds no encouragement of banks to take more risk, despite a reduction in interest margins.

These contradictory results justify the present investigation and, considering the explanations above, the following hypotheses to

test are formulated.

Hypothesis IV. *NIRPs leads to greater bank risk taking.*

Hypothesis V. *The effect of a change in interest rates on bank risk taking is differentiated under NIRPs.*

Lucas et al. (2019), in an empirical study of 208 European banks between 2008Q1 and 2015Q4, identify six distinct business models and conclude that changes in the slope of the yield curve change in terms of average business model characteristics. A bank's risk response is therefore expected to be differentiated depending on its business model (Schwaab, 2017). This leads us to formulate the following additional research hypothesis.

Hypothesis VI. *The effect of an NIRP on bank risk taking depends on the bank's business model.*

3. Methodology and data

In this section, we introduce the methodology and empirical models that allow for an analysis of the impacts of the adoption of NIRPs by some central banks on profitability and risk taking in European banks. For this purpose, profitability and risk taking measures are defined and discussed. The variables used to characterize the interest rate environment are also specified. To investigate whether these impacts are differentiated according to the bank's business model, we also describe the methodology that allows us to allocate banks to different business models.

3.1. Profitability and risk taking measures

To measure a bank's profitability,[1] two main indicators are considered: the net interest margin, defined as the difference between interest-earning assets and interest-bearing liabilities, divided by total earning assets, and the ROA, a common performance measure, defined as the ratio of net income over total assets. Because monetary policy also has an impact on other items of profit (Borio et al., 2017), in addition to net interest margin, we also study the effect of an NIRP on net fees and commissions, net trading income, and other operating revenues and, finally, on loan loss provisions.[2]

Considering the different risk channels of monetary policy identified in the literature review, we consider the following three measures of risk (e.g. Boungou, 2020):

(i) To measure credit risk in the literature, the NPL ratio (Andries et al., 2015; Dell'Ariccia et al., 2017; de Mendonça and de Moraes, 2018), defined as the NPL divided by gross loans, and the ratio of loan loss provisions to gross loans (de Moraes et al., 2016; De Mendonça and de Moraes, 2018; Montes et al., 2021) are often used as a proxy. Because, during the period under study, there was an increase in loan loss provisions due to a tightening in the regulation rules by the European regulatory authorities, we use the NPL ratio to measure the credit risk.

(ii) We consider also the ratio of RWA over total assets (De Nicolo et al., 2010; Khan et al., 2017). In a context of reduced interest rates, the search for yield effect leads banks to adopt riskier investment strategies, increasing their exposure to risk and, consequently, this ratio.

(iii) Lastly, we consider the Z-score[3] ratio as a measure of solvency risk (Chen et al., 2017). This ratio is estimated as the sum of current ROA with the ratio of equity to assets divided by the standard deviation of ROA (σ_{ROA}).[4] The idea behind the Z-score is that a bank becomes insolvent when its current losses exhaust all its equity. Thus, a lower Z-score implies a greater risk of insolvency (Ngambou Djatche, 2019).

3.2. Interest rate environment measures

This study is concerned with the impact the adoption of NIRPs by some central banks in Europe has had on bank profitability and risk taking. To this end, the following variables are considered: a short-term interest rate, the slope of the yield curve, and a dummy variable reflecting whether an NIRP has been adopted or not.

For the short-term interest rate, we use the three-month interbank money market interest rate (Delis and Kouretas, 2011; Bikker and Vervliet, 2018). We prefer an interbank money market interest rate to the central bank's policy rate, because the former reflects more appropriately the adoption of unconventional monetary policy measures. Making the same assumption as in the literature, that the short-term interest rate reflects the general interest rate level, we expect i) lower interest rates to decrease banks' net interest margins, ii) lower interest rates to increase risk exposure, and iii) this impact to be stronger when interest rates are already low or negative.

The slope of the yield curve, which also helps control for the effects of unconventional monetary policy measures, is approximated

[1] Similar measures are considered by Borio et al. (2017) and Boungou (2019).

[2] All these variables are considered in our models as a percentage of total assets.

[3] Because the literature indicates that the Z-score is highly skewed, we used a natural logarithmic transformation.

[4] Because the sample period covered by the present investigation is relatively short, we assume that σ_{ROA} is constant and given by the standard deviation of the ROA in the period under analysis.

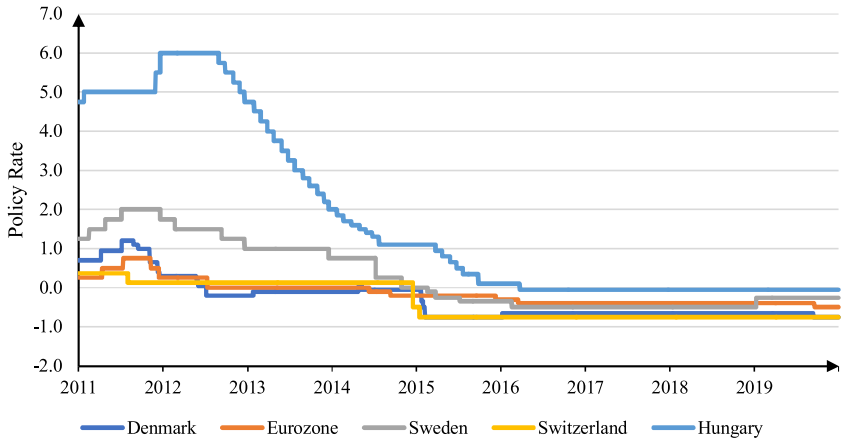

Fig. 1. Evolution of the central bank's policy rate in European countries that adopted NIRPs (2011–2019).

by the difference between the 10-year Treasury yield and the three-month interbank money market interest rate (e.g. Borio et al., 2017; Claessens et al., 2018). Because of the maturity transformation function performed by banks, a positive correlation is expected between banks' profits or net interest margins and the slope of the yield curve (Alessandri and Nelson, 2015).

Finally, to characterize the interest rate environment, we consider a dummy variable to reflect whether the central bank of the country where the bank is based adopted an NIPR or not. Fig. 1 shows the evolution of the central bank's policy rate[5] in European countries that adopted NIRPs.

3.3. Model specifications and the estimation method

To study the effects of interest rates on bank profitability and risk taking due to the adoption of NIRPs, we consider the following models:

$$y_{it} = \beta_0 + \beta_1 * ir_{t-1} + \beta_2 * slope_{t-1} + \beta_3 * NIRP_{t-1} + \gamma_1 * X_{t-1} + \gamma_2 * W_{t-1} + \mu_i + \delta_t + \varepsilon_{it} \quad (1)$$

$$y_{it} = \alpha_0 + \alpha_1 * ir_{t-1} + \alpha_2 * slope_{t-1} + \alpha_3 * NIRP_{t-1} * ir_{t-1} + \alpha_4 * NIRP_{t-1} * slope_{t-1} + \gamma_1 * X_{it-1} + \gamma_2 * W_{t-1} + \mu_i + \delta_t + \varepsilon_{it} \quad (2)$$

where, for bank i and year t, y_{it} alternatively represents either the bank's profitability or risk taking measures defined above; ir_t represents the short-term interest rate; $slope_t$ represents the slope of the yield curve; $NIRP_t$ takes the value of one if the country where the bank is based adopted an NIRP in year t, and zero otherwise; X_{it} and W_t represent vectors of bank-specific and macroeconomic variables, respectively; and μ_i and δ_t represent bank-specific effects and time fixed effects, respectively. In all regressions, we follow Borio et al. (2017) and Leroy and Lucotte (2017), lagging explanatory variables by one period and including bank and time fixed effects to mitigate potential endogeneity bias. Both equations are estimated using a fixed effect estimator, and, in the statistical inference, robust standard errors clustered at the bank level are used to take into account autocorrelation and/or heteroscedasticity.

For the profitability models, we expect $\beta_3 < 0$ in Eq. (1), meaning that the adoption of NIRPs will put pressure on the bank's net interest margin and profitability (Hypothesis I). Considering Eq. (2), the marginal effect of a change in the short-term interest rate on net interest margins and profitability is given by $\alpha_1 - \alpha_2 + \alpha_3 - \alpha_4$ if NIRP was implemented, and by $\alpha_1 - \alpha_2$ if NIRP was not implemented.[6] So, according to Hypothesis II, it is expected that $\alpha_3 - \alpha_4 \neq 0$, meaning that a change in short-term interest rates will lead to a change in banks' net interest margins and profitability, whether an NIRP was implemented or not.

For risk taking models, using similar reasoning, according to Hypothesis IV, it is expected that $\beta_3 < 0$ if the risk measure is the Z-score, and $\beta_3 > 0$ if the risk is measured by the NPL ratio or the ratio of RWA to total assets. According to Hypothesis V, we expect $\alpha_3 - \alpha_4 \neq 0$.

To control for the possible effects of other determinants of bank profitability and risk taking, we include the following bank-specific variables in vector X_{it}. First, we consider bank size, measured by the natural logarithm of total assets. According to Goddard et al. (2004), a bank's size positively influences its profitability through the realization of economies of scale. However, as suggested by Demirgüç-Kunt et al. (2004), large, efficient banks could apply lower spreads to customers through increasing returns to scale. The

[5] The central bank's policy rate refers to the main deposit policy rate in most cases and to the main refinancing rate for the Riksbank. No historical data are reported for Bulgaria due to lack of availability.

[6] Remember that the variable $slope_t$ is given by the difference between the long-term interest rate and the short-term interest rate (ir_t). Using Eq. (2), the marginal effect of the short-run interest rate (ir_t) on the dependent variable (y_{it}) is given by the partial derivative of y_{it} of the order ir_t. When an NIRP is not implemented (NIRP = 0), this effect is given by $\alpha_1 - \alpha_2$, whereas, when NIRP is implemented (NIRP = 1), this effect is given by $\alpha_1 - \alpha_2 + \alpha_3 - \alpha_4$.

Table 1
NIRP announcements.

Country	Central bank	Policy rate	Date	Rate (%)
Bulgaria	Central Bank of Hungary	Overnight deposit rate	January 2016	−0.30
Denmark	Danmarks Nationalbank	1-week certificate deposit rate	July 2012	−0.20
Eurozone	European Central Bank	Overnight deposit facility rate	June 2014	−0.10
Hungary	Magyar Nemzeti Bank	Overnight deposit rate	March 2016	−0.05
Sweden	Sveriges Riksbank	1-week repo rate	February 2015	−0.10
Switzerland	Swiss National Bank	Overnight sight deposit rate	December 2014	−0.25

Sources: The central banks in question.

effect of *bank size* on profitability is thus unclear. The same conclusion can be drawn regarding the relationship between the bank's size and risk. On the one hand, managers of large banks could be tempted to adopt higher-risk policies in case governments are prepared to bail out large problematic banks (Demirgüç-Kunt and Huizinga, 2013); on the other hand, larger banks can achieve economies of scale that allow them to be more stable than small banks (Williamson, 1986).

We employ several variables to control for bank risk aversion, credit risk, and bank operating efficiency. We used *capitalization*, measured by the ratio of equity over total assets, to proxy for bank risk aversion. Given their risk aversion, we expected that better-capitalized banks will require higher margins and take on less risk (Berger, 1995; Bikker and Vervliet, 2018). Credit risk is measured by the *NPL ratio*. We expect that banks with higher credit risk will apply a premium to margins (Molyneux et al., 2019) and exhibit higher overall risk.[7] Bank management *inefficiency* is measured using the cost-to-income ratio. As noted by Molyneux et al. (2019), a bank's inefficient management translates into lower margins and profit and, consequently, more risk.

To control for the impact of bank business models, we also consider a bank's *asset composition,* measured by the loans-to-asset ratio, as a determinant of its profitability and risk taking; the bank's funding structure, measured by the *share of wholesale funding;* and the diversity of its income, measured by its *non-interest income share* (Bikker and Vervliet, 2018; Molyneux et al., 2019).

The banking literature suggests that the macroeconomic environment in which banks operate can have effects on their behaviour. Thus, both the structure of the banking sector and the economic environment can affect bank profitability and risk taking. As Boungou (2019), we considered real gross domestic product (GDP) growth and the inflation rate to characterize macroeconomic conditions. To measure the impact of market structure on bank profitability and risk taking, we used the Herfindahl–Hirschman Index (HHI; see Chen et al., 2017), which is measured as the sum of the squares of individual banks' market share in total banking assets, to proxy for the average concentration level of the banking sector. A HHI close to one indicates greater concentration.

In Table A1 of the Appendix, we present a detailed description of all the variables used in the current investigation, as well as the different sources of information used.

To analyse the research hypotheses III and VI, we first need to identify the different business models in European banking and, second, allocate each bank in our sample to one of the identified business models. For this purpose, following the methodology adopted by Hryckiewicz and Kozłowski (2017) and Roengpitya et al. (2017), we use k-median[8] clustering to assign each bank to a specific banking business model, given its asset and funding structure.

The objective of this k-median clustering is to group banks with similar asset and funding structures into the same cluster and those with different characteristics into different clusters. The k-median approach identifies a cluster by minimizing the differences between the individual financial variables of different banks using the Manhattan distance, as follows:

$$S = \sum_{k=1}^{K} \sum_{x_i \in C_k} \left| x_{ij} - med_{kj} \right| \tag{3}$$

where K is the number of clusters, x_{ij} is the observation of the j financial variables for bank i used in the cluster analysis, C_k is the k th cluster, and med_{kj} is the median cluster k. For our analysis, we perform the grouping based on earning asset structures and liability sources. Among bank asset structures, we distinguish the following positions: loans to customers and loans and advances to banks and trading securities, all scaled by bank total assets. Among bank funding sources, we distinguish between customer deposits and wholesale funding.[9] Additionally, because the adoption of NIRPs could cause banks to change their business model, we allow our sample banks to modify their banking business models throughout the sample period.

To ensure a good compromise between the homogeneity within each cluster and the number of clusters selected, we use the pseudo-*F*-index proposed by Calinski and Harabasz (1974) to help us decide.[10] To evaluate the robustness of clustering by considering how well the clusters are separated and how compact they are, we used the silhouette coefficient. This measure ranges from -1 to +1, where a high value indicates that the bank is well matched to its cluster and poorly matched to neighbouring clusters (Rousseeuw, 1987).

[7] In the risk taking model in which the dependent variable is the NPL ratio, for methodological reasons, this variable is not considered an explanatory variable.
[8] We prefer *k*-median clustering to *k*-mean clustering, because medians are less sensitive to outliers than means are.
[9] This item includes bank deposits, debt securities, repurchase agreements, and subordinated liabilities.
[10] We should select the number of clusters that maximize the pseudo-*F*-index.

3.3.1. Sample description and data statistics

In our investigation, we use an unbalanced panel data of European banks, covering the period from 2011 to 2019, from the following 29 countries: 18 countries that, at the end of 2019, belonged to the eurozone,[11] Bulgaria, Croatia, the Czech Republic, Denmark, Hungary, Norway, Poland, Romania, Sweden, Switzerland, and the United Kingdom. In these countries, six central banks adopted NIRPs. Table 1 summarizes information on the date and level of the policy rates at which the six central banks first adopted an NIRP.

Specific information about bank variables was obtained from Moody's Analytics BankFocus, with all data converted to euros.[12] Historical information about the short-term interest rate, the 10-year Treasury yield, the GDP growth rate, and the inflation rate were obtained from Thomson Datastream. Finally, the HHI is computed using data on banks' total assets available from Moody's Analytics BankFocus database.

After excluding banks missing data or with implausible data for the variables used, we obtain a final unbalanced panel data sample of 2596 banks,[13] with 15,119 bank–year observations, 8743 corresponding to the period after the implementation of NIRPs by the central banks.

The descriptive statistics of the variables used in the main regressions are reported in Table 2, distinguishing the pre-NIRP period from the NIRP period. As we can see, the adoption of NIRPs by several central banks in Europe resulted in a considerable decrease in short-term interest rates. Namely, on average, short-term interest rates fell by 143.1 basis points (bps), from 1.142 % to -0.289 %. There was also a sharp decline in long-term interest rates from the pre-NIRP period to the NIRP period, smoothing the yield curve, with its slope's mean value decreasing from 2.456 to 1.375. This latter movement can be explained by the various asset purchase programs implemented by several central banks during the period under analysis.

Because of the decrease in short-term interest rates and the slope of the yield curve, the mean value of the net interest margin decreased by 39.9 bps from the pre-NIRP period to the NIRP period, from 2.289 % to 1.890 %. The mean value of the ROA registered only a slight decrease, from 0.386 % to 0.342 %, from one period to the other. This less pronounced decrease in the ROA can be partly explained by a less severe loan loss provision policy and an increase in the mean value of other operating revenues: the mean value of loan loss provisions relative to total assets decreased from 0.365 % in the period pre-NIRP to 0.204 % in the NIRP period, while the other operating revenues in total assets increased from 0.223 % to 0.360 %.

Looking at risk taking measures, we can conclude that banks took on less risk in the NIRP period. From the pre-NIRP period to the NIRP period, the mean value of the natural logarithm of the Z-score, a proxy for overall bank risk, increased from 4.283 to 4.737. The mean value of the NPL ratio, a proxy for credit risk, decreased from 6.759 % to 5.343 % from the pre-NIRP period to the NIRP period. Lastly, the mean value of the ratio of RWA to total assets also decreased, which indicates that, on average, banks adopted less risky investment strategies in the NIRP period. Thus, the preliminary evidence does not allow us to conclude that bank risk taking increased with the implementation of NIRPs.

To test for the existence of unit roots in the variables of the panel data, we consider the battery of tests proposed by Choi (2001). Because our panel data are unbalanced and contain gaps, we perform the unit-root Fisher test.[14] The results allow us to reject the null hypothesis of all panels containing unit roots and to conclude that all the series are stationary at least for some panels.

4. Effects of negative interest rates on bank profitability

In this section, we present the estimation results of Eqs. (1) and (2) that allow us to analyse the effects of NIRP adoption on the profitability of European banks. Table 3 shows the results for the net interest margin and the ROA. The analysis of columns (1) and (3), namely, the estimation results obtained for the parameter β_3, allow us to conclude that, in the European countries where NIRPs were implemented, banks' net interest margin, as well their overall profitability, measured by their ROA, suffered substantial reductions, corroborating our research hypothesis I. We can conclude that, in the NIRP period, the net interest margin and the ROA decreased, on average, by 14.5 bps and 18.5 bps, respectively, in line with the results obtained by Campmas (2020).

Looking at the other items that influence overall profitability (see the estimation results for parameter β_3 in columns (1) and (3) of Tables A2 and A3 in the Appendix), we can conclude that the adoption of NIRPs raised the weight of fees and commissions charged by banks. Contrary to our expectations, in countries where NIRPs were implemented, the weight of net trading income on total assets decreased and the weight of loan loss provisions increased. These results could be a consequence of a tightening in the regulation rules by the European regulatory authorities in the last decade, requiring greater provisioning and less risky investment strategies. The adoption of an NIRP was not shown to have a statistically significant impact on the weight of other operating income in a bank's total assets.

Turning our attention to the effect that changes in short-term interest rates can have on the net interest margin and overall profitability, we conclude that this effect differs depending on whether an NIRP was implemented or not (see the results of the hy-

[11] We did not include the banks of Estonia, because some macroeconomic data were not available.

[12] We consider all commercial banks, savings banks, real estate and mortgage banks, cooperative banks, and bank holdings and holding companies with at least two years of data. We consider consolidated accounts when available, and unconsolidated accounts for individual banks. We exclude all domestic bank subsidiaries (to avoid data duplication) and holding companies with residual bank activity.

[13] Note that the sample used is dominated by German banks, which represent 48.57% of the total number of banks, followed by Italian banks, with 16.80%.

[14] To carry out this test, different versions can be used. This research uses the P_m statistic. For more details, see Choi (2001).

Table 2
Descriptive statistics.

	Pre-NIRP period					NIRP period						
Variables	Obs.	Mean	S.D.	Min	Max	Obs.	Mean	S. D.	Min	Max	*t*-Test	Unit-root Fisher test
Panel A: Bank profitability measures and items												
Net interest margin	6376	2.289	0.842	0.190	8.400	8743	1.890	0.669	0.150	8.440	−31.345***	48.844***
ROA	6376	0.386	0.677	−7.650	7.070	8743	0.342	0.792	−9.450	57.910	−3.684***	48.435***
Panel B: Items that influence bank profitability												
Net fees and commissions	6376	0.670	0.885	−1.852	38.416	8743	0.683	0.651	−0.681	21.429	0.977	66.089***
Net trading income	6376	0.168	0.469	−1.891	13.193	8743	0.117	0.385	−2.271	11.452	−7.025***	46.192***
Other operating revenues	6376	0.223	0.427	−2.364	9.731	8743	0.360	5.050	−3.851	401.989	2.529***	27.952***
Loan loss provisions	6376	0.365	0.746	−5.060	10.450	8743	0.204	0.515	−2.99	17.12	−14.873***	78.236***
Panel C: Bank risk taking measures												
Ln(Z-score)	6376	4.283	1.784	−2.407	41.686	8743	4.737	1.871	−2.305	41.734	15.122***	79.661***
NPL ratio	6376	6.759	7.195	0.000	58.730	8743	5.343	7.376	0.000	100.000	−11.820***	38.725***
RWA/total assets	6376	56.787	14.484	0.040	99.870	8743	53.066	13.648	5.880	97.880	−15.980***	54.152***
Panel D: Interest rate environment measures												
Short-term interest rate	146	1.142	1.243	−0.027	6.867	109	−0.289	0.178	−0.955	−0.013	−13.724***	63.636***
Slope of the yield curve	146	2.456	2.794	−0.569	23.064	109	1.375	1.468	0.070	10.252	−3.993***	123.249***
Panel E: Bank-specific variables												
Size	6376	7.097	2.044	2.944	14.588	8743	6.904	1.880	2.398	14.588		60.770***
Capitalization	6376	9.577	3.622	0.180	69.300	8743	10.189	3.655	0.900	67.540		46.542***
Inefficiency	6376	65.752	13.337	6.430	99.930	8743	69.745	12.267	13.700	100.000		71.299***
Liquidity	6376	20.961	15.314	0.230	94.680	8743	19.936	15.651	0.310	87.320		67.848***
Share of wholesale funding	6376	25.398	17.757	0.000	96.030	8743	18.805	14.936	0.000	99.130		72.830***
Asset composition	6376	62.198	15.637	2.540	97.830	8743	61.461	14.943	4.850	98.230		39.340***
Non-interest income share	6376	32.608	12.639	0.030	98.800	8743	37.243	12.714	0.200	99.090		56.061***
Panel F: Country variables												
Real GDP growth	146	1.637	2.532	−9.132	8.706	109	2.852	2.788	−0.438	25.163		72.165***
Inflation	146	1.719	1.487	−1.545	5.789	109	0.955	1.016	−1.736	3.723		82.448***
HHI	146	0.105	0.064	0.027	0.388	109	0.125	0.070	0.025	0.316		24.254***

Note: The table shows the variable descriptive statistics. Panel A provides information on bank profitability, Panel B lists information about items that influence bank profitability, Panel C contains information on bank risk taking, Panel D includes information about short-term interest rates and the yield curve, and Panel E reports bank-specific variables. Panel F shows the information on country-specific variables. The *t*-test refers to the sample value of the test statistic for comparing the means in the two periods analysed. The unit-root Fisher test, proposed by Choi (2001), is used to test the null hypothesis of all the panels containing unit roots against the alternative hypothesis of at least one panel being stationary. *, **, and *** indicate statistical significance at the 10 %, 5 % and 1 % levels, respectively.

Table 3
Effect of interest rates and NIRPs on the net interest margin and ROA.

	Net interest margin		Return on assets	
	(1)	(2)	(3)	(4)
L.Short-term interest rate	0.043	0.031	−0.300**	−0.337**
	(0.033)	(0.035)	(0.146)	(0.157)
L.Slope of the yield curve	−0.025**	−0.019**	0.051**	0.068**
	(0.010)	(0.010)	(0.023)	(0.027)
L.NIRP	−0.145***		−0.185***	
	(0.026)		(0.062)	
L.NIRP * Short-term interest rate		0.132**		0.529***
		(0.067)		(0.188)
L.NIRP * Slope of the yield curve		0.013		0.085
		(0.009)		(0.059)
L.Size	−0.325***	−0.329***	−0.298***	−0.297***
	(0.052)	(0.053)	(0.085)	(0.084)
L.Capitalization	0.003	0.003	0.010	0.012
	(0.007)	(0.007)	(0.010)	(0.011)
L.Inefficiency	−0.004***	−0.005***	0.001	0.000
	(0.001)	(0.001)	(0.003)	(0.003)
L.NPL ratio	0.005***	0.005**	−0.007	−0.009*
	(0.002)	(0.002)	(0.006)	(0.005)
L.Share of wholesale funding	−0.007***	−0.007***	0.001	0.002
	(0.001)	(0.001)	(0.005)	(0.005)
L.Asset composition	0.010***	0.010***	−0.011***	−0.010***
	(0.001)	(0.001)	(0.003)	(0.002)
L.Non-interest income share	−0.014***	−0.014***	−0.002	−0.002
	(0.001)	(0.001)	(0.002)	(0.002)
L.Real GDP growth	0.018***	0.018***	0.016*	0.009
	(0.005)	(0.005)	(0.009)	(0.011)
L.Inflation	0.033***	0.034***	−0.001	−0.005
	(0.007)	(0.007)	(0.021)	(0.024)
L.HHI	−0.518**	−1.256***	0.575	−0.620
	(0.248)	(0.208)	(0.576)	(0.422)
Constant	4.526***	4.519***	3.251***	3.163***
	(0.418)	(0.420)	(0.716)	(0.694)
Research hypotheses:				
H1[$\beta_3 = 0$]	−5.475***		−2.966***	
H2[$\alpha_3 - \alpha_4 = 0$]		1.735**		2.269**
Additional hypotheses:				
$\alpha_1 - \alpha_2 = 0$		1.511		−2.675***
$\alpha_1 - \alpha_2 + \alpha_3 - \alpha_4 = 0$		2.989***		0.422
Number of observations	12,050	12,050	12,050	12,050
Number of banks	2562	2562	2562	2562
R-Squared	0.497	0.492	0.027	0.030
F-Test	206.66***	191.44***	5.71***	5.10***

Note: This table shows the results of the effects of the adoption of NIRPs and interest rates on banks' net interest margins and ROA. In all regressions, explanatory variables are lagged one period (L is a lag operator), and we include bank and time fixed effects to attenuate potential endogeneity issues. Rows "Research hypotheses" and "Additional hypotheses" report the t-statistics for the respective null hypotheses. Robust standard errors clustered at the bank level are reported below their coefficient estimates. *, **, and *** indicate statistical significance at the 10 %, 5 % and 1 % levels, respectively.

pothesis testing that $\alpha_3 - \alpha_4 = 0$ in columns (2) and (4) of Table 3). This validates our research hypothesis II, and these results are in line with those of Claessens et al. (2018) in a study on the effect of short-term interest rates on the net interest margin and the ROA, distinguishing between low– and high–interest rate environments. Namely, it can be concluded that an additional decrease in short-term interest rates in the NIRP period had a negative impact on banks' net interest margins. Nonetheless, this impact was not statistically significant in the pre-NIRP period (see the additional hypothesis rows in Table 3). Regarding the effect of a decrease in short-term interest rates on overall profitability, as measured by the ROA, we conclude that this effect was positive in the pre-NIRP period, not being statistically significant in the NIRP period. This is because, during the NIRP period, banks faced with a decrease in short-term interest rates and offset the decrease in the net interest margin and the increase in provisions for loan losses with increases in net fees and commissions (see the additional hypothesis rows in Tables A2 and A3 in the Appendix). In the pre-NIRP period, the increase in ROA motivated by the decrease in short-term interest rates is partially explained by the decrease in loan loss provisions, given the lower probability of default of borrowers when the interest rates dropped.

The other items net trading income and other operating revenues that could have an impact on the ROA as a result of a change in short-term interest rates did not prove to be statistically significant, neither in the pre-NIRP period nor in the NIRP period (see the additional hypothesis rows in Tables A2 and A3 of the Appendix).

Table 4
Effect of interest rates and NIRPs on bank risk taking.

	Ln(Z-score)		NPL ratio		RWA/total assets	
	(1)	(2)	(3)	(4)	(5)	(6)
L.Short-term interest rate	−0.045	−0.050	1.029**	1.117**	1.030**	1.131**
	(0.031)	(0.033)	(0.487)	(0.537)	(0.458)	(0.461)
L.Slope of the yield curve	0.018**	0.014**	−0.641***	−0.715***	0.977***	0.725***
	(0.007)	(0.007)	(0.149)	(0.167)	(0.207)	(0.185)
L.NIRP	−0.015		0.269		0.666	
	(0.014)		(0.320)		(0.417)	
L.NIRP * Short-term int.rate		0.037		−1.425*		−2.747***
		(0.040)		(0.824)		(0.912)
L.NIRP * Slope yield curve		−0.026***		−0.425***		−1.627***
		(0.007)		(0.164)		(0.254)
L.Size	−0.114***	−0.111***	0.132	0.129	0.412	0.491
	(0.027)	(0.027)	(0.493)	(0.498)	(0.853)	(0.866)
L.Capitalization	0.045***	0.043***	−0.042	−0.056	0.671***	0.615***
	(0.005)	(0.005)	(0.069)	(0.069)	(0.159)	(0.156)
L.Inefficiency	−0.001***	−0.001***	−0.029***	−0.028***	0.005	0.010
	(0.000)	(0.000)	(0.007)	(0.007)	(0.011)	(0.011)
L.NPL ratio	−0.004**	−0.003**			0.116***	0.153***
	(0.001)	(0.001)			(0.038)	(-0.04)
L.Share wholesale funding	0.001**	0.001	0.068***	0.064***	0.046**	0.028
	(0.001)	(0.001)	(0.011)	(0.011)	(0.020)	(0.020)
L.Asset composition	0.000	0.000	0.000	−0.003	0.274***	0.269***
	(0.001)	(0.001)	(0.014)	(0.014)	(0.028)	(0.027)
L.Non-interest income share	−0.001*	−0.001**	0.035***	0.034***	0.005	0.001
	(0.001)	(0.001)	(-0.01)	(-0.01)	(0.016)	(0.016)
L.Real GDP growth	0.002	0.005**	−0.174***	−0.134**	0.183**	0.326***
	(0.002)	(0.002)	(0.067)	(0.065)	(0.081)	(0.090)
L.Inflation	−0.002	0.000	−0.327***	−0.293***	0.020	(0.165)
	(0.004)	(0.004)	(0.092)	(0.097)	(0.140)	(0.141)
L.HHI	−0.373***	−0.240**	−17.632***	−14.218***	8.868*	22.062***
	(0.117)	(0.108)	(2.677)	(2.277)	(4.782)	(4.486)
Constant	5.091***	5.095***	5.906	6.371	21.499***	22.344***
	(0.222)	(0.223)	(3.966)	(4.023)	(7.425)	(7.586)
Research hypotheses:						
H4 $[\beta_3 = 0]$	−1.056		0,840		1.597	
H5 $[\alpha_3 - \alpha_4 = 0]$		1.510		−1.181		−1.205
Additional hypotheses:						
$\alpha_1 - \alpha_2 = 0$		−2.055**		3.597***		0.929
$\alpha_1 - \alpha_2 + \alpha_3 - \alpha_4 = 0$		−0.064		1.579		−0.816
Number of observations	12,050	12,050	12,050	12,050	12,050	12,050
Number of banks	2562	2562	2562	2562	2562	2562
R-Squared	0.204	0.209	0.182	0.186	0.238	0.252
F-Test	31.74***	36.73***	42.387***	44.126***	46.01***	48.41***

Note: This table shows the results of the effects of the adoption of NIRP and interest rates on bank risk taking. In all regressions, explanatory variables are lagged one period (L is a lag operator), and we include bank and time fixed effects to attenuate potential endogeneity issues. Rows "Research hypotheses" and "Additional hypotheses" report the t-statistics for the respective hypotheses. Robust standard errors clustered at the bank level are reported below their coefficient estimates. *, **, and *** indicate statistical significance at the 10 %, 5 %, and 1 % levels, respectively.

Discussing now the impact of the other control variables on bank profitability, we find a negative and statistically significant relationship between the net interest margin and the ROA with bank size, indicating that larger banks present lower levels of profitability. We also conclude that less efficient banks, where the wholesale funding share is greater and with high diversification in income sources, have lower net interest margins, in line with our expectations. Banks with a higher level of credit risk exposure have higher net interest margins as expected. Asset composition, measured by the weight of loans to customers in total assets, positively influences the net interest margin, but negatively influences the ROA. This means that banks more oriented towards lending to their customers have a lower ROA.

In terms of the effects that macroeconomic variables have on banks' net interest margins, we conclude that both economic growth and inflation have, as expected, a positive effect on the net interest margin. Contrary to expectations, we find that, in countries with higher levels of bank concentration, the net interest margin is lower. The macroeconomic variables considered in the study do not have a statistically significant influence on overall profitability.

5. Effects of negative interest rates on bank risk taking

Table 4 presents the estimation results of Eqs. (1) and (2) that allow for the analysis of the effect of the adoption of NIRPs on bank

Table 5
Business model identification based on banks' asset structures and their sources of financing.

Variable	Business model			
	Model I	Model II	Model III	Model IV
Variables used in the cluster analysis (% of total assets):				
Loans to customers	63.62	76.60	53.03	51.41
Loans and advances to banks	8.40	5.58	7.26	31.45
Trading securities	22.11	13.45	35.25	12.04
Customer deposits	43.40	72.06	76.89	77.46
Wholesale funding	41.69	15.58	10.80	9.74
Other variables (% of operational revenues except for total assets):				
Total assets (in millions €)	71,320	8419	3715	6744
Net interest margin	61.10	67.96	64.03	60.94
Net fees and commissions	22.49	21.30	22.70	26.17
Net trading income	10.54	1.67	3.17	3.18
Other operational revenues	5.87	9.07	10.11	9.71
Number of banks	**628**	**1288**	**1180**	**355**

Note: This table shows the mean values of the variables listed for each business model.

risk taking. As can be seen, regardless of the risk taking indicator considered, we verify that the adoption of NIRPs in some European countries did not have any impact on bank risk taking. These results do not allow us to validate our research hypothesis IV, indicating that the adoption of NIRPs in some countries in Europe did not lead banks to adopt riskier investment strategies.

The analysis of the estimation results presented in columns (2), (4), and (6) in Table 4 allows the following conclusions to be drawn:

15 In the pre-NIRP period, a decrease in short-term interest rates had a positive effect on the Z-score and a negative effect on the NPL ratio, both statistically significant at the 5 % significance level.[15] In the same period, the short-term interest rate did not have a statistically significant effect on the ratio of RWA to total assets. This means that, in an environment of low but positive interest rates, further decreases in short-term interest rates decrease the probability of default of borrowers on bank loans, decreasing credit risk, as measured by the NPL ratio and the solvency risk of the bank measured by the Z-score. In this context, there seems to be no evidence of the so-called search for yield effect and loosening lending standards.

16 In the NIRP period, a decrease in short-term interest rates has no statistically significant effect on the Z-score, NPL ratio, or the ratio of RWA to total assets.[16] This means that, in an environment of negative interest rates, additional decreases in short-term interest rates do not lead banks to take on more risk.

The conclusions above partially confirm research hypothesis V, since a decline in short-term interest rates, in a context in which they are still in positive territory, reduces the solvency and credit risks, while the same is not true when interest rates are in negative territory. However, when we test if $\alpha_3 - \alpha_4 = 0$, we do not reject the null hypothesis for the three indicators of risk taking used, allowing us to conclude that the effect of a change in interest rates on bank risk taking is not different, whether an NIRP is implemented or not. This contradiction in the results can be partly explained by the fact that, when short-term interest rates are positive, the slope is higher than when they are negative and by the presence of multicollinearity.

Looking at the effect of the other control variables on banks' risk taking, we can conclude that smaller banks, which are better capitalized, more efficient, less exposed to non-interest income and credit risk, show greater financial stability, as measured by the Z-score, which is in line with our expectations. We also conclude that banks that operate in more concentrated markets exhibit less financial stability.

Regarding exposure to credit risk, as measured by the NPL ratio, we conclude that the most efficient banks have lower credit risk, while banks with a higher share of wholesale funding and non-interest income are more exposed to default's risk. Economic growth, inflation, and increased banking concentration have a positive, statistically significant effect on credit risk, decreasing the NPL ratio.

Lastly, we can conclude that banks that are better capitalized, more exposed to credit risk, and with high loan-to-asset ratios follow riskier investment strategies, as measured by RWA over total assets. Higher economic growth and greater banking concentration also lead to greater risk taking by banks.

6. Effects of NIRPs on different bank business models

To study whether the effects of implementing an NIRP on profitability and risk taking depend on the business model adopted by the bank, we used the methodology described in Section 3. Based on banks' asset structures and their sources of financing, using cluster analysis, we conclude that the optimal number of business models to use in our sample is four. These four business models are characterized in Table 5 by the set of characteristics listed there. We designate the four business models as follows.

[15] The null hypothesis $\alpha_1 - \alpha_2 = 0$ is rejected at the 5% significance level for the Ln(Z-score) and NPL ratio variables.

[16] The null hypothesis $\alpha_1 - \alpha_2 + \alpha_3 - \alpha_4 = 0$ is not rejected at the 10% significance level for the variables Ln(Z-score), NPL ratio, and RWA to total assets.

Table 6
Effect of interest rates and NIRPs on the net interest margin and ROA by business model.

Bank business model	Explanatory variables	Net interest margin		Return on assets	
		(1)	(2)	(3)	(4)
Investment-oriented banks, type I	L.Short-term interest rate	0.129*	0.118	0.203**	0.223**
		(0.070)	(0.074)	(0.099)	(0.106)
	L.Slope of the yield curve	0.017	0.011	0.155***	0.148***
		(0.018)	(0.019)	(0.044)	(0.038)
	L.NIRP	0.095		−0.011	
		(0.058)		(0.082)	
	L.NIRP * Short-term interest rate		−0.066		−0.049
			(0.142)		(0.211)
	L.NIRP * Slope of the yield curve		0.029**		0.083**
			(0.014)		(0.038)
	Research hypotheses:				
	H1 $[\beta_3 = 0]$	1.639		−0.135	
	H2 $[\alpha_3 - \alpha_4 = 0]$		−0.661		−0.594
	Additional hypotheses:				
	$\alpha_1 - \alpha_2 = 0$		1.619		0.727
	$\alpha_1 - \alpha_2 + \alpha_3 - \alpha_4 = 0$		0.110		−0.327
	Number of observations	2481	2481	2481	2481
Retail-oriented banks	L.Short-term interest rate	−0.041	−0.061	0.050	0.044
		(0.047)	(0.049)	(0.079)	(0.088)
	L.Slope of the yield curve	−0.016	−0.012	0.036	0.045
		(0.021)	(0.021)	(0.062)	(0.060)
	L.NIRP	−0.163***		−0.055	
		(0.032)		(0.052)	
	L.NIRP * Short-term interest rate		0.155***		0.162
			(0.063)		(0.121)
	L.NIRP * Slope of the yield curve		−0.033*		0.139
			(0.017)		(0.103)
	Research hypotheses:				
	H1 $[\beta_3 = 0]$	−5.110***		−1.070	
	H2 $[\alpha_3 - \alpha_4 = 0]$		2.817***		0.188
	Additional hypotheses:				
	$\alpha_1 - \alpha_2 = 0$		−1.124		−0.006
	$\alpha_1 - \alpha_2 + \alpha_3 - \alpha_4 = 0$		2.231**		0.265
	Number of observations	4313	4313	4313	4313
Investment-oriented banks, type II	L.Short-term interest rate	0.042	0.013	−0.218	−0.301
		(0.066)	(0.069)	(0.197)	(0.224)
	L.Slope of the yield curve	−0.048***	−0.031	0.028	−0.010
		(0.018)	(0.019)	(0.047)	(0.049)
	L.NIRP	−0.226***		−0.279	
				(0.205)	
	L.NIRP * Short-term interest rate		0.062		0.488
			(0.181)		(0.367)
			0.040		−0.150***
			(0.027)		(0.048)
	Research hypotheses:				
	H1 $[\beta_3 = 0]$	−2.729***		−1.631	
	H2 $[\alpha_3 - \alpha_4 = 0]$		0.118		1.702*
	Additional hypotheses:				
	$\alpha_1 - \alpha_2 = 0$		0.679		−1.315
	$\alpha_1 - \alpha_2 + \alpha_3 - \alpha_4 = 0$		0.370		1.378
	Number of observations	4305	4305	4305	4305
Interbank lending–oriented banks	L.Short-term interest rate	0.207***	0.176***	−0.211	−0.302
		(0.057)	(0.067)	(0.256)	(0.253)
	L.Slope of the yield curve	0.017	0.051*	0.124	0.156**
		(0.029)	(0.030)	(0.075)	(0.075)
	L.NIRP	−0.322***		−0.326	
		(0.114)		(0.740)	
	L.NIRP * Short-term interest rate		0.596***		1.045
			(0.244)		(0.655)
	L.NIRP * Slope of the yield curve		−0.103***		−0.040
			(0.020)		(0.057)
	Research hypotheses:				
	H1 $[\beta_3 = 0]$	−2.825***		−0.441	
			2.870***		1.638

(*continued on next page*)

Table 6 (*continued*)

Bank business model	Explanatory variables	Net interest margin		Return on assets	
		(1)	(2)	(3)	(4)
	H2 $[\alpha_3 - \alpha_4 = 0]$				
	Additional hypotheses:				
	$\alpha_1 - \alpha_2 = 0$		1.631		−1.755*
	$\alpha_1 - \alpha_2 + \alpha_3 - \alpha_4 = 0$		3.786***		1.015
	Number of observations	951	951	951	951

Note: This table shows the (partial) results of the effects of the adoption of NIRPs and interest rates on banks' net interest margins and ROA by business model. In all regressions, explanatory variables are lagged one period (L is a lag operator), and we include bank and time fixed effects to attenuate potential endogeneity issues. Rows "Research hypothesis" and "Additional hypothesis" report the t-statistics for the respective hypotheses. Robust standard errors clustered at the bank level are reported below their coefficient estimates. *, **, and *** indicate statistical significance at the 10 %, 5 %, and 1 % levels, respectively.

- **Investment-oriented banks, type I (Model I):** Large banks with diversified funding sources that engage in substantial trading activities and whose trading income has a relatively high weight on operational revenues.
- **Retail-oriented banks (Model II)**: Midsize banks whose main source of financing is customer deposits and that are highly oriented towards lending to customers. Their major sources of operating revenues are net interest margins and net fees and commissions.
- **Investment-oriented banks, type II (Model III)**: Small banks whose main source of financing is customer deposits and that engage in substantial trading activities. Their major sources of operating revenues are net interest margins and net fees and commissions.
- **Interbank lending–oriented banks (Model IV)**: Midsize banks whose main source of financing is customer deposits and that are highly oriented towards lending to other banks. Their major sources of operating revenues are net interest margins and net fees and commissions.

After identifying the different bank business models in our sample, we study the effects of the implementation of NIRPs on the profitability and risk taking of each model. Regarding the effects of short-term interest rates and NIRPs on profitability, Table 6 reports the (partial) estimation results of Eqs. (1) and (2) for the net interest margin (columns (1) and (2)) and the ROA (columns (3) and (4).

Looking at the effects of the implementation of NIRPs in some European countries, we can conclude that, except for investment-oriented banks (type I), all other banks saw their net interest margin decrease (in columns (1) and (3) of Table 6, see the results for the hypothesis test of $\beta_3 = 0$). In particular, it appears that the greater the weight of customer deposits in the bank's financing, the greater the negative impact on the bank's net interest margin. In interbank lending–oriented banks, where customer deposits represent, on average, 77.46 % of funding sources and loans and advances to banks represent 31.45 % of investments, the net interest margin, on average, dropped by 32.2 bps as a result of the implementation of the NIRP. This happened because banks that adopt this business model were forced to lower interest rates on bank loans without being able to lower interest rates on customer deposits, given their reluctance to lower the latter to negative values. It can also be seen that, when interest rates are already in negative territory, an additional drop puts greater pressure on the net interest margin of retail- and interbank lending–oriented banks (in columns (2) and (4) of Table 6, see the results for the hypothesis test of $\alpha_1 - \alpha_2 + \alpha_3 - \alpha_4 = 0$).

In analysing the effect of interest rates and NIRPs on overall profitability, as measured by the ROA, there seems to be no difference between the pre-NIRP period and the NIRP period across different bank business models.[17]

Table 7 reports the (partial) estimation results of Eqs. (1) and (2) for the effects of short-term interest rates and NIRPs on bank risk taking. Looking at the research and additional hypothesis rows in columns (1) and (2), we can conclude that the adoption of NIRPs did not affect banks' financial stability, as measured by the Z-score, regardless of their business model. Only for interbank lending–oriented banks can we conclude that the effect of short-term interest rates on banks' financial stability, as measured by the Z-score, differs depending on whether an NIRP was implemented or not. Namely, we find that decreases in short-term interest rates increase financial stability when these rates are positive and have no impact when they are already negative.

We also conclude that the adoption of NIRPs did not have a different impact on the credit risk of the different bank business models identified (see the research hypothesis and additional hypothesis rows in columns (3) and (4) of Table 7). Only for investment-oriented banks of type II and for interbank lending–oriented banks can we conclude that a decrease in short-term interest rates causes a decrease in credit risk when interest rates are positive, which does not happen when they are already negative. For investment-oriented banks of type I, we can conclude that, when the interest rates are negative, a decrease in short-term interest rates leads to a decrease in credit risk. However, the same is not true when the interest rates are positive.

Lastly, looking at column (5) of Table 7, we can conclude that, in the NIRP period, investment-oriented banks (type I) and interbank

[17] For the four bank business models considered, we concluded that, for the conventional significance levels, the null hypothesis of $\beta_3 = 0$ is not rejected. The hypothesis of $\alpha_3 - \alpha_4 = 0$ is only rejected if we consider a significance level of 10% and for Investment-oriented banks type II. For the others business models, that hypothesis was never rejected [in columns (2) and (4) of Table 6, see results for the hypothesis tests of $\alpha_3 - \alpha_4 = 0$].

Table 7
Effect of interest rates and NIRPs on bank risk taking by business model.

Business model	Explanatory variables	Ln(Z-score)		NPL ratio		RWA/total assets	
		(1)	(2)	(3)	(4)	(5)	(6)
Investment-oriented banks, type I	L.Short-term interest rate	0.014	0.014	−1.032	−1.291	0.414	0.438
		(0.020)	(0.020)	(0.725)	(0.799)	(1.002)	(1.000)
	L.Slope of the yield curve	0.023*	0.024*	−1.811***	−1.803***	0.383	0.324
		(0.012)	(0.013)	(0.273)	(0.259)	(0.474)	(0.501)
	L.NIRP	−0.007		−0.066		2.780***	
		(0.031)		(0.618)		(1.008)	
	L.NIRP * Short-term interest rate		−0.001		2.245		−5.882***
			(0.078)		(1.752)		(2.579)
	L.NIRP * Slope of the yield curve		−0.014		0.142		−0.681
			(0.014)		(0.274)		(0.477)
	Research hypotheses:						
	H3 $[\beta_3 = 0]$	−0.220		−0.108		2.757***	
	H4 $[\alpha_3 - \alpha_4 = 0]$		0.162		1.188		−1.997**
	Additional hypotheses:						
	$\alpha_1 - \alpha_2 = 0$		−0.063		0.659		0.133
	$\alpha_1 - \alpha_2 + \alpha_3 - \alpha_4 = 0$		0.035		1.762*		−2.041**
	Number of observations (Banks)	2481	2481	2481	2481	2481	2481
Retail-oriented banks	L.Short-term interest rate	0.026	0.027	0.088	0.013	1.311***	1.125*
		(0.018)	(0.021)	(0.418)	(0.493)	(0.641)	(0.682)
	L.Slope of the yield curve	0.022*	0.021*	−0.028	−0.041	0.835***	0.759**
		(0.013)	(0.012)	(0.325)	(0.329)	(0.360)	(0.363)
	L.NIRP	0.008		−0.136		−0.960*	
		(0.012)		(0.254)		(0.531)	
	L.NIRP * Short-term interest rate		−0.029		0.282		−0.064
			(0.025)		(0.640)		(1.035)
	L.NIRP * Slope of the yield curve		−0.022*		−0.269		−1.983***
			(0.013)		(0.252)		(0.436)
	Research hypotheses:						
	H3 $[\beta_3 = 0]$	0.710		−0.536		−1.807*	
	H4 $[\alpha_3 - \alpha_4 = 0]$		−0.253		0.816		1.700*
	Additional hypotheses:						
	$\alpha_1 - \alpha_2 = 0$		0.339		0.122		0.562
	$\alpha_1 - \alpha_2 + \alpha_3 - \alpha_4 = 0$		−0.040		1.359		2.265**
	Number of observations	4313	4313	4313	4313	4313	4313
Investment-oriented banks, type II	L.Short-term interest rate	−0.021	−0.042	1.089	1.307*	−0.488	−0.639
		(0.050)	(0.060)	(0.681)	(0.740)	(0.707)	(0.684)
	L.Slope of the yield curve	0.016	−0.004	−0.217	−0.265	1.421***	0.874**
		(0.012)	(0.012)	(0.305)	(0.321)	(0.404)	(0.409)
	L.NIRP	−0.070		0.896		−0.019	
		(0.058)		(1.107)		(0.677)	
	L.NIRP * Short-term interest rate		0.031		−2.164		−2.150
			(0.099)		(2.086)		(1.837)
	L.NIRP * Slope of the yield curve		−0.073***		−0.121		−1.941***
			(0.013)		(0.284)		(0.431)
	Research hypotheses:						
	H3 $[\beta_3 = 0]$	−1.202		0.809		−0.028	
	H4 $[\alpha_3 - \alpha_4 = 0]$		1.014		−0.969		−0.118
	Additional hypotheses:						
	$\alpha_1 - \alpha_2 = 0$		−0.705		2.541**		−2.306**
	$\alpha_1 - \alpha_2 + \alpha_3 - \alpha_4 = 0$		1.046		−0.265		−0.992
	Number of observations	4305	4305	4305	4305	4305	4305
Interbank lending–oriented banks	L.Short-term interest rate	−0.016	−0.029	3.942***	4.266***	0.501	2.091
		(0.053)	(0.056)	(1.937)	(2.312)	(1.379)	(1.843)
	L.Slope of the yield curve	0.057**	0.068**	−0.533	−0.468	2.170*	2.122*
		(0.026)	(0.027)	(0.488)	(0.489)	(1.121)	(1.171)
	L.NIRP	−0.107		−0.782		4.865**	
		(0.113)		(2.824)		(2.246)	
	L.NIRP * Short-term interest rate		0.207*		−2.387		−9.640
			(0.112)		(6.293)		(6.132)
	L.NIRP * Slope of the yield curve		−0.029**		−0.540		−1.471***
			(0.014)		(0.349)		(0.543)
	Research hypotheses:						
	H3 $[\beta_3 = 0]$	−0.953		−0.277		2.166**	
			1.994**		−0.294		−1.338

(*continued on next page*)

Table 7 (*continued*)

Business model	Explanatory variables	Ln(Z-score)		NPL ratio		RWA/total assets	
		(1)	(2)	(3)	(4)	(5)	(6)
	H4 $[\alpha_3 - \alpha_4 = 0]$						
	Additional hypotheses:						
	$\alpha_1 - \alpha_2 = 0$		−1.710*		1.954*		−0.014
	$\alpha_1 - \alpha_2 + \alpha_3 - \alpha_4 = 0$		1.455		0.616		−1.429
	Number of observations	951	951	951	951	951	951

Note: This table shows the partial results of the effects of the adoption of NIRPs and interest rates on bank risk taking by business model. In all regressions, explanatory variables are lagged one period (L is a lag operator), and we include bank and time fixed effects to attenuate potential endogeneity issues. Rows "Research hypotheses" and "Additional hypotheses" report the t-statistics for the respective hypotheses. Robust standard errors clustered at the bank level are reported below their coefficient estimates. *, **, and *** indicate statistical significance at the 10 %, 5 %, and 1 % levels, respectively.

lending–oriented banks adopted riskier investment strategies,[18] in line with the idea of search for yield presented by Rajan (2005). On the contrary, in the NIRP period, retail-oriented banks implemented less risky strategies. Regarding column (6), we also verify that, when interest rates are already in negative territory, an additional drop leads investment-oriented banks (type I) to increase their risk exposure, while retail-oriented banks reduce their risk exposure.[19] When interest rates are in positive territory, we verify that, if short-term interest rates decline, investment-oriented banks of type II increment their risk exposure.[20]

From the analysis, we can conclude for research hypotheses III and VI that the effect of an NIRP on the net interest margin and the risk associated with the investment strategy adopted, measured by the RWA to total assets, is influenced by the business model adopted by the bank. With regard to overall profitability, credit risk, and financial stability, that dependency is not so evident.

7. Conclusions

Since 2012, several central banks have implemented NIRPs, with the intention of boosting economic activity and fighting low inflation rates, by facilitating an increase in the supply of bank loans. These policies generated controversy, with the most sceptical pointing to several factors that could affect bank financial stability and raising doubts about the transmission mechanism from negative policy rates to higher levels of bank lending.

This investigation studies the effect of negative interest rates on bank profitability and risk taking. Using a sample of 2596 banks from European countries over the period 2011–2019, we conclude that NIRP implementation lowered the net interest margin of a representative bank by 14.5 bps. Despite the rise in the weight of fees and commissions charged by banks, the decrease of the weight of net trading income and the increase of the weight of loan loss provisions led the overall profitability of a representative bank, as measured by the ROA, to decrease by 18.5 bps.

We also conclude that, when interest rates were already negative, a decrease in short-term interest rates lowered the net interest margin, but did not affect the ROA. In this scenario, banks tried to compensate for the decrease in the net interest margin with a more pronounced increase in net fees and commissions. When interest rates were in positive territory, decreases in short-term interest did not affect the net interest margin, but increased the ROA, given the lower loan loss provisions.

Despite the negative effect that the implementation of NIRP had on the net interest margin, we do not find that European banks, on average, increased risk taking. We also conclude that, in an environment of negative interest rates, additional decreases in short-term interest rates did not lead banks to take on more risk; that is, there is no evidence of the search for yield effect.

Based on banks' asset structures and their sources of financing, using cluster analysis, we identify four different business models: investment-oriented banks (type I), retail-oriented banks, investment-oriented banks (type II), and interbank lending–oriented banks.

Our study leads us to conclude that, except for investment-oriented banks (type I), all other banks saw their net interest margin decrease with the implementation of NIRPs. This is particularly true for those banks whose main source of finance was retail deposits. We also conclude that, when interest rates were already in negative territory, an additional drop put greater pressure on the net interest margin of retail- and interbank lending–oriented banks. Looking at the effect of interest rates and NIRPs on the ROA, we find no differences between the pre-NIRP period and the NIRP period across different bank business models.

The analysis also allows us to conclude that the implementation of NIRPs did not affect bank financial stability or credit risk, regardless of the bank business model. Lastly, we conclude that investment-oriented banks (type I) and interbank lending–oriented banks adopted riskier investment strategies, while retail-oriented banks adopted less risky investment strategies.

The empirical results of this study suggest that the regulatory and supervisory entities of European banking systems should give special emphasis to the monitoring of the profitability and risk taking of those bank that were the most affected by the introduction of NIRPs.

[18] For these two groups of banks, we conclude that the parameter β_3 is statistically significant and its estimate is positive, which allows us to conclude that those banks in the NIRP period adopted riskier investment strategies.

[19] For these two groups of banks and for conventional significance levels, we reject the null hypothesis of $\alpha_1 - \alpha_2 + \alpha_3 - \alpha_4 = 0$.

[20] For this group of banks and for conventional significance levels, we reject the null hypothesis of $\alpha_1 - \alpha_2 = 0$.

Data availability

Data will be made available on request.

Author statement

Celia López Penabad: Conceptualization, Formal analysis, Visualization, Supervision, Validation, Writing-Reviewing and Editing. Ana Iglesias Casal: Conceptualization, Methodology, Supervision, Formal analysis, Visualization, Writing-Reviewing and Editing. José Fernando Silva Neto: Conceptualization, Writing-Original draft preparation, Data curation, Software, Formal Analysis.

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Appendix A

Table A1
Variables definitions and data sources.

Variable	Units	Description	Source
Bank profitability:			
Net interest margin	percentage	Difference between interest-earning assets and interest-bearing liabilities, divided by total earning assets	BankFocus database
Return on assets	percentage	Net income divided by total assets	BankFocus database
Net fees and commissions	percentage	Net fees and commissions divided by total assets	BankFocus database
Net trading income	percentage	Net trading income divided by total assets	BankFocus database
Other operating revenues	percentage	Other operating revenues divided by total assets	BankFocus database
Loan loss provisions	percentage	Loan loss provisions divided by total assets	BankFocus database
Bank risk-taking:			
Ln(Z-score)	logarithm	The Z-score is computed as the ratio between the ratio of the sum of the expected ROA and equity to total assets and the standard deviation of the ROA	BankFocus database and own calculations
NPL ratio	percentage	NPL divided by gross loans	BankFocus database
RWA/Total assets	percentage	RWA divided by total assets	BankFocus database
Bank-specific variables:			
Size	logarithm	Natural logarithm of total assets	BankFocus database
Capitalization	percentage	Equity divided by total assets	BankFocus database
Inefficiency	percentage	Cost-to-income ratio, computed as the ratio of operating expenses on the net operating income	BankFocus database
Liquidity	percentage	Liquid assets divided by total assets	BankFocus database
Share of wholesale funding	percentage	Wholesale funding divided by total funding	BankFocus database
Asset composition	percentage	Loans and advances to customers divided by total assets	BankFocus database
Non-interest income share	percentage	Non-interest income divided by operating revenues	BankFocus database
Interest rate environment measures:			
Short-term interest rate	percentage	3-month interbank rate	Thomson Datastream
Slope of yield curve	percentage	Difference between the 10-year Treasury yield and the 3-month interbank rate	Thomson Datastream
NIRP	Dummy variable	Takes the value of 1 if an NIRP was adopted, and 0 otherwise	Central banks
Country variables:			
Real GDP growth	percentage	Yearly growth rate of the real GDP	Thomson Datastream
Inflation	percentage	Yearly growth rate of the consumer price index	Thomson Datastream
HHI (assets)	units	Measure of market concentration	BankFocus database and own calculations

Table A2
Effect of interest rates and NIRPs on net fees and commission income and net trading income.

	Net fees and commissions		Net trading income	
	(1)	(2)	(3)	(4)
L.Short-term interest rate	0.012	0.025	0.027	0.027
	(0.014)	(0.015)	(0.020)	(0.021)
L.Slope of the yield curve	0.005	0.003	0.031***	0.017*
	(0.007)	(0.007)	(0.009)	(0.009)
L.NIRP	0.081***		−0.052***	
	(0.022)		(0.017)	
L.NIRP * Short-term interest rate		−0.134***		−0.125***
		(0.038)		(0.042)
L.NIRP * Slope of the yield curve		0.007		−0.106***
		(0.009)		(0.015)
L.Size	−0.055	−0.056*	0.043	0.045
	(0.034)	(0.034)	(0.050)	(0.048)
L.Capitalization	0.015	0.015	0.014**	0.010*
	(0.015)	(0.015)	(0.006)	(0.006)
L.Inefficiency	0.000	0.000	−0.002***	−0.002***
	(0.001)	(0.001)	(0.000)	(0.000)
L.NPL ratio	0.004**	0.004**	−0.004*	−0.002
	(0.002)	(0.002)	(0.002)	(0.002)
L.Share of wholesale funding	−0.003**	−0.003**	−0.021***	−0.011**
	(0.001)	(0.001)	(0.005)	(0.004)
L.Asset composition	0.000	0.000	−0.003**	−0.003**
	(0.001)	(0.001)	(0.001)	(0.001)
L.Non-interest income share	0.001**	0.002**	0.005***	0.004***
	(0.001)	(0.001)	(0.001)	(0.001)
L.Real GDP growth	0.007*	0.005	−0.021***	−0.011**
	(0.004)	(0.004)	(0.005)	(0.004)
L.Inflation	0.003	0.001	−0.030***	−0.019***
	(0.004)	(0.005)	(0.006)	(0.006)
L.HHI	−0.065	0.211	−0.538***	−0.123
	(0.257)	(0.194)	(0.163)	(0.138)
Constant	0.819***	0.829***	−0.122	−0.063
	(0.292)	(0.293)	(0.410)	(0.403)
Research hypotheses:				
H1[$\beta_3 = 0$]	3.727***		−3.048***	
H2[$\alpha_3 - \alpha_4 = 0$]		−3.723***		−0.458
Additional hypotheses:				
$\alpha_1 - \alpha_2 = 0$		1.474		0.500
$\alpha_1 - \alpha_2 + \alpha_3 - \alpha_4 = 0$		−3.350***		−0.256
Number of observations	12,050	12,050	12,050	12,050
Number of banks	2562	2562	2562	2562
R-Squared	0.038	0.037	0.102	0.126
F-Test	11.83***	11.06***	23.71***	25.70***

Note: This table shows the results of the effects of the adoption of NIRPs and interest rates on net fees and commissions income and net trading income. In all regressions, explanatory variables are lagged one period (L is a lag operator), and we include bank and time fixed effects to attenuate potential endogeneity issues. Rows "Research hypotheses" and "Additional hypotheses" report the t-statistics for the respective hypotheses. Robust standard errors clustered at the bank level are reported below their coefficient estimates. *, **, and *** indicate statistical significance at the 10 %, 5 %, and 1 % levels, respectively.

Table A3
Effect of interest rates and NIRPs on other operating revenues and loan loss provisions.

	Other operating revenues		Loan loss provisions	
	(1)	(2)	(3)	(4)
L. Short-term interest rate	−0.121	−0.140	0.298***	0.342***
	(0.106)	(0.123)	(0.095)	(0.100)
L.Slope of the yield curve	−0.206	−0.222	−0.013	−0.041*
	(0.163)	(0.175)	(0.021)	(0.024)
L.NIRP	−0.321		0.103**	
	(0.239)		(0.049)	
L.NIRP * Short-term interest rate		−0.003		−0.748***
		(0.075)		(0.139)
L.NIRP * Slope of the yield curve		−0.176		−0.180***

(*continued on next page*)

Table A3 (*continued*)

	Other operating revenues		Loan loss provisions	
	(1)	(2)	(3)	(4)
		(0.131)		(0.057)
L.Size	−0.159*	−0.160*	0.259***	0.254***
	(0.082)	(0.082)	(0.082)	(0.080)
L.Capitalization	0.003	−0.003	0.008	0.003
	(0.005)	(0.009)	(0.012)	(0.013)
L.Inefficiency	0.003***	0.003***	−0.003***	−0.003***
	(0.001)	(0.001)	(0.001)	(0.001)
L.NPL ratio	0.001	0.004	0.000	0.004
	(0.002)	(0.003)	(0.006)	(0.005)
L.Share of wholesale funding	0.003	0.002	0.009***	0.007***
	(0.003)	(0.002)	(0.002)	(0.003)
L.Asset composition	0.000	−0.002	0.013***	0.012***
	(0.002)	(0.002)	(0.003)	(0.002)
L.Non-interest income share	0.001	−0.001	−0.001	−0.001
	(0.001)	(0.003)	(0.001)	(0.001)
L.Real GDP growth	−0.155	−0.136	−0.031***	−0.014*
	(0.119)	(0.105)	(0.007)	(0.008)
L.Inflation	0.087	0.109	−0.012	0.003
	(0.068)	(0.084)	(0.018)	(0.017)
L.HHI	8.890	8.530	−0.686*	0.636*
	(6.836)	(6.561)	(0.388)	(0.361)
Constant	1.265**	1.359**	−2.484***	−2.322***
	(0.597)	(0.655)	(0.695)	(0.669)
Research hypotheses:				
H1 $[\beta_3 = 0]$	−1.340		2.079**	
H2 $[\alpha_3 - \alpha_4 = 0]$		1.022		−4.145***
Additional hypotheses:				
$\alpha_1 - \alpha_2 = 0$		1.386		3.862***
$\alpha_1 - \alpha_2 + \alpha_3 - \alpha_4 = 0$		1.157		−2.323**
Number of observations	12,050	12,050	12,050	12,050
Number of banks	2562	2562	2562	2562
R-Squared	0.007	0.008	0.095	0.123
F-Test	2.00***	2.02***	16.61***	16.69***

Note: This table shows the results of the effects of the adoption of NIRPs and interest rates on other operating revenues and loan loss provisions. In all regressions, explanatory variables are lagged one period (L is a lag operator), and we include bank and time fixed effects to attenuate potential endogeneity issues. Rows "Research hypotheses" and "Additional hypotheses" report the t-statistics for the respective hypotheses. Robust standard errors clustered at the bank level are reported below their coefficient estimates. *, **, and *** indicate statistical significance at the 10 %, 5 %, and 1 % levels, respectively.

References

Adrian, T., Shin, H.S., 2009. Money, liquidity, and monetary policy. Am. Econ. Rev. 99 (2), 600–605. https://doi.org/10.1257/aer.99.2.600.

Adrian, T., Estrella, A., Shin, H.S., 2010. Monetary Cycles, Financial Cycles and the Business Cycle. SSRN Scholarly Paper ID 1532309. https://doi.org/10.2139/ssrn.1532309.

Alessandri, P., Nelson, B.D., 2015. Simple banking: profitability and the yield curve. J. Money Credit Bank. 47 (1), 143–175. https://doi.org/10.1111/jmcb.12172.

Altavilla, C., Boucinha, M., Peydró, J.-L., 2017. Monetary Policy and Bank Profitability in a Low Interest Rate Environment. CSEF Working Papers 486. University of Naples, Italy. https://ideas.repec.org/p/sef/csefwp/486.html.

Altunbas, Y., Gambacorta, L., Marques-Ibanez, D., 2014. Does monetary policy affect bank risk? Int. J. Cent. Bank. 10 (1), 95–135.

Andries, A.M., Cocriş, V., Pleşcău, I., 2015. Low interest rates and bank risk-taking: has the crisis changed anything? Evidence from the Eurozone. Rev. Econ. Bus. Stud. 8 (1), 125–148. https://doi.org/10.1515/rebs-2016-0019.

Arteta, C., Kose, M.A., Stocker, M., Taskin, T., 2016. Negative interest rate policies: sources and implications. In: Policy Research Working Paper, 7791, p. 66.

Basten, C., Mariathasan, M., 2018. How Banks Respond to Negative Interest Rates: Evidence From the Swiss Exemption Threshold. SSRN Scholarly Paper ID 3164780. https://papers.ssrn.com/abstract=3164780.

Berger, A.N., 1995. The profit-structure relationship in banking—tests of market-power and efficient-structure hypotheses. J. Money Credit Bank. 27 (2), 404–431. https://doi.org/10.2307/2077876. JSTOR.

Bikker, J.A., Vervliet, T.M., 2018. Bank profitability and risk-taking under low interest rates. Int. J. Financ. Econ. 23 (1), 3–18. https://doi.org/10.1002/ijfe.1595.

Borio, C., Gambacorta, L., Hofmann, B., 2017. The influence of monetary policy on bank profitability. Int. Financ. 20 (1), 48–63. https://doi.org/10.1111/infi.12104.

Borio, C.E.V., Zhu, H., 2008. Capital Regulation, Risk-taking and Monetary Policy: a Missing Link in the Transmission Mechanism? SSRN Scholarly Paper ID 1334132 https://doi.org/10.2139/ssrn.1334132.

Boungou, W., 2019. Negative Interest Rates, Bank Profitability and Risk-taking. SSRN Scholarly Paper ID 3416762. https://doi.org/10.2139/ssrn.3416762.

Boungou, W., 2020. Negative interest rates policy and banks' risk-taking: empirical evidence. Econ. Lett. 186, 108760 https://doi.org/10.1016/j.econlet.2019.108760.

Busch, R., Memmel, C., 2017. Banks' Net Interest Margin and the Level of Interest Rates. SSRN Scholarly Paper ID 3035251. https://papers.ssrn.com/abstract=3035251.

Calinski, T., Harabasz, J., 1974. A dendrite method for cluster analysis. Commun. Stat. - Theory Methods 3 (1), 1–27. https://doi.org/10.1080/03610927408827101.

Campmas, A., 2020. How do European banks portray the effect of policy interest rates and prudential behavior on profitability? Res. Int. Bus. Financ. 51, 100950 https://doi.org/10.1016/j.ribaf.2018.09.001.

Chen, M., Wu, J., Jeon, B.N., Wang, R., 2017. Monetary policy and bank risk-taking: evidence from emerging economies. Emerg. Mark. Rev. 31, 116–140. https://doi.org/10.1016/j.ememar.2017.04.001.
Choi, I., 2001. Unit root tests for panel data. J. Int. Money Finance 20 (2), 249–272. https://doi.org/10.1016/S0261-5606(00)00048-6.
Claessens, S., Coleman, N., Donnelly, M., 2018. "Low-For-Long" interest rates and banks' interest margins and profitability: cross-country evidence. J. Financ. Intermediation 35, 1–16. https://doi.org/10.1016/j.jfi.2017.05.004.
Cœuré, B., 2016. Assessing the implications of negative interest rates. In: Speech at the Yale Financial Crisis Forum. Yale School of Management, July 28, 2016, New Haven. https://www.ecb.europa.eu/press/key/date/2016/html/sp160728.en.html.
De Mendonça, H.F., de Moraes, C.O., 2018. Central bank disclosure as a macroprudential tool for financial stability. Econ. Syst. 42 (4), 625–636. https://doi.org/10.1016/j.ecosys.2018.07.001.
De Moraes, C.O., Montes, G.C., Antunes, J.A.P., 2016. How does capital regulation react to monetary policy? New evidence on the risk-taking channel. Econ. Model. 56, 177–186. https://doi.org/10.1016/j.econmod.2016.03.025.
De Nicolo, G., Dell'Ariccia, G., Laeven, L., Valencia, F., 2010. Monetary Policy and Bank Risk Taking. SSRN Scholarly Paper ID 1654582. https://doi.org/10.2139/ssrn.1654582.
Delis, M.D., Kouretas, G.P., 2011. Interest rates and bank risk-taking. J. Bank. Financ. 35 (4), 840–855. https://doi.org/10.1016/j.jbankfin.2010.09.032.
Dell'Ariccia, G., Laeven, L., Suarez, G.A., 2017. Bank leverage and monetary policy's risk-taking channel: evidence from the United States. J. Finance 72 (2), 613–654. https://doi.org/10.1111/jofi.12467.
Dell'Ariccia, G., Laeven, L., Marquez, R., 2014. Real interest rates, leverage, and bank risk-taking. J. Econ. Theory 149, 65–99. https://doi.org/10.1016/j.jet.2013.06.002.
Demirgüç-Kunt, A., Huizinga, H., 2013. Are banks too big to fail or too big to save? International evidence from equity prices and CDS spreads. J. Bank. Financ. 37 (3), 875–894. https://doi.org/10.1016/j.jbankfin.2012.10.010.
Demirgüç-Kunt, A., Laeven, L., Levine, R., 2004. Regulations, market structure, institutions, and the cost of financial intermediation. J. Money Credit Bank. 36 (3), 593–622. JSTOR.
Genay, H., Podjasek, R., 2014. What is the impact of a low interest rate environment on bank profitability? Chicago Fed Lett. 324. https://ideas.repec.org/a/fip/fedhle/00009.html.
Goddard, J., Molyneux, P., Wilson, J.O.S., 2004. The profitability of European banks: a cross-sectional and dynamic panel analysis. Manchester Sch. 72 (3), 363–381. https://doi.org/10.1111/j.1467-9957.2004.00397.x.
Heider, F., Saidi, F., Schepens, G., 2018. Life Below Zero: Bank Lending Under Negative Policy Rates. SSRN Scholarly Paper ID 3225043. https://papers.ssrn.com/abstract=3225043.
Hryckiewicz, A., Kozłowski, Ł., 2017. Banking business models and the nature of financial crisis. J. Int. Money Finance 71, 1–24. https://doi.org/10.1016/j.jimonfin.2016.10.008.
Ioannidou, V., Ongena, S., Peydró, J.L., 2009. Monetary Policy and Subprime Lending: "A Tall Tale of Low Federal Funds Rates, Hazardous Loans, and Reduced Loans Spreads". European Banking Center Discussion Paper.
Jiménez, G., Ongena, S., Peydró, J.-L., Saurina, J., 2014. Hazardous times for monetary policy: what do twenty-three million bank loans say about the effects of monetary policy on credit risk-taking? Econometrica 82 (2), 463–505. https://doi.org/10.3982/ECTA10104.
Khan, M.S., Scheule, H., Wu, E., 2017. Funding liquidity and bank risk taking. J. Bank. Financ. 82, 203–216. https://doi.org/10.1016/j.jbankfin.2016.09.005.
Leroy, A., Lucotte, Y., 2017. Is there a competition-stability trade-off in European banking? J. Int. Financial Mark. Inst. Money 46, 199–215. https://doi.org/10.1016/j.intfin.2016.08.009.
Lopez, J.A., Rose, A.K., Spiegel, M.M., 2020. Why have negative nominal interest rates had such a small effect on bank performance? Cross country evidence. Eur. Econ. Rev. 124, 103402 https://doi.org/10.1016/j.euroecorev.2020.103402.
Lucas, A., Schaumburg, J., Schwaab, B., 2019. Bank business models at zero interest rates. J. Bus. Econ. Stat. 37 (3), 542–555. https://doi.org/10.1080/07350015.2017.1386567.
Madaschi, C., Pablos Nuevo, I., 2017. The Profitability of Banks in a Context of Negative Monetary Policy Rates: the Cases of Sweden and Denmark. European Central Bank Occasional Paper Series 195. https://ideas.repec.org/p/ecb/ecbops/2017195.html.
Maddaloni, A., Peydró, J.-L., 2011. Bank risk-taking, securitization, supervision, and low interest rates: evidence from the euro-area and the U.S. Lending standards. Rev. Financ. Stud. 24 (6), 2121–2165. JSTOR.
Martynova, N., Ratnovski, L., Vlahu, R., 2019. Bank profitability, leverage constraints, and risk-taking. J. Financ. Intermediation 44, 100821. https://doi.org/10.1016/j.jfi.2019.03.006.
Molyneux, P., Reghezza, A., Xie, R., 2019. Bank margins and profits in a world of negative rates. J. Bank. Financ. 107, 105613 https://doi.org/10.1016/j.jbankfin.2019.105613.
Molyneux, P., Reghezza, A., Thornton, J., Xie, R., 2020. Did negative interest rates improve bank lending? J. Financ. Serv. Res. 57 (1), 51–68. https://doi.org/10.1007/s10693-019-00322-8.
Montes, G.C., Valladares, M., de Moraes, C.O., 2021. Impacts of the sovereign risk perception on financial stability: evidence from Brazil. Q. Rev. Econ. Financ. 81, 358–369. https://doi.org/10.1016/j.qref.2021.06.010.
Ngambou Djatche, M.J., 2019. Re-exploring the nexus between monetary policy and banks' risk-taking. Econ. Model. 82, 294–307. https://doi.org/10.1016/j.econmod.2019.01.016.
Rajan, R.G., 2005. Has Financial Development Made the World Riskier? SSRN Scholarly Paper ID 842464. https://papers.ssrn.com/abstract=842464.
Repullo, R., 2004. Capital requirements, market power, and risk-taking in banking. J. Financ. Intermediation 13 (2), 156–182. https://doi.org/10.1016/j.jfi.2003.08.005.
Roengpitya, R., Tarashev, N., Tsatsaronis, K., Villegas, A., 2017. Bank Business Models: Popularity and Performance. BIS Working Papers 682. https://ideas.repec.org/p/bis/biswps/682.html.
Rousseeuw, P.J., 1987. Silhouettes: a graphical aid to the interpretation and validation of cluster analysis. J. Comput. Appl. Math. 20, 53–65. https://doi.org/10.1016/0377-0427(87)90125-7.
Scheiber, T., Silgoner, M.A., Stern, C., 2016. The development of bank profitability in Denmark, Sweden and Switzerland during a period of ultra-low and negative interest rates. In: Focus on European Economic Integration, 3, pp. 8–28.
Schwaab, B., 2017. Bank Business Models at Negative Interest Rates. European Central Bank Research Bulletin 40. https://ideas.repec.org/a/ecb/ecbrbu/20170040.html.
Williamson, S.D., 1986. Costly monitoring, financial intermediation, and equilibrium credit rationing. J. Monet. Econ. 18 (2), 159–179. https://doi.org/10.1016/0304-3932(86)90074-7.
Zimmermann, K., 2019. Monetary Policy and Bank Profitability, 1870–2015. SSRN Scholarly Paper ID 3322331. https://doi.org/10.2139/ssrn.3322331.