Capital-Labor Substitution, Negative Interest Rates, and Bank Lending: Theory and Evidence from the Euro Area*

Fatih Öztürk†
University of California, Los Angeles

This version: November 1, 2023
[Click here for the most recent version]

Abstract

This paper studies the impact of negative interest rate policies on bank lending, investment, and employment, taking into account the role of capital-labor substitution in production. Using matched firm-bank data from seven euro area countries and employing a difference-in-differences approach, I find that following the introduction of these policies, firms linked to banks with higher deposit ratios receive less credit relative to their counterparts associated with banks with lower deposit ratios. These firms also invest less but tend to hire more employees, especially in industries with high capital-labor substitutability. These findings highlight the role of capital-labor substitution in shaping the effects of negative interest rate policies. To further analyze these findings in a general equilibrium framework and to quantify the aggregate effects of these policies, I use a DSGE model that incorporates bank lending and a CES production function. I find that negative interest rate policies increase lending, investment, employment, and welfare in consumption equivalent units. This model also reveals that higher capital-labor substitutability surprisingly leads to larger declines in output and bank equity following a negative capital productivity shock. Based on this insight, I show that welfare gains from implementing negative interest rate policies increase with capital-labor substitution, and even slight variations in capital-labor substitution elasticity can have significant implications for both the economy and banks.

Keywords: Capital-Labor substitution, Negative interest rate policy, Bank lending
JEL classification: E23, E44, E52, E58, G21

*I am deeply indebted to Lee Ohanian, Pierre-Olivier Weill, and Gary Hansen for their invaluable guidance, advice, and support. I also thank Andy Atkeson and Saki Bigio for useful suggestions and advice. I thank Ryan Banerjee and Boris Hofmann for their mentorship during my Fellowship at the Bank for International Settlements. I thank Mariano Palleja, Paula Beltran, Joaquin Serrano, and Luis Cabezas for their special support and long discussions for which I am grateful. I thank the seminar participants at UCLA.

†UCLA, Department of Economics. Email:f.ozturk@ucla.edu; Website:www.faozturk.com.

1 Introduction

Several central banks, including the European Central Bank, implemented negative interest rate policies to stimulate their economies following the weak recovery from the Great Financial Crisis. These policies involve imposing a fee on banks' excess reserves, effectively resulting in a negative interest rate on these funds. The objective was to motivate banks to channel their excess liquidity into the economy through loans, rather than letting them remain idle at central banks. However, the effects of such policies remain debated, with literature showing mixed results regarding their impact on stimulating economies (Heider, Saidi and Schepens, 2021; Balloch, Koby and Ulate, 2022).

A critical factor that is overlooked in this debate is related to how substitutable capital and labor are in production. This substitutability plays a pivotal role in determining the extent of the decrease in output after capital productivity shocks. Consequently, when the central bank aims to stimulate the economy, the magnitude of interest rate adjustments, including the decision to implement negative rates, is closely tied to this substitutability. Understanding this relationship is essential for central banks in their interest rate decisions. This is particularly true for the European Central Bank, which manages monetary policy for the Euro area. However, the Euro area is diverse, and its member countries might exhibit varying elasticities of substitution between capital and labor, stemming from differences in technologies and institutions (Knoblach and Stöckl, 2020).

In this paper, I provide both empirical and theoretical analyses to examine the impact of negative interest rate policies on bank lending, investment, and employment. I emphasize the role of capital-labor substitution in production in shaping the effects of these policies and extend the existing literature by underscoring its influence. I construct matched firm-bank data based on firms' banking relationships from seven euro area countries to identify the effects of these policies and how capital-labor substitution shapes them. To situate these empirical findings within a general equilibrium framework, I use my empirical estimates within a general equilibrium model to inform its production block. Through this model, I quantify the aggregate and welfare effects of negative interest rate policies and examine how capital-labor substitution influences these effects.

In my empirical analysis, I utilize matched firm-bank data that I construct from seven euro area countries. I employ a difference-in-differences approach in which I exploit banks' ex-ante heterogeneous exposure to these policies to causally identify the effects. Negative interest rate policies affect banks differently based on the extent to which they fund themselves through deposits (Heider, Saidi and Schepens, 2019). Banks with higher deposit-to-asset ratios are more affected than those with lower ratios because the deposit interest rate remains at zero while the non-deposit interest rate becomes negative. As a result, banks with higher deposit ratios experience a smaller decrease in their funding costs and are, therefore, expected to lend less. The richness of my data allows me to control the demand for bank credit using four-digit-industry-country-year fixed effects. I assume that firms operating within narrowly defined industries exhibit similar credit demands. My key empirical findings are twofold.

First, banks that are more exposed to negative interest rate policies supply less credit to firms. Following the introduction of these policies, a one-standard deviation increase in the deposit-to-asset ratio leads to a 1% decrease in lending growth. This decrease is both statistically and economically significant, given that the average credit growth between the periods before and after the policies is 1.4%. While the magnitude of my estimates is smaller than those of other studies that also report negative effects on bank lending, this highlights the importance of my approach in controlling the demand for bank credit and the significance of my data, which consists of more representative firms in Europe.

Second, the decrease in lending translates into a reduction in firm investment: A one-standard deviation increase in the deposit-to-asset ratio leads to a 50 basis points decrease in investment. This decrease is also both statistically and economically significant, considering that the average change in investment between the periods before and after the policies is 3%. However, I find that firms linked to banks with higher deposit ratios often maintain or even increase employment, compared to firms linked to banks with lower deposit ratios, especially in industries with high capital-labor substitution. These observations underscore the potential influence of capital-labor substitution on the effects of negative interest rate policies.

In my theoretical analysis, I draw upon my empirical findings and consider the potential role of capital-labor substitution. I incorporate these empirical estimates into a dynamic stochastic general equilibrium (DSGE) model, which features bank lending and a normalized constant elasticity of substitution (CES) production function. Using this model, I assess the aggregate effects of negative interest rate policies, conduct a welfare analysis, and explore how the elasticity of substitution between capital and labor impacts both the aggregate effects of these policies and the welfare analysis. I have two main theoretical conclusions.

First, I find that a higher elasticity of substitution between capital and labor in production leads to a larger drop in output and bank equity following a negative shock to capital productivity. At first glance, it might seem that higher elasticity would help mitigate the economic downturn. This is because firms could more easily substitute capital with labor, potentially leading to a smaller decrease in employment and the marginal product of capital. However, this perspective overlooks the household response to the negative capital productivity shock. Households anticipate that, with a higher elasticity of substitution, the return on their savings will yield much less. This is because the return on capital drops more sharply due to a more pronounced drop in the demand for capital. Consequently, households choose to reduce their savings by more and decrease their consumption by less, as their intertemporal optimality condition suggests. As a result, they enjoy leisure more and supply less labor when the elasticity of substitution is higher.

I show that this finding has significant implications for banks. In particular, it suggests that a higher elasticity of substitution between capital and labor in production function amplifies banks' vulnerability following a negative shock to capital productivity. The return on bank loan is tied to the marginal product of capital. With a higher elasticity of substitution, the marginal product of capital decreases by more since employment drops by more. As a result, banks absorb bigger losses on their loans which hurts their equity much more. For instance, in response to the same negative shock to capital productivity, banks in an economy with the elasticity of substitution of 1.25 experience an additional 26 basis points drop in their capital ratio compared to banks in an economy with the elasticity of substitution of 1. This additional decrease in the capital ratio suggests, based on estimates from Berger and Bouwman (2013), that the default probability increases by 11%. Utilizing findings from Laeven, Ratnovski and Tong (2016), such a decrease translates into an increase in loan losses of nearly $1 billion for a bank with total assets of $100 billion. Furthermore, this decline corresponds to a decrease in banks' quarterly stock return by 14.3 basis points, based on estimates from Demirgunc-Kunt, Detragiache and Merrouche (2013).

I then inform the production block of my model using my cross-sectional estimates, which are well-identified macro moments, in the moment matching exercise (Nakamura and Steinsson, 2018). Specifically, I calibrate the elasticity of substitution parameter in the production function of the model to match the cross-sectional identified bank lending effects in the Euro area.

Second, using the calibrated model that features the elasticity of substitution between capital and labor in production of 1.25, I find that negative interest rate policies effectively stimulate the economy in response to a negative shock to capital productivity. This elasticity value aligns with the estimates of Karabarbounis and Neiman (2014), who found it to be 1.25 using cross-country data, and with Hubmer (2023), who estimated it at 1.35 based on US data.

In the model, comparing on-impact responses of a scenario where central banks implement negative interest rate policies to a counterfactual one where they do not, I find that bank lending is 1.33% higher with the policies in place. Concurrently, the spread between the bank loan rate and the policy rate is 65 basis points lower. Furthermore, investment is 2.52% higher when these policies are adopted. Output and employment are also higher, with increases of 44 basis points and 66 basis points, respectively, under negative interest rate policies. Welfare gains from implementing negative interest rate policies are 0.02%. This means that households would be willing to give up 0.02% of their initial consumption at the steady state in favor of negative interest rate policies.

1.1 Related literature

This paper is related to the literature that studies the effects of negative interest rate policies. It makes two distinct contributions to the literature.

First, it contributes to the scant literature that explores the effects of negative interest rate policies theoretically. Balloch et al. (2022) offer an insightful survey of this literature. While Eggertsson, Juelsrud, Summers and Wold (2023) and Abadi, Brunnermeier and Koby (2023) suggest that negative interest rates can be detrimental, research from Ulate (2021), Onofri, Peersman and Smets (2023), and de Groot and Haas (2023) indicate that interest rate cuts in negative territory, though less effective than those in positive territory, still stimulate the economy.

In comparison to the existing literature, this paper explores the role of the substitutability of capital and labor in production when analyzing the effects of negative interest rate policies on bank lending, as well as firm investment and employment. I find that a higher elasticity of substitution between capital and labor leads to larger declines in output and bank equity following a negative capital productivity shock. Consequently, the benefits of implementing negative interest rate policies rise with this elasticity. Even minor changes in the elasticity can have profound effects on the economy and the stability of banks. This finding holds significant implications for central banks.

Second, it contributes to the large body of empirical literature that examines the effects of negative interest rates on banks and the economy. These studies vary in their empirical methodologies, as discussed in Balloch et al. (2022), which offers an excellent survey of the literature. Studies using high-frequency identification (Ampudia and Van den Heuvel, 2022) find that unexpected policy rate cuts in negative territory decrease bank equity values and have negative effects on bank stock prices. A prevalent method compares banks with different exposure levels to these policies. Studies by Amzallag, Calza, Georgarakos and Sousa (2019) for Italy, Eggertsson et al. (2023) for Sweden, Kwan, Ulate and Voutilainen (2023) for Finland, Balloch and Koby (2019) for Japan, and Heider et al. (2019) for the euro area indicates that more exposed banks tend to reduce lending and raise interest rates post-policy. Conversely, studies by Demiralp, Eisenschmidt and Vlassopoulos (2021) for the euro area, Grandi and Guille (2023) and Girotti, Horny and Sahuc (2022) for France, Basten and Mariathasan (2018) and Schelling and Towbin (2022) for Switzerland, Hong and Kandrac (2022) for

Japan, and Bottero, Minoiu, Peydró, Polo, Presbitero and Sette (2022) for Italy report opposing findings.

Compared to the existing literature, this paper constructs a matched firm-bank level dataset from seven euro area countries, enabling more precise identification of the effects of negative interest rate policies. The richness of my data allows me to control the demand for bank credit using four-digit-industry-country-year fixed effects. Furthermore, firms in the dataset come from a diverse cross-section of various industries and are highly representative of average European firms, which are unable to switch from bank credit.

The remainder of the paper is organized as follows: Section 2 introduces the data and outlines the empirical strategy. Section 3 presents the empirical results. Section 4 introduces the model. Section 5 presents the calibration of the parameter for the elasticity of substitution in production, provides results from numerical simulations, and discusses them. Section 6 concludes the paper.

2 Data and identification strategy

In this section, I first describe the data and the matching procedure used in the paper. I then turn to the identification strategy used to causally identify the effects of negative interest rate policies.

2.1 Data and matching

I use the Orbis dataset to construct a novel matched firm-bank dataset for the years 2011 to 2019 from seven euro area countries that implement negative interest rate policies.

2.1.1 Data

Orbis is the largest cross-country firm-level database, and it is frequently used in literature because it offers granular and harmonized data at both the firm and bank levels across countries. Orbis has detailed balance sheet and income statement information on millions of firms worldwide, and it covers all industries in the economy and includes both private and public firms. Furthermore, firms in Orbis report their associated banks. This information is crucial for me to construct a novel matched firm-bank level dataset.

The Orbis dataset captures a diverse cross-section of firms from various industries and is highly representative of an average European firm. Firms with fewer than 250 employees constitute a significant portion of the dataset. Such firms typically cannot switch to alternative funding sources. This sharpens my identification of the effects of bank funding on them, aligning well with my primary objective: to quantify the impact of bank credit supply on firms and their respective reactions. Some studies primarily focus on firms with access to syndicated loans, limiting their analysis to a sample dominated by very large firms.

2.1.2 Matching firm- and bank-level data

I match firms with their respective banks to causally identify how negative interest rate policies affect the banks' credit supply to firms and the subsequent responses of these firms.

Although firms in my data report their banks' names, linking the reported bank name to its corresponding name in Orbis is not straightforward, as there is no standardized procedure to match them. I address this challenge by employing fuzzy name matching techniques in Python to match the reported bank names with bank balance sheet data. My matching procedure achieves a matching rate of over 95%.

Kalemli-Özcan, Laeven and Moreno (2022) employ a similar matching approach within the Orbis dataset to study the relationship between weak bank balance sheets and firm-level investment following the Great Financial Crisis. This matching technique is also used in other studies, such as Giannetti and Ongena (2012) and Ongena, Peydro and Horen (2015), which examine the role of foreign banks in transmitting crises.

2.1.3 Sample

In constructing and cleaning my dataset, I follow the methodology outlined in Kalemli-Ozcan, Sorensen, Villegas-Sanchez, Volosovych and Yesiltas (2015).

The sample covers the period from 2011 to 2019. This includes 3 years before the introduction of negative interest rate policies in 2014 and 6 years following their implementation, allowing for an analysis of both short-term and long-term effects. I exclude 2020 from the sample due to the Covid-19 crisis and the significant policy responses to it.

I restrict my sample to the non-financial sector, which includes firms with NACE Rev. 2 codes ranging from 01 to 98, with the exception of codes 64 through 66[1]. I use firms from 7 euro area countries: Austria, France, Germany, Greece, the Netherlands, Portugal, and Spain. Firms in Italy do not report their bankers, and therefore Italy is excluded from the sample.

Firms in Orbis report their outstanding short- and long-term liabilities without breaking down individual bank debts. Therefore, to identify credit supply effects, I ex-

[1]NACE Rev. 2 codes 64-66 refers to Financial and insurance activities.

clude firms that borrow from multiple banks and retain only those with a single bank affiliation. While 99% of firms in France report a single bank, 60% of firms in Portugal do the same. It is common for many European firms to have a lending relationship with only one bank. Using 15 credit registries from Europe, Altavilla, Boucinha, Peydró and Smets (2020) found that the share of firms with a single bank ranges from 54% to 90%, depending on the country.

I use unconsolidated accounts to avoid double counting when both the parent and subsidiary companies are in my dataset. In addition to the country and sector restrictions, I limit my sample to firm-year observations that consistently report key financial variables, which are assets, liabilities, bank credit, sales, and cash and cash equivalents, over a span of 9 consecutive years.

As a result, my constructed sample, covering the period from 2011 to 2019, has over 1 million observations, with 180k unique firms from 7 European countries, spanning 700 different industries and working with over 1000 different banks. Table 1 presents descriptive statistics for the main regression variables, both before and after the introduction of negative interest rate policies.

2.2 Identification strategy

In this section, I describe the identification strategy used to causally identify the effects of negative interest rate policies on bank lending, investment, and employment, and how capital-labor substitution influences these effects.

2.2.1 Setting

During the Great Recession, many central banks lowered their rates to zero or very close to zero in order to provide monetary accommodation to their economies. This led them to reach the lower bound of conventional monetary policy. However, the recovery after the crisis, especially in Europe, was subdued. Consequently, several central banks in Europe, including the European Central Bank in 2014, started implementing negative interest rate policies to stimulate economic growth in their countries. Moving into negative territory is unusual, but understanding its impact on the banking sector, especially regarding their funding sources, is crucial.

Negative interest rate policies affect banks differently based on the extent to which they fund themselves through deposits. Specifically, banks with higher deposit-to-asset ratios are more affected than those with lower ratios. Both interest rates on deposits and on other funding sources follow the policy rate when it is non-negative. However, when the policy interest rate becomes negative, non-deposit interest rates follow the policy rate and also become negative, while the deposit rate remains at zero.

Table 1: Descriptive statistics.

Panel A:	Before, 2012-2013					
Variable	Mean	SD	p25	p50	p75	N
Asset	14.014	1.757	12.908	13.841	14.972	327579
Leverage	0.621	0.359	0.386	0.603	0.807	327579
As Annual growth $\Delta \ln(.)$						
Bank credit	-0.068	1.028	-0.357	-0.076	0.157	239159
Interest rate	0.006	1.388	-0.355	0.013	0.381	212000
Cash	-0.008	1.223	-0.487	0	0.46	321858
Net investment	-0.037	0.498	-0.219	-0.069	0.045	311041
Employment	-0.019	0.265	-0.071	0	0.022	198238
Employee expenses	-0.007	0.255	-0.078	0.004	0.078	306467
Sales	-0.017	0.336	-0.117	-0.008	0.093	327579
Material expenses	-0.027	0.505	-0.164	-0.011	0.130	276245
Panel B:	After, 2014-2019					
Variable	Mean	SD	p25	p50	p75	N
Asset	14.062	1.782	12.948	13.896	15.036	845468
Leverage	0.59	0.379	0.336	0.557	0.776	845468
As Annual growth $\Delta \ln(.)$						
Bank credit	-0.057	1.009	-0.335	-0.062	0.172	599514
Interest rate	-0.038	1.392	-0.394	-0.024	0.330	467655
Cash	0.055	1.155	-0.377	0.046	0.479	832195
Net investment	-0.007	0.506	-0.194	-0.051	0.08	795683
Employment	0.013	0.238	0	0	0.067	609433
Employee expenses	0.016	0.228	-0.048	0.015	0.091	699270
Sales	0.012	0.299	-0.068	0.010	0.105	845468
Material expenses	0.003	0.476	-0.119	0.010	0.145	632348

Notes: Based on an unbalanced sample of firms that are matched to their banks. Panel A presents descriptive statistics for the period 2012-2013. Panel B presents descriptive statistics for the period 2012-2013. Asset refers to the natural logarithm of total assets. Leverage is computed total liabilities to total assets. Bank credit is the sum of both long- and short-term financial debt. Interest rate is calculated as interest expenses to bank credit. Cash refers to cash and cash equivalent. Net investment is tangible fixed assets. Employment is the number of employees. Employee expenses refer to employees' costs (including pension costs). Sales are net sales. Material expenses are material costs. Source: My own calculations based on Orbis.

Banks are hesitant to transmit negative rates to their deposits (Eisenschmidt and Smets, 2019; Lopez, Rose and Spiegel, 2020). As a result, banks with higher deposit-to-asset ratios experience a decline in net interest margins, seeing a smaller reduction in their funding costs when the policy rate turns negative. Consequently, these banks are expected to lend less following the introduction of negative interest rate policies, compared to those with lower ratios.

2.2.2 Identification

I employ a difference-in-differences identification strategy in which I exploit banks' ex-ante heterogeneous exposure to these policies to determine how negative interest rate policies affect bank lending and how changes in bank lending translate into firm performance in terms of investment and employment.

I control for the demand for bank credit from firms using four-digit-industry-country-year fixed effects. The underlying identifying assumption is that firms within the same four-digit-industry-country-year classification experience similar demand shocks. This allows me to disentangle the effect of firms' credit demand from the banks' credit supply following the introduction of negative interest rate policies, as monetary policy reacts to macroeconomic conditions. This approach is similar to that of Degryse, De Jonghe, Jakovljević, Mulier and Schepens (2019), which utilize the Belgian credit registry and use industry-location-size-time fixed effects to control for credit demand when firms have a single bank. I also include firm and bank fixed effects to control for the effect of their existing relationship.

I note that I capture the relative cross-sectional effects, not the overall aggregate effects. This is due to the time fixed effects in my comprehensive fixed effect structure, which absorb the aggregate impacts of negative interest rate policies. As a result, the estimates from my regressions do not directly measure the effect of negative interest rate policies on aggregate variables. However, these estimates are well-identified macro moments and will be used in a moment-matching exercise to inform the production function block of my general equilibrium model. This approach is similar to Nakamura and Steinsson (2018). To assess the impact of negative interest rate policies on the broader economy, such as their effect on total lending, as well as to conduct a welfare analysis, I use a general equilibrium model in Section 4.

2.2.3 Empirical specifications

In this section, I present the empirical specification to causally identify the effects of the policies on the variables of interest.

Effect on credit supply

To causally identify the effects of negative interest rate policies on the credit supply, I employ the following specification

$$\text{Loan growth}_{isct} = \beta \text{Deposit ratio}_b \times \text{Post}_t + \alpha_b + \delta_{sct} + \gamma' X_{isct-1} + \epsilon_{isct} \quad (1)$$

where Loan growth$_{isct}$ denotes loan growth at of firm i in sector s in country c in year t, and is calculated as the difference in the natural logarithm of credit between periods t and $t-1$. Deposit ratio corresponds to firm i's bank b's deposits to assets at the end of 2013. Post is a dummy variable equal to one for the years $t = \{2014, \ldots, 2019\}$ and equal to zero for the years $t = \{2012, 2013\}$. α_b is bank fixed effects, accounting for both observable and unobservable bank-specific factors. It also controls for the effect of the existing relationship between bank b and firm i. δ_{sct} is sector-country-year fixed effects. They control for time-varying sector-country fixed effects. X refers to firm-level controls. I control for leverage, which is defined as the ratio of total liabilities to total assets; sales growth, defined as the annual change in the natural logarithm of sales; cash, defined as the ratio of cash and cash equivalents to total assets; and size, determined as the logarithm of total assets. Highly leveraged firms are less likely to obtain bank credit due to their elevated default rates. Sales growth controls for firms' growth opportunities, with those exhibiting high sales growth typically expected to invest and borrow more. Holding cash reduces a firm's dependence on external financing, including bank credit. Firm size is a significant determinant of leverage, and consequently, of access to bank credit.

The estimate of β captures the causal impact of negative rates on bank lending. As previously mentioned, I expect β to be negative. This coefficient measures how much banks with higher deposit ratios, compared to those with lower deposit ratios, reduce their lending following negative interest rate policies.

I note that the inclusion of sector-country-year fixed effects, δ_{sct}, means that I cannot estimate the coefficient on Post. Similarly, including either firm fixed effect, α_i, or bank fixed effect, α_b, prevents me from estimating the coefficient on Deposit ratio.

My difference-in-differences methodology requires that firms linked to banks with higher deposit ratios and those associated with banks with lower deposit ratios should have the same loan growth trend before the introduction of negative interest rate policies. This *parallel trend assumption* is foundational to the difference-in-differences approach. To bolster the validity of my empirical strategy, I investigate whether this assumption holds true. I address this by conducting the following regression. It is an event study difference-in-differences with the time-varying regression coefficients, showing the differential evolution of loan growth between firms associated with banks with higher deposit ratios and those linked to banks with lower deposit ratios over the years.

$$\text{Loan growth}_{isct} = \sum_{t=2012}^{2019} \beta_t D_{Year=t} \times \text{Deposit ratio}_b + \alpha_b + \delta_{sct} + \gamma' X_{isct-1} + \epsilon_{isct} \quad (2)$$

The variable $D_{Year=t}$ is a dummy variable taking the value one if the year is equal to t, where $t = \{2012, \ldots, 2019\}$. I pick 2013 as the reference year, which is the year right before the introduction of negative interest rate policies in 2014.

The time-varying regression coefficient, β_t, captures the differential evolution of loan growth over the years between firms associated with banks with higher deposit ratios and those linked to banks with lower deposit ratios. If the coefficients for the pre-period years of 2012 and 2013 are around zero, this bolsters the *parallel trend assumption*, indicating that these firms experienced similar credit growth prior to the introduction of negative interest rate policies. I will also use the same regression framework for other variables of interest.

Effect on interest rate

I also use my baseline specification to estimate the effect on interest rate, using interest rate growth as the dependent variable in the regression. It is calculated as the difference in the natural logarithm of interest rate between periods t and $t-1$. Interest rate refers to the ratio of interest expenses to the sum of both long- and short-term financial debt as recorded in Orbis.

In this regression, where the dependent variable is interest rate growth, I expect β to be positive. This is because banks with higher deposit ratios tend to experience a decrease in profitability compared to those with lower deposit ratios, due to the mechanism mentioned above. Consequently, to boost their profits, banks with higher deposit ratios charge higher interest rates following negative interest rate policies than those with lower deposit ratios.

Effect on other financial variables

I also examine the effects on other firm-level financial variables. I check whether firms with banks more exposed to these policies switch to other funding sources. This is to verify whether my results truly stem from banks more exposed to negative interest rate policies supplying less credit to firms, compared to their peers less exposed to these policies. Consequently, I estimate the following regression, which is identical to Equation (5), but with a different dependent variable.

$$\text{Firm other financial}_{isct} = \beta \text{Deposit ratio}_b \times \text{Post}_t + \alpha_b + \delta_{sct} + \gamma' X_{isct-1} + \epsilon_{isct} \quad (3)$$

Firm other financial is (i) leverage, calculated as the ratio of total liabilities (excluding equity) to total assets in period t and (ii) cash growth, measured as the difference in the natural logarithm of cash and cash equivalent between periods t and $t-1$.

In the regression, where the dependent variable is leverage, I expect β to be negative. This is because firms associated with banks with higher deposit ratios experience a reduction in bank credit and they cannot switch to alternative funding sources. As a result, I expect their leverage to be lower than that of firms linked to banks with lower deposit ratios. Conversely, in the regression, where the dependent variable is cash growth, I expect β to be positive. Following the credit reduction, firms associated with banks with higher deposit ratios are expected to increase their cash holding. This can be attributed to the self-financing motive (Almeida, Campello, Laranjeira and Weisbenner, 2012).

Effect on risk taking

I also examine the effects of negative interest rate policies on bank risk-taking through bank lending. I employ my baseline specification detailed in Equation (1) and split the sample into safe and risky firms.

My ex-ante risk measure is based on firms' ex-ante return on asset volatility (expressed as a standard deviation) between 2011 and 2013, a period before the introduction of negative interest rate policies (Heider et al., 2019). The return on assets is calculated using the sum of operating profit and financial profits before tax, divided by assets.

I define risky firms as those with a standard deviation of their return on assets above the median of the distribution in their country, while safe firms are those with volatility below the median of that distribution.

The sign of the coefficient β depends on whether *the risk-bearing channel* or *the reaching for yield channel* is more important. According to *the risk-bearing channel*, banks tend to take less risk following a decline in their profitability. This is because they have less capital to absorb losses and to meet regulatory capital requirements. In contrast, *the reaching for yield channel* operates in the opposite direction. It posits that a decrease in bank profitability encourages banks to take on more risk by lending to riskier firms.

Effect on investment and employment

I also investigate how a change in bank lending translates into investment and employment in firms that borrow from banks more exposed to negative interest rate policies. My goal is to quantify the real effects of these policies through bank lending to firms. Consequently, I estimate the following regression, which is identical to Equation (1), but with a different dependent variable.

$$\text{Firm outcome growth}_{isct} = \beta \text{Deposit ratio}_b \times \text{Post}_t + \alpha_b + \delta_{sct} + \gamma' X_{isct-1} + \epsilon_{isct} \quad (4)$$

Firm outcome growth is (i) net investment, calculated as the difference in the natural logarithm of tangible fixed assets between periods t and $t-1$ and (ii) employment growth, defined as the difference in the natural logarithm of number of employees between periods t and $t-1$.

In the regression, where the dependent variable is net investment, I expect β to be negative. Firms associated with banks with higher deposit ratios are more likely to invest less compared to those linked to banks with lower deposit ratios. This is because capital becomes more expensive for them as their banks lend less and charge higher interest rates.

In the regression, where the dependent variable is employment, the sign of the coefficient β depends on how easily firms can substitute capital with labor. If capital and labor are complements, I expect β to be negative. However, if capital and labor are substitutes, I expect β to be positive.

Effect of elasticity of substitution on investment and employment

I examine the effects of the elasticity of substitution between capital and labor in production on investment and employment. Drawing on previous work, Herrendorf, Herrington and Valentinyi (2015) estimate the elasticity of substitution between capital and labor by sector for the United States. They find that the primary[2] and secondary sectors[3] exhibit a higher elasticity of substitution than the tertiary[4] sector. In essence, capital and labor are less substitutable in the tertiary sector compared to other sectors. Similarly, Kopecna, Scasny and Recka (2020) arrive at the same conclusion for the European Union.

Given these insights, for my analysis, I use the baseline specification detailed in Equation (1). I then divide the sample into two groups based on their sectorial elasticities: firms in sectors with higher elasticity, from the primary and secondary sectors, and those in sectors with lower elasticity, from the tertiary sectors.

In the regression, where the dependent variable is net investment, I expect β to be

[2]The primary sectors encompass Agriculture, Forestry and Fishing, and Mining and Quarrying.

[3]The secondary sectors cover Manufacturing; Electricity, Gas, Steam, and Air Conditioning Supply; Water Supply, Sewerage, Waste Management, and Remediation Activities; and Construction.

[4]The tertiary sectors comprise Wholesale and Retail Trade; Repair of Motor Vehicles and Motorcycles; Transport and Storage; Accommodation and Food Service Activities; Information and Communication; Real Estate Activities; Professional, Scientific, and Technical Activities; Administrative and Support Service Activities; Public Administration and Defence; Compulsory Social Security; Education; Human Health and Social Work Activities; Arts, Entertainment and Recreation; and Other Service Activities.

negative for both sectors. Firms associated with banks with higher deposit ratios are more likely to invest less compared to those linked to banks with lower deposit ratios. This is because capital becomes more expensive for them as their banks lend less and charge higher interest rates. I expect this to hold true for firms in sectors with both lower and higher elasticity.

In contrast, in the regression, where the dependent variable is employment, the sign of the coefficient β depends on how easily firms can substitute capital with labor. If capital and labor are less substitutable (more complementary), as seen in the tertiary sector, I expect β to be negative. Conversely, if capital and labor are more substitutable (more like substitutes), as observed in the primary and secondary sectors, I expect β to be positive.

3 Empirical results

In this section, I present in five steps my results for the estimations outlined in the previous section. First, I document the effect of negative interest rate policies on bank lending and the lending rate. Second, I show the effects on other financial variables, leverage and cash holdings, to strengthen my lending results. Third, I present the effects on firm performance in terms of investment and employment and emphasize the role of capital-labor substitution in shaping these effects. Fourth, To provide further evidence supporting my empirical approach, I examine whether the *parallel trend assumption* is satisfied. Fifth, I investigate whether there is an increase in risk taking.

3.1 Lending and lending rate

Table 2 reports lending results.

The estimated coefficient on the interaction term, β, shown in Columns (1) to (4) of Table 2, is negative and highly significant. This suggests that firms with banks more exposed to negative interest rate policies receive less bank credit compared to firms with less exposed banks following the introduction of these policies.

Based on the estimate in Column (1), in terms of economic significance, a one-standard deviation increase in the deposit-to-asset ratio leads to a 1% decrease in lending growth. This decrease is relevant and economically significant, especially considering that the average credit growth between the periods before and after the policies is 1.4%.

The result is robust when adding firm-level variables in Column (2) to control for observable determinants of credit demand. In Columns (3) and (4), I modify the exposure measure, the main independent variable, from continuous to binary. This new

Table 2: Negative Interest Rates and Bank Credit Supply

Dependent variable:	Loan growth			
	(1)	(2)	(3)	(4)
Deposit ratio × Post	-0.0594**	-0.0598**		
(%)	(0.0252)	(0.0251)		
Deposit ratio × Post			-0.0209***	-0.0208***
(0/1)			(0.00777)	(0.00770)
Firm Control	No	Yes	No	Yes
Bank FE	Yes	Yes	Yes	Yes
Country-Industry-Time FE	Yes	Yes	Yes	Yes
Observations	735780	735780	735780	735780
R^2	0.0273	0.0280	0.0273	0.0280

Notes: The table presents OLS estimates of the following model at the bank-firm level.

$$\text{Loan growth}_{isct} = \beta \text{Deposit ratio}_b \times \text{Post}_t + \alpha_b + \delta_{sct} + \gamma' X_{isct-1} + \epsilon_{isct}$$

The dependent variable is loan growth at the firm-bank level and is calculated as the difference in the natural logarithm of credit between periods t and $t-1$. Credit refers to the sum of long- and short-term financial debt recorded in Orbis. The deposit ratio, presented in Columns (1) and (2), denotes the ratio of deposits over total assets (in %) for the year 2013. In Columns (3) and (4), the deposit ratio is assigned a value of one if the ratio of deposits to total assets in 2013 is above the median of its respective country's distribution. Post is a dummy variable representing the period from 2014 onward. The set of firm control variables (not reported) includes i) size, measured as the logarithm of total assets, ii) leverage, defined as the ratio of total liabilities to total assets, iii) sales growth, measured as the annual change in the natural logarithm of sales, iv) cash, defined as the ratio of cash and cash equivalents to total assets. Bank fixed effects are included. Country-Industry-Time fixed effects are based on four-digit NACE Rev.2 codes. Robust standard errors, clustered at the bank level, are in parentheses. ***, **, and * indicate significance at 1%, 5%, and 10%, respectively.

independent variable takes a value of one if the deposit-to-asset ratio is above the median within its country's deposit-to-asset distribution. The coefficient on the interaction term is negative and statistically significant. This suggests that banks more exposed to policies, relative to their less exposed counterparts, supply less credit. The resulting decrease in lending growth is equal to 2%.

My findings align with prior research that reports negative effects on bank lending. However, the magnitude of the effects that I have identified is notably smaller than that found in some other studies. For instance, Heider et al. (2019) find a decrease of 13% following a one-standard deviation increase in the deposit-to-asset ratio, while Eggertsson et al. (2023) report a decline of 2.6%. In contrast, my research suggests a more moderate decrease of 1%. One potential reason for this difference might be the unique strengths and precision of my dataset. Firstly, firms in my dataset, representative of an average European business, predominantly rely on bank credit, making it an ideal sample to study lending effects with greater accuracy. Secondly, I comprehensively control bank credit demand using four-digit-industry-country-year fixed effects spanning 708 industries across 7 countries over an 8-year period, with the assumption that firms within specific industries have similar credit needs.

Moving to the interest rate results in Table 3, I note that the coefficients in Columns (1) to (4) are positive and statistically significant. This implies that banks more exposed to negative interest rate policies charge higher interest rates than their less exposed counterparts. This approach aligns with their aim to boost their profitability.

Based on the estimate in Column (1), in terms of the economic significance, a one-standard deviation increase in the deposit-to-asset ratio leads to a 11 basis points increase in interest rate. This increase is both relevant and economically significant, especially when considering that the cost associated with the inability to pass on negative rates to depositors stands at around 25 basis points, given the average deposit-to-asset ratio of 50%.

3.2 Leverage and cash holding

Table 4 reports the effects on other financial variables, leverage and cash holdings.

Beginning with the leverage results, I observe that the coefficients in Columns (1) and (2) are positive and statistically significant at the 1 percent level. This suggests that firms with more exposed banks cannot substitute the decrease in bank credit with other funding sources, resulting in a reduction of their leverage ratio.

Turning to the cash holdings results, I observe that the coefficients in Columns (3) and (4) are positive and statistically significant. This indicates that firms associated with banks more exposed to negative interest rate policies increase their cash holdings more than their counterparts linked to less exposed banks, following the introduction

Table 3: Negative Interest Rates and Loan Interest Rate

Dependent variable:	Interest rate growth			
	(1)	(2)	(3)	(4)
Deposit ratio × Post	0.0716**	0.0727**		
(%)	(0.0364)	(0.0365)		
Deposit ratio × Post			0.0209*	0.0211*
(0/1)			(0.0111)	(0.0111)
Firm Control	No	Yes	No	Yes
Bank FE	Yes	Yes	Yes	Yes
Country-Industry-Time FE	Yes	Yes	Yes	Yes
Observations	580228	580228	580228	580228
R^2	0.0325	0.0328	0.0325	0.0328

Notes: The table presents OLS estimates of the following model at the bank-firm level.

$$\text{Interest rate growth}_{isct} = \beta \text{Deposit ratio}_b \times \text{Post}_t + \alpha_b + \delta_{sct} + \gamma' X_{isct-1} + \epsilon_{isct}$$

The dependent variable is interest rate growth at the firm-bank level and is calculated as the difference in the natural logarithm of interest rate between periods t and $t-1$. Interest rate refers to the ratio of interest expenses to the sum of long- and short-term financial debt as recorded in Orbis. The deposit ratio, presented in Columns (1) and (2), denotes the ratio of deposits over total assets (in %) for the year 2013. In Columns (3) and (4), the deposit ratio is assigned a value of one if the ratio of deposits to total assets in 2013 is above the median of its respective country's distribution. Post is a dummy variable representing the period from 2014 onward. The set of firm control variables (not reported) includes i) size, measured as the logarithm of total assets, ii) leverage, defined as the ratio of total liabilities to total assets, iii) sales growth, measured as the annual change in the natural logarithm of sales, iv) cash, defined as the ratio of cash and cash equivalents to total assets. Bank fixed effects are included. Country-Industry-Time fixed effects are based on four-digit NACE Rev.2 codes. Robust standard errors, clustered at the bank level, are in parentheses. ***, **, and * indicate significance at 1%, 5%, and 10%, respectively.

Table 4: Negative Interest Rates and Other Firm Financial Variables

Dependent variable:	Leverage		Cash growth	
	(1)	(2)	(3)	(4)
Deposit ratio × Post	-0.00687***		0.0610**	
(%)	(0.00214)		(0.0252)	
Deposit ratio × Post		-0.00275***		0.0119**
(0/1)		(0.000689)		(0.00599)
Firm Control	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes
Country-Industry-Time FE	Yes	Yes	Yes	Yes
Observations	1016143	1016143	997570	997570
R^2	0.914	0.914	0.205	0.205

Notes: The table presents OLS estimates of the following model at the bank-firm level.

$$\text{Leverage}_{isct} = \beta \text{Deposit ratio}_b \times \text{Post}_t + \alpha_i + \delta_{sct} + \gamma' X_{isct-1} + \epsilon_{isct}$$
$$\text{Cash growth}_{isct} = \beta \text{Deposit ratio}_b \times \text{Post}_t + \alpha_i + \delta_{sct} + \gamma' X_{isct-1} + \epsilon_{isct}$$

The dependent variable in Columns (1) and (2) is leverage at the firm level and is calculated as the ratio of total liabilities to total assets in period t. The dependent variable in Columns (3) and (4) is cash growth at the firm level and is calculated as the difference in the natural logarithm of cash and cash equivalent between periods t and $t-1$. The deposit ratio, presented in Columns (1) and (3), denotes the ratio of deposits over total assets (in %) for the year 2013. In Columns (2) and (4), the deposit ratio is assigned a value of one if the ratio of deposits to total assets in 2013 is above the median of its respective country's distribution. Post is a dummy variable representing the period from 2014 onward. The set of firm control variables (not reported) includes i) size, measured as the logarithm of total assets, ii) leverage, defined as the ratio of total liabilities to total assets, iii) sales growth, measured as the annual change in the natural logarithm of sales, iv) cash, defined as the ratio of cash and cash equivalents to total assets. Bank fixed effects are included. Country-Industry-Time fixed effects are based on four-digit NACE Rev.2 codes. Robust standard errors, clustered at the bank level, are in parentheses. ***, **, and * indicate significance at 1%, 5%, and 10%, respectively.

of these policies. Such behavior is consistent with their self-financing motive.

The result is robust to adding firm level variables to control for observable determinants of credit demand and changing the main dependent variable from continuous to binary.

These results verify my results truly stem from banks more exposed to negative interest rate policies supplying less credit to firms, compared to their peers less exposed to these policies.

3.3 Investment and employment

My lending results show that banks more exposed to negative interest rate policies reduce their credit supply to firms borrowing from them, relative to banks that are less exposed, after these policies are implemented. In this section, I study how a decrease in bank lending translates into investment and employment in firms that borrow from banks more exposed to negative interest rate policies and how capital-labor substitution shapes these effects.

Table 5 reports the effects on real firm outcomes, investment and employment.

Beginning with the investment results, the estimated coefficient on the interaction term, β, shown in Columns (1) to (4) of Table 5, is negative and highly significant. This suggests that firms with banks more exposed to negative interest rate policies invest less compared to firms with less exposed banks following the introduction of these policies.

Based on the estimate in Column (1), in terms of the economic significance, a one-standard deviation increase in the deposit-to-asset ratio leads to an approximately 50 basis points decrease in investment. This decrease is relevant and economically significant, especially considering that the average change investment between the periods before and after the policies is 3%.

The result is robust when adding firm-level variables in Column (2) to control for observable determinants of investment.

In Columns (3) and (4), I modify the exposure measure, the main independent variable, from continuous to binary. This new independent variable takes a value of one if the deposit-to-asset ratio is above the median within its country's deposit-to-asset distribution. The coefficient on the interaction term is negative and statistically significant. This suggests that banks more exposed to policies, compared to their less exposed counterparts, supply less credit. The resulting decrease in lending growth is equal to 60 basis points.

These findings contrast with the conclusions of Bittner, Bonfim, Heider, Saidi, Schepens and Soares (2022), Bottero et al. (2022), and Altavilla, Burlon, Giannetti and Holton (2022), who find increase in investment in firms associated with banks more exposed

Table 5: Negative Interest Rates and Investment

Dependent variable:	Net investment			
	(1)	(2)	(3)	(4)
Deposit ratio × Post	-0.0274***	-0.0261***		
(%)	(0.00994)	(0.00993)		
Deposit ratio × Post			-0.00591*	-0.00590**
(0/1)			(0.00306)	(0.00301)
Firm Control	No	Yes	No	Yes
Firm FE	Yes	Yes	Yes	Yes
Country-Industry-Time FE	Yes	Yes	Yes	Yes
Observations	955772	955772	955772	955772
R^2	0.199	0.211	0.199	0.211

Notes: The table presents OLS estimates of the following model at the bank-firm level.

$$\text{Net investment}_{isct} = \beta \text{Deposit ratio}_b \times \text{Post}_t + \alpha_i + \delta_{sct} + \gamma' X_{isct-1} + \epsilon_{isct}$$

The dependent variable is net investment at the firm level and is calculated as the difference in the natural logarithm of tangible fixed assets between periods t and $t-1$. The deposit ratio, presented in Columns (1) and (2), denotes the ratio of deposits over total assets (in %) for the year 2013. In Columns (3) and (4), the deposit ratio is assigned a value of one if the ratio of deposits to total assets in 2013 is above the median of its respective country's distribution. Post is a dummy variable representing the period from 2014 onward. The set of firm control variables (not reported) includes i) size, measured as the logarithm of total assets, ii) leverage, defined as the ratio of total liabilities to total assets, iii) sales growth, measured as the annual change in the natural logarithm of sales, iv) cash, defined as the ratio of cash and cash equivalents to total assets. Bank fixed effects are included. Country-Industry-Time fixed effects are based on four-digit NACE Rev.2 codes. Robust standard errors, clustered at the bank level, are in parentheses. ***, **, and * indicate significance at 1%, 5%, and 10%, respectively.

to policies. The divergence arises because, while they observe positive effects on bank lending, I identify negative effects. Less credit translates into less investment, as capital financing becomes more costly for firms associated with banks that are more exposed to negative interest rate policies.

Moving to the employment results in Table 6, I observe that the coefficients in Columns (1) and (2) are positive, but they are not statistically significant and do not differ from zero. This suggests that firms associated with banks more exposed to negative interest rate policies might attempt to substitute capital with labor, as capital becomes more expensive due to their banks charging higher rates. Such behavior hints that capital and labor could be gross substitutes in production. To assess the robustness of this result, I change the dependent variable to payroll expenses in Columns (3) and (4). Consistent with the initial result, the coefficient associated with the interaction term remains positive, but is not statistically significant.

In Table 10 in Appendix B, to further support my argument that firms associated with more exposed banks increase their employment compared to those linked to less exposed banks, I examine the effects on output growth, defined as the annual change in the natural logarithm of output, and on intermediate input growth in production, defined as the annual change in the natural logarithm of materials. I find that the coefficients on the interaction term in both the output regression and the intermediate input regression are positive, though not statistically significant.

The coefficient on the interaction term suggests there is no significant difference in output growth between firms associated with more exposed banks and those linked to less exposed banks. However, given that firms with more exposed banks experience reduced capital yet maintain similar output levels, it is logical to infer that these firms have increased their labor to compensate for the decreased capital, especially considering that intermediate inputs remain consistent across both types of firms.

3.3.1 Effect of elasticity of substitution on investment and employment

Table 7 reports the effects of the elasticity of substitution on both investment and employment for sectors with higher and lower elasticity of substitution.

Starting with the investment results, the estimated coefficient on the interaction term, β, shown in Columns (1) to (2) of Table 7, is negative. This observation is consistent and appears unrelated to the sector's elasticity of substitution. This is because firms associated with banks with higher deposit ratios charge higher interest rates on their loans, making capital more expensive.

Turning to the employment results, the coefficient in Column (3) is positive and statistically significant. This underscores that firms in sectors with higher elasticity of substitution increase their employment. Conversely, the coefficient in Column (4) is

Table 6: Negative Interest Rates and Employment

Dependent variable:	Employment growth		Employee expenses growth	
	(1)	(2)	(3)	(4)
Deposit ratio × Post	0.00489		0.00234	
(%)	(0.00901)		(0.00525)	
Deposit ratio × Post		0.00133		0.00169
(0/1)		(0.00179)		(0.00164)
Firm Control	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Country-Industry-Time FE	Yes	Yes	Yes	Yes
Observations	701950	701950	861511	861511
R^2	0.187	0.187	0.223	0.223

Notes: The table presents OLS estimates of the following model at the bank-firm level.

$$\text{Employment growth}_{isct} = \beta \text{Deposit ratio}_b \times \text{Post}_t + \alpha_i + \delta_{sct} + \gamma' X_{isct-1} + \epsilon_{isct}$$
$$\text{Employee expenses growth}_{isct} = \beta \text{Deposit ratio}_b \times \text{Post}_t + \alpha_i + \delta_{sct} + \gamma' X_{isct-1} + \epsilon_{isct}$$

The dependent variable in Columns (1) and (2) is employment growth at the firm level and is calculated as the difference in the natural logarithm of number of employees between periods t and $t-1$. The dependent variable in Columns (3) and (4) is employee expenses growth at the firm level and is calculated as the difference in the natural logarithm of employee expenses between periods t and $t-1$. Employee expenses refer to the employees costs of the company (including pension costs) in Orbis. The deposit ratio, presented in Columns (1) and (3), denotes the ratio of deposits over total assets (in %) for the year 2013. In Columns (2) and (4), the deposit ratio is assigned a value of one if the ratio of deposits to total assets in 2013 is above the median of its respective country's distribution. Post is a dummy variable representing the period from 2014 onward. The set of firm control variables (not reported) includes i) size, measured as the logarithm of total assets, ii) leverage, defined as the ratio of total liabilities to total assets, iii) sales growth, measured as the annual change in the natural logarithm of sales, iv) cash, defined as the ratio of cash and cash equivalents to total assets. Bank fixed effects are included. Country-Industry-Time fixed effects are based on four-digit NACE Rev.2 codes. Robust standard errors, clustered at the bank level, are in parentheses. ***, **, and * indicate significance at 1%, 5%, and 10%, respectively.

Table 7: Negative Interest Rates and Elasticity of Substitution

Dependent variable:	Net investment		Employment growth	
	(1)	(2)	(3)	(4)
Sample:	Primary & Secondary	Tertiary	Primary & Secondary	Tertiary
Deposit ratio × Post	-0.0188	-0.0305***	0.0278**	-0.00801
(%)	(0.0161)	(0.0116)	(0.0125)	(0.0107)
Firm Control	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Country-Industry-Time FE	Yes	Yes	Yes	Yes
Observations	346739	609033	243474	458476
R^2	0.215	0.209	0.183	0.180

Notes: The table presents OLS estimates of the following model at the bank-firm level.

$$\text{Net investment}_{isct} = \beta \text{Deposit ratio}_b \times \text{Post}_t + \alpha_i + \delta_{sct} + \gamma' X_{isct-1} + \epsilon_{isct}$$
$$\text{Employment growth}_{isct} = \beta \text{Deposit ratio}_b \times \text{Post}_t + \alpha_i + \delta_{sct} + \gamma' X_{isct-1} + \epsilon_{isct}$$

The dependent variable in Columns (1) and (2) is net investment at the firm level and is calculated as the difference in the natural logarithm of tangible fixed assets between periods t and t−1. The sample is restricted to firms in Primary (agriculture and mining) and Secondary (manufacturing, electricity and water supply, and construction) sectors in Column (1) and firms in Tertiary (wholesale trade, transportation, accommodation, information and communication, real estate, professional services, education, health) sector in Column (2). The dependent variable in Columns (3) and (4) is employment growth at the firm level and is calculated as the difference in the natural logarithm of number of employees between periods t and $t-1$. The sample is restricted to firms in Primary (agriculture and mining) and Secondary (manufacturing, electricity and water supply, and construction) sectors in Column (3) and firms in Tertiary (wholesale trade, transportation, accommodation, information and communication, real estate, professional services, education, health) sector in Column (4). The deposit ratio denotes the ratio of deposits over total assets (in %) for the year 2013. Post is a dummy variable representing the period from 2014 onward. The set of firm control variables (not reported) includes i) size, measured as the logarithm of total assets, ii) leverage, defined as the ratio of total liabilities to total assets, iii) sales growth, measured as the annual change in the natural logarithm of sales, iv) cash, defined as the ratio of cash and cash equivalents to total assets. Bank fixed effects are included. Country-Industry-Time fixed effects are based on four-digit NACE Rev.2 codes. Robust standard errors, clustered at the bank level, are in parentheses. ***, **, and * indicate significance at 1%, 5%, and 10%, respectively.

negative, but not statistically significant, and does not differ from zero. This suggests that firms operating in sectors with production technology characterized by lower elasticity of substitution did not increase their employment.

These employment findings indicate that firms linked to banks more exposed to negative interest rate policies increase their employment compared to firms with less exposed banks, but this is mostly observed in sectors that feature a higher elasticity of substitution after the introduction of these policies. This observation aligns with the findings of Laeven, McAdam and Popov (2023) who draw a similar conclusion when studying the effects of the credit crunch on Spanish firms in the aftermath of the Great Financial Crisis.

3.4 Checking parallel trend assumption

Figure 1 displays the time-varying regression coefficients of the model relative to the year 2013, using loan growth as the dependent variable, with the confidence intervals of a 90% confidence level. The coefficient is not statistically different from zero for the pre-period years of 2012 and 2013, but it becomes negative and significant at the 10 percent level from 2014 through 2019. This provides further support for the causal interpretation of my results.

In Appendix A, I present figures for leverage, cash holdings, and investment, similar to the previous one on credit growth, to assess whether a trend exists before the introduction of the policy. The results remain consistent: the coefficients are not statistically different from zero for the pre-policy years of 2012 and 2013. Following the policy's introduction in 2014, they become significant.

3.5 Risk-taking

Table 8 reports the effects of negative interest rate policies on risk-taking through bank lending, splitting the sample into safe and risky firms. In Columns (1) and (2), the risk measure is based on the sum of operating and financial profits over assets. In Columns (3) and (4), the risk measure uses EBITDA, which is defined as the sum of operating profits and depreciation, over sales.

The estimated coefficient for the interaction term of safe firms in Column (1) is negative, but not statistically significant. In contrast, the coefficient for risky firms in Column (2) is negative and is statistically significant, with a much larger magnitude than in Column (1). Moving to the estimated coefficients in Columns (3) and (4), I find that the decrease in bank credit for safe firms is smaller than that for risky firms. These results suggest that banks with higher deposit ratios supply less credit to risky firms than to safe firms following negative interest rate policies.

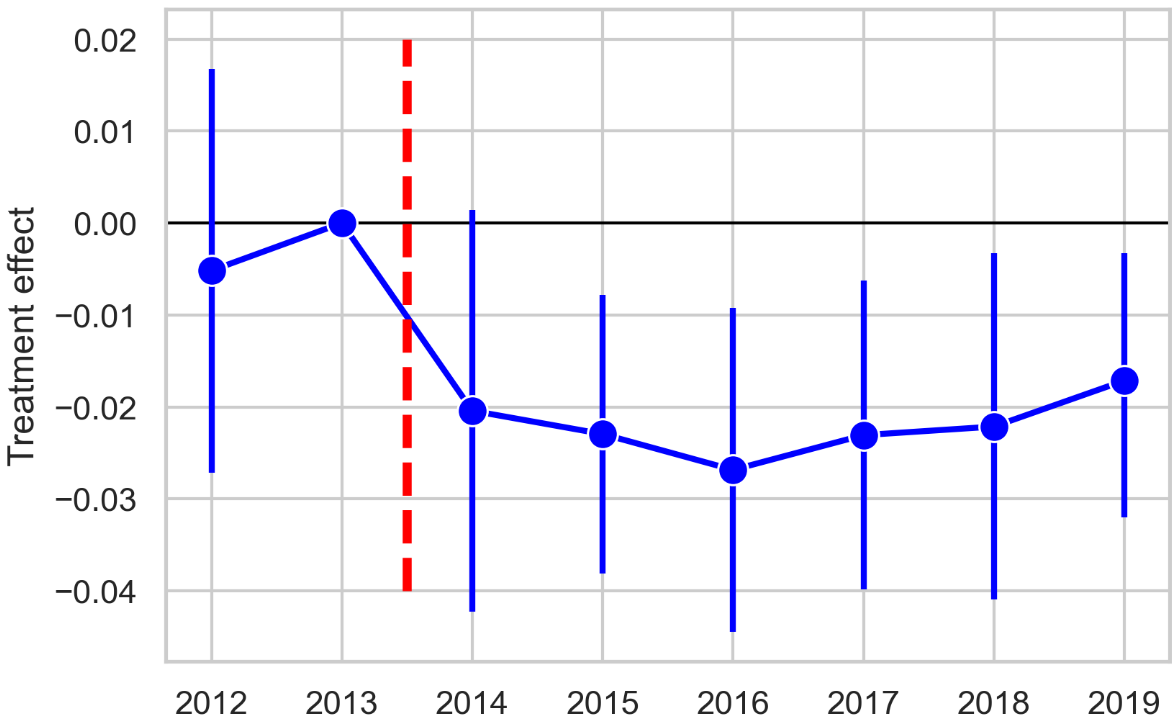


Figure 1: Impact of Negative Interest Rate Policies on Bank Credit Supply.

Note: This figure plots the coefficient estimates $\hat{\beta}_t$ of the following model at the bank-firm level:

$$\text{Loan growth}_{isct} = \sum_{t=2012}^{2019} \beta_t D_{\text{Year}=t} \times \text{Deposit ratio}_b + \alpha_b + \delta_{sct} + \gamma' X_{isct-1} + \epsilon_{isct}$$

$\hat{\beta}_t$ is time-varying treatment effect of negative rates on loan growth. Vertical bars correspond to 90% confidence intervals. $D_{Year=t}$ is dummy variable taking the value one if the year is equal to t, where $t = \{2012, \dots, 2019\}$. The year 2013 is the reference year. The dependent variable is loan growth at the firm-bank level and is calculated as the difference in the natural logarithm of credit between periods t and $t-1$. Credit refers to the sum of both long- and short-term financial debt as recorded in Orbis. The deposit ratio denotes the ratio of deposits over total assets (in %) for the year 2013. The set of firm control variables (not reported) includes i) size, measured as the logarithm of total assets, ii) leverage, defined as the ratio of total liabilities to total assets, iii) sales growth, measured as the annual change in the natural logarithm of sales, iv) cash, defined as the ratio of cash and cash equivalents to total assets. Bank fixed effects are included. Country-Industry-Time fixed effects are based on four-digit NACE Rev.2 codes. Robust standard errors are clustered at the bank level.

Table 8: Negative Interest Rates and Risk Taking

Dependent Variable	Loan growth			
	(1)	(2)	(3)	(4)
Sample:	Safe	Risky	Safe	Risky
Deposit ratio × Post	-0.0290	-0.0955***	-0.0487*	-0.0698*
	(0.0277)	(0.0353)	(0.0283)	(0.0358)
Firm Control	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes
Country-Industry-Time FE	Yes	Yes	Yes	Yes
Observations	354462	314136	346068	317820
R^2	0.0392	0.0424	0.0394	0.0403

Notes: The table presents OLS estimates of the following model at the bank-firm level.

$$\text{Loan growth}_{isct} = \beta \text{Deposit ratio}_b \times \text{Post}_t + \alpha_b + \delta_{sct} + \gamma' X_{isct-1} + \epsilon_{isct}$$

The dependent variable is loan growth at the firm-bank level and is calculated as the difference in the natural logarithm of credit between periods t and $t-1$. Credit refers to the sum of both long- and short-term financial debt as recorded in Orbis. The sample is restricted to safe firms in Columns (1) and (3). The sample is restricted to risky firms in Columns (2) and (4). In Columns (1) and (2), a firm is assumed to be safe when the standard deviation of its return on assets (using the sum of operating profit and financial profits before tax) before 2014 is below the median of the distribution in its country, while risky firms are those whose standard deviation of its return on assets is above the median of that distribution. In Columns (3) and (4), a firm is assumed to be safe when the standard deviation of its return on sales (using the sum of operating profit and depreciation) before 2014 is below the median of the distribution in its country, while risky firms are those whose standard deviation of its return on assets is above the median of that distribution. The deposit ratio denotes the ratio of deposits over total assets (in %) for the year 2013. Post is a dummy variable representing the period from 2014 onward. The set of firm control variables (not reported) includes i) size, measured as the logarithm of total assets, ii) leverage, defined as the ratio of total liabilities to total assets, iii) sales growth, measured as the annual change in the natural logarithm of sales, iv) cash, defined as the ratio of cash and cash equivalents to total assets. Bank fixed effects are included. Country-Industry-Time fixed effects are based on four-digit NACE Rev.2 codes. Robust standard errors, clustered at the bank level, are in parentheses. ***, **, and * indicate significance at 1%, 5%, and 10%, respectively.

This evidence is consistent with *the risk-bearing channel*. According to this channel, following a decline in bank profitability, banks tend to take less risk. This is because they have less capital to absorb losses and to meet regulatory capital requirements. This channel operates in the opposite direction of *the reaching for yield channel*, which posits that a decrease in bank profitability encourages banks to take on more risk by lending to riskier firms.

This result aligns with the findings of Arce, Garcia-Posada, Mayordomo and Ongena (2021), who find that more exposed banks provide less credit to risky firms compared to their safer counterparts, and of Boungou (2020), who finds that banks taking less risks in countries after negative interest rates have been introduced.

4 Model

In this section, I present the model that I will use to study the aggregate effects of negative interest rate policies and to understand the role of capital-labor substitution in shaping these effects. This model will then be used for the numerical simulations in Section 5.

I utilize a New Keynesian DSGE model based on Ulate (2021), which extends Gertler and Karadi (2011) with monopolistic banks a la Gerali, Neri, Sessa and Signoretti (2010). While Ulate (2021) employs a Cobb Douglas production function, I use a normalized CES production function, which nests the Cobb Douglas production function. The novelty of my model is that it considers the role of capital-labor substitution in shaping the effects of negative interest rate policies, drawing from my empirical findings. Specifically, I consider different substitution elasticities between capital and labor in production—a critical but overlooked factor in debates about negative interest rate policies. As I discuss in subsequent sections, even minor variations in this elasticity of substitution between capital and labor in production have considerable implications for the economy, banks, and welfare.

The model consists of households, intermediate goods producers, capital producers, retailers, banks, government, and central bank. Households work, consume, and save through bank deposits. Intermediate goods firms use capital and labor to produce intermediate inputs. Retailers transform these inputs into retail goods, which are then used to produce final consumption goods. Capital producers produce new capital. Banks collect deposits from households, lend to intermediate goods firms, and invest in central bank reserves. The central bank conducts monetary policy through a Taylor rule and can set negative interest rates on reserves.

In addition, households exhibit habit formation, and capital producers face investment adjustment costs. These features help capture business cycles in a more realistic manner. They are essential for quantifying the role of capital-labor substitution in shaping the effects of negative interest rates and for welfare analysis

4.1 Households block

The economy is populated by a continuum of households of mass one. Households consume, C_t, supply labor, N_t, and save in bank deposits, D_t. Bank deposits are one-period contracts that yield nominal gross interest return $1 + i^d_{t-1}$ from period $t-1$ to t.

In the utility function below, β represents households' discount factor, h denotes their habit formation behavior, χ is labor utility weight, and η stands for the Frisch elasticity of labor supply.

Households maximize their expected lifetime discounted utility:

$$\max_{C_t, D_t} E_0 \sum_{t=0}^{\infty} \beta^t \left[\ln(C_t - hC_{t-1}) - \chi \frac{N_t^{1+\frac{1}{\eta}}}{1+\frac{1}{\eta}} \right], \tag{5}$$

subject to their budget constraint:

$$P_t C_t + D_t = W_t N_t + \Pi_t - T_t + (1 + i^d_{t-1}) D_{t-1}, \tag{6}$$

where P_t is price level, W_t is nominal wage, Π_t is nominal profits to households from ownership of banks and firms, T_t is nominal lump sum taxes.

The first order conditions are as follows with respect to labor supply, bank deposits, and consumption.

$$\chi N_t^{\frac{1}{\eta}} = \phi_t \frac{W_t}{P_t} \tag{7}$$

$$1 = E_t \left[\beta \Lambda_{t,t+1} (1 + i^d_t) \frac{P_t}{P_{t+1}} \right] \tag{8}$$

$$\phi_t = (C_t - hC_{t-1})^{-1} - \beta h E_t (C_{t+1} - hC_t)^{-1} \tag{9}$$

$$\Lambda_{t,t+1} = \frac{\phi_{t+1}}{\phi_t}, \tag{10}$$

where $\Lambda_{t,t+1}$ is the stochastic discount factor.

4.2 Firms block

There are three firms in this block: intermediate goods producers, capital producing firms, and retailers.

4.2.1 Intermediate goods producers

Intermediate goods producers produce intermediate inputs using capital and labor following the normalized CES production function.

I choose to work with the normalized CES production function for two reasons. First, the empirical results presented in the previous section suggest a potential departure from the Cobb Douglas production function concerning its elasticity of substitution between capital and labor. Given this, I aim to understand how responses to negative interest rate policies, as captured by the impulse response functions, vary when the elasticity differs from what the Cobb Douglas production function implies. Second, Cantore and Levine (2012) and others[5] argue that normalization of CES production function is essential when compare economies that are distinguished solely by their substitution parameters because using non-normalized CES production not only obscures calibration results but could also affect dynamic responses to shocks as the elasticity of output with respect to production inputs can change at different steady state. Without normalization, a meaningful and consistent comparison would be unattainable.

At the end of period $t-1$, intermediate good producers borrow an amount of capital K_t from their banks to use in the next period t in their production. After the production, they return the capital to their banks. And there are no capital adjustment costs at intermediate good producers.

The firm produces intermediate output Y_t^m according to the normalized CES production function relating their output (Y_t^m) to capital (K_t) and labor (N_t):

$$Y_t^m = Y_0 A_t \left[\alpha_0 \left(\frac{K_t}{K_0} \xi_t \right)^{\frac{\sigma-1}{\sigma}} + (1-\alpha_0) \left(\frac{N_t}{N_0} \right)^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}, \tag{11}$$

where σ is the elasticity of substitution between capital and labor, α_0 is capital share, and Y_0, K_0, N_0 are the steady-state values resulting from the normalization associated with the normalized CES production function. A_t denotes total factor productivity and ξ_t denotes the quality of capital.

Let P_t^m be the price of intermediate goods output. Then the firm chooses its labor demand as follows:

$$P_t^m (1-\alpha_0) \left(\frac{Y_0^m}{N_0} A_t \right)^{\frac{\sigma-1}{\sigma}} \left(\frac{Y_t^m}{N_t} \right)^{\frac{1}{\sigma}} = W_t. \tag{12}$$

And given that the firm earns zero profit, the stochastic nominal gross return for banks

[5] The other papers using the normalized CES production function are de la Grandville and Solow (2009); León-Ledesma, McAdam and Willman (2010); Klump, McAdam and Willman (2012); Cantore and Levine (2012); Cantore, Leon-Ledesma, McAdam and Willman (2014).

is given by

$$1 + i^l_{t+1} = \frac{Q_{t+1}\xi_{t+1}(1-\delta) + P^m_{t+1}\alpha_0\left(\frac{Y^m_0}{K_0}A_{t+1}\xi_{t+1}\right)^{\frac{\sigma-1}{\sigma}}\left(\frac{Y^m_{t+1}}{K_{t+1}}\right)^{\frac{1}{\sigma}}}{Q_t} \tag{13}$$

Intermediate goods producers face no financial frictions when obtaining capital from banks. Consequently, they are able to transfer all their residual stochastic returns to their banks. In a manner akin to Gertler and Karadi (2011), these producers effectively offer their banks a perfectly state-contingent security.

4.2.2 Capital producers

Capital producing firms produce new capital. However, when adjusting their investment, I_t, they face adjustment costs, which I denote with $f(\cdot)$. The evolution of capital is:

$$K_{t+1} = (1-\delta)\xi_t K_t + I_t. \tag{14}$$

Capital producing firms maximize discounted real profits:

$$\max_{I_\tau} E_t \sum_{\tau=t}^{\infty} \beta^{\tau-t}\Lambda_{t,\tau}\left\{\left(\frac{Q_\tau}{P_\tau}-1\right)I_\tau - f\left(\frac{I_\tau}{I_{\tau-1}}\right)I_\tau\right\}, \tag{15}$$

where $\Lambda_{t,\tau}$ denotes households stochastic discount factor between periods t and τ, as given in Equation 10.

The first order condition with respect to investment gives the real price of capital, $\frac{Q_t}{P_t}$:

$$\frac{Q_t}{P_t} = 1 + f\left(\frac{I_t}{I_{t-1}}\right) + f'\left(\frac{I_t}{I_{t-1}}\right)\frac{I_t}{I_{t-1}} - E_t\beta\Lambda_{t,t+1}f'\left(\frac{I_{t+1}}{I_t}\right)\left(\frac{I_{t+1}}{I_t}\right)^2. \tag{16}$$

4.2.3 Retailers

Each retail firm s uses intermediate inputs and costlessly transforms them into a differentiated variety of a retail good, $Y_t(s)$. And final output, Y_t, is a CES composite of a continuum of mass unity of differentiated retail firms.

$$Y_t = \left(\int_0^1 Y_t(s)^{\frac{\theta-1}{\theta}}ds\right)^{\frac{\theta}{\theta-1}}. \tag{17}$$

From the cost minimization of final good producer:

$$Y_t(s) = \left(\frac{P_t(s)}{P_t}\right)^{-\theta} Y_t \tag{18}$$

$$P_t = \left(\int_0^1 P_t(s)^{1-\theta} ds\right)^{\frac{1}{1-\theta}} \tag{19}$$

And the retail firm s is able to freely adjust its prices with probability $1 - \gamma$ and choose the optimal price $P_t^*(s)$ to solve

$$\max E_t \sum_{r=0}^{\infty} \gamma^r \beta^r \Lambda_{t,t+r} \frac{P_t}{P_{t+r}} [P_t^*(s) - P_{t+r}^m] Y_{t+r}(s). \tag{20}$$

The first-order condition related to price setting is:

$$1 = (1-\gamma)\left(\frac{P_t^*}{P_t}\right)^{1-\theta} + \gamma\left(\frac{P_{t-1}}{P_t}\right)^{1-\theta}. \tag{21}$$

The evolution of prices and dispersion of prices are as follows:

$$\Gamma_t^1 = \phi_t \varphi_t \frac{P_t^m}{P_t} Y_t + \gamma\beta E_t \left(\frac{P_t}{P_{t+1}}\right)^{-\theta} \Gamma_{t+1}^1 \tag{22}$$

$$\Gamma_t^2 = \phi_t \varphi_t \frac{P_t^*}{P_t} Y_t + \gamma\beta E_t \frac{P_t^*}{P_{t+1}^*} \left(\frac{P_t}{P_{t+1}}\right)^{-\theta} \Gamma_{t+1}^2 \tag{23}$$

where $\theta\Gamma_t^1 = (\theta - 1)\Gamma_t^2$. The relationship between final and intermediate outputs is:

$$Y_t^m = Y_t \nu_t^p, \tag{24}$$

where $\nu_t^p = \gamma\left(\frac{P_{t-1}}{P_t}\right)^{-\theta} \nu_{t-1}^p + (1-\gamma)\left(\frac{P_t^*}{P_t}\right)^{-\theta}$.

4.3 Banks block

Banks are from Ulate (2021), so I will keep the description of this bank block brief. There is a continuum of banks $j \in [0,1]$. Each bank operates under a monopolistic framework, exerting its influence both in deposit and loan markets. Let ϵ^l denote the loan elasticity of substitution and ϵ^d denote the deposit elasticity of substitution. Since all banks behave identically in equilibrium, I drop the subscript j in what follows.

Banks have equity F_t and determine the interest rate they charge on loans, denoted as i_t^l, the amount they lend, L_t, the interest rate they pay on deposits i_t^d, the amount of deposits they accept, D_t, and the amount of reserves they hold in the central bank, H_t, which earns the policy rate i_t. Consequently, banks have the following balance sheet identity (in real terms):

$$\frac{L_t}{P_t} + \frac{H_t}{P_t} = \frac{F_t}{P_t} + \frac{D_t}{P_t} \tag{25}$$

Banks maximize the presented discounted value of the dividends, DIV_{t+1}, that return to households.

$$\max E_t \sum_{s=0}^{\infty} \beta^{s+1} \Lambda_{t,t+s+1} DIV_{j,t+s+1} \tag{26}$$

where $\Lambda_{t,t+s+1}$ denotes households stochastic discount factor between period t and $t+s+1$. Banks pay a $1-\omega$ fraction of their total profits, denoted by X_t, as dividends. The remaining fraction ω of X_t will remain inside the bank to accumulate bank equity F_t, such that:

$$F_{t+1} = F_t(1-\zeta)(1+\pi_{t+1}) + \omega X_{t+1} \tag{27}$$

where ζ is the fraction of nominal bank equity used for bank managerial costs. Total profits net of managerial costs, and inclusive of an adjustment for inflation, X_t is:

$$X_{t+1} = i_t F_t + (i^l_{t+1} - \mu^l_t - i_t)L_t + (i_t + \mu^d_t - i^d_t)D_t - \Psi\left(\frac{L_t}{F_t}; \kappa, \nu\right)F_t - F_t(1-\zeta)\pi_{t+1} \tag{28}$$

where $\Psi(\cdot)$ represents costs associated with deviation from target loan-to-equity ratio, ν, (Gerali et al., 2010)[6]. μ^d_t represents benefits of issuing deposit and μ^l_t denotes cost of issuing loans (Ulate, 2021).

The first order conditions are as follows for deposit and loan rates, respectively.

$$1 + i^d_t = \frac{\epsilon^d}{\epsilon^d - 1}(1 + i_t + \mu^d_t) \tag{29}$$

$$E_t(1 + i^l_{t+1}) = \frac{\epsilon^l}{\epsilon^l - 1}(1 + i_t + \mu^l_t) + \kappa\nu\frac{\epsilon^l}{\epsilon^l - 1}\left(\ln\frac{L_t}{F_t} - \ln\nu\right) \tag{30}$$

4.4 Monetary policy and aggregate resource constraint

Output is divided between consumption, investment, government consumption, G_t, and adjustment costs. The economy-wide resource constraint is thus given by

$$Y_t = C_t + I_t + G_t + f\left(\frac{I_t}{I_{t-1}}\right)I_t + \mu^l_t\frac{L_{t-1}}{P_t} - \mu^d_t\frac{D_{t-1}}{P_t} + \zeta\frac{F_{t-1}}{P_t} + \Psi\left(\frac{L_{t-1}}{F_{t-1}}; \kappa, \nu\right)\frac{F_{t-1}}{P_t}, \tag{31}$$

[6]The costs associated with deviating from the target ratio are approximately quadratic cost, which is parameterized by coefficient κ. Using a quadratic cost is a modeling shortcut that captures the importance of bank capital in a tractable manner.

And total loans equal to value of capital:

$$L_t = Q_t K_{t+1} \tag{32}$$

The monetary policy is characterized by the following Taylor rule with interest-rate smoothing. Let i_t be the net nominal interest rate and $\bar{\imath}$ is the steady state nominal rate.

$$i_t = (1 - \rho_i)(\bar{\imath} + \Psi_\pi(\pi_t - \bar{\pi})) + \rho_i i_{t-1} + \epsilon_t^i \tag{33}$$

where ρ_i is smoothing parameter and ϵ_t^i denotes exogenous shock to monetary policy. The processes for the shocks (technology and government) are standard in the model. The lump sum transfers from government to households are given by: $T_t = H_t - (1 + i_{t-1})H_{t-1} - P_t G_t$.

5 Numerical simulations

I simulate the model using the Guerrieri and Iacoviello (2015) toolkit and their piecewise second-order perturbation approach to account for the occasionally binding constraints.

My crisis experiment is a shock to capital quality a la Gertler and Karadi (2011). The capital productivity declines by 2.5 percent on-impact, with an autocorrelation of 0.90. The fall in real bank equity due to the shock is similar to what the banks in Europe experienced after the Great Financial Crisis (Kalemli-Ozcan, Sorensen and Yesiltas, 2012). I compare the results obtained under three different scenarios.

1. Benchmark ZLB scenario: Deposit rate is constrained to be non-negative and policy rate can be negative but cannot pass –50 basis points. This scenario assumes that banks cannot pass negative interest rates onto their deposit rates, mirroring the real-world practice[7].

2. Counterfactual ZLB scenario: Both deposit rate and policy rate can be negative but they cannot pass –50 basis points. This scenario provides a theoretical alternative to the current real-world bank behavior.

3. Traditional ZLB scenario: Both deposit rate and policy are constrained to be non-negative. This scenario provides a theoretical alternative if the central bank does not opt for a negative interest rate policy.

[7] The lowest interest rate set by the ECB is –50 basis points.

I first focus on the Benchmark ZLB scenario with the Counterfactual ZLB scenario. Within these models, I compare their lending responses. My objective is to quantify the additional credit that banks would extend if they either passed on negative rates to depositors or diversified their funding sources. This conclusion is drawn from my causally identified empirical estimates. The difference in lending between these scenarios plays a crucial role in my calibration, which aims to determine the elasticity of substitution in the production function. Specifically, I will use the difference in lending between these scenarios to determine the elasticity of substitution between capital and labor in the production function, employing a moment-matching exercise in line with Nakamura and Steinsson (2018).

After determining the elasticity parameter, I will then assess the aggregate effects of negative interest rate policies using the calibrated model. Subsequently, I compare responses of the Benchmark ZLB scenario to the Traditional ZLB scenario. My goal is to study the aggregate effects of negative interest rate policies because my empirical estimates do not capture these effects due to the time fixed effects present in my rich fixed effect structure.

I examine the impact of the elasticity of substitution between capital and labor in the production function on the economy under the Benchmark ZLB scenario. I consider various levels of elasticity parameters that are from the literature while maintaining both the size of the shock and its persistence the same.

5.1 Calibrating the elasticity of substitution between capital and labor in the production

In this section, I calibrate the parameter for the elasticity of substitution between capital and labor in the normalized CES production function of the model. I follow a calibration strategy similar to Nakamura and Steinsson (2018). I use estimates from my bank lending regressions. These estimates serve as well-identified macro moments suitable for moment-matching exercise, thus providing target moments for the theoretical model.

I choose a target moment based on my cross-sectional estimate of bank lending. This target moment quantifies the additional bank credit that might have been provided if banks were not subject to the zero lower bound on their deposits. In the theoretical model, I compare the differences in bank lending under two scenarios: the Benchmark ZLB, where banks cannot pass on negative rates, and the Counterfactual ZLB, where they can. This comparison quantifies the additional credit banks would extend if they either passed on negative rates to depositors or diversified their funding sources. I then choose the elasticity of substitution between capital and labor in the production function so that the lending difference matches the target.

Table 9: Model Parameters

Parameter	Definition	Value	Parameter	Definition	Value
β	Discount factor	0.9937	ω	Fraction staying in bank	1/9
h	Habit parameter	0.815	ζ	Bank managerial cost	0.01
χ	Utility weight of labor	3.409	ν	Loan-to-equity ratio target	9
η	Frisch elasticity	1	κ	Cost of deviating from target	0.0012
α	Capital share	0.33	ϵ^d	Deposits elasticity of substitution	-268
δ	Depreciation rate	0.025	ϵ^l	Loans elasticity of substitution	203
υ	Inverse elasticity of investment	1.728	μ^d	Benefits of issuing deposits	0.25%
θ	Elasticity of substitution among goods	6	μ^l	Cost of issuing loans	0.25%
γ	Probability of keeping prices fixed	0.75	$\bar{H}/\bar{F}$	Reserves-to-equity ratio	2
ψ_π	Inflation coefficient, Taylor rule	3.5			
ρ_i	Smoothing parameter, Taylor rule	0.8			
g	Steady state G/Y	0.2			

Notes: Parameters used in the model. The substitution elasticity σ between capital and labor in the CES production is calibrated using the cross-sectional estimates within the model.

My empirical coefficient estimate indicates a 1.30 percent increase in lending in response to a 22 percent decrease in the deposit-to-asset ratio following the implementation of negative interest rate policies.

$$0.013 \approx -0.0594 \times -0.22 \tag{34}$$

A 22% decrease in the deposit-to-asset ratio corresponds to the difference in the mean deposit-to-asset ratio between high-deposit banks (those with a deposit-to-asset ratio above the median in the distribution) and low-deposit banks. Therefore, the 22% difference in the deposit-to-asset ratio between high-deposit and low-deposit banks helps us understand and quantify the magnitude of extra credit that low-deposit banks might provide relative to high-deposit banks. Essentially, I am allowing every bank in my sample to utilize more wholesale funding, thereby reducing the pressure due to the zero lower bound constraint on deposit rates.[8]

The figure above represents annual growth. Since my model is based on quarters, I need to convert this to quarterly growth. This conversion can be approximated by dividing the annual growth by 4.

$$0.0032 \approx -0.0594 \times -0.22 \times \frac{1}{4} \tag{35}$$

Hence, in my model, I aim to capture this change in credit growth, amounting to 32 basis points, between the Benchmark ZLB scenario and the Counterfactual ZLB scenario.

In my model, in the Benchmark ZLB scenario, banks cannot pass on negative rates to their depositors. However, in the Counterfactual ZLB scenario, they can. By comparing lending responses between these scenarios, I aim to quantify the additional credit that banks would extend if they were to pass on negative rates to depositors or if they diversified their funding sources. Alternative funding sources, such as wholesale funding, bonds, or interbank loans, do not face the same zero lower bound challenges as traditional deposit accounts do.

Figure 2 illustrates the on-impact difference in the percentage deviation of lending from its steady-state level between the Benchmark scenario and the Counterfactual scenario, plotted as a function of the elasticity of substitution between capital and labor. From the figure, it is evident that when the elasticity of substitution parameter is set to 1.25, the difference in lending responses between the two scenarios matches the empirical estimate from my regression, which amounts to 32 basis points. This elasticity value aligns with the estimates of Karabarbounis and Neiman (2014), who found it to be 1.25 using cross-country data, and with Hubmer (2023), who estimated it at 1.35 based on US data.

For robustness, I follow the same steps and procedures as in my previous analysis. However, this time, my objective is to match the differences in interest rates rather than lending. The results derived from this alternative approach align with my earlier findings, further validating the reliability of my calibrated elasticity of substitution parameter. As depicted in Figure 3, when the elasticity of substitution parameter is set at 1.25, the difference in interest rate outcomes between the two scenarios aligns with the empirical finding from my regression, amounting to 39 basis points.

[8] One can observe similar changes in the deposit-to-asset ratio by examining the differences between high-deposit and low-deposit banks at the 5th, 25th, 50th, 75th, and 95th percentiles.

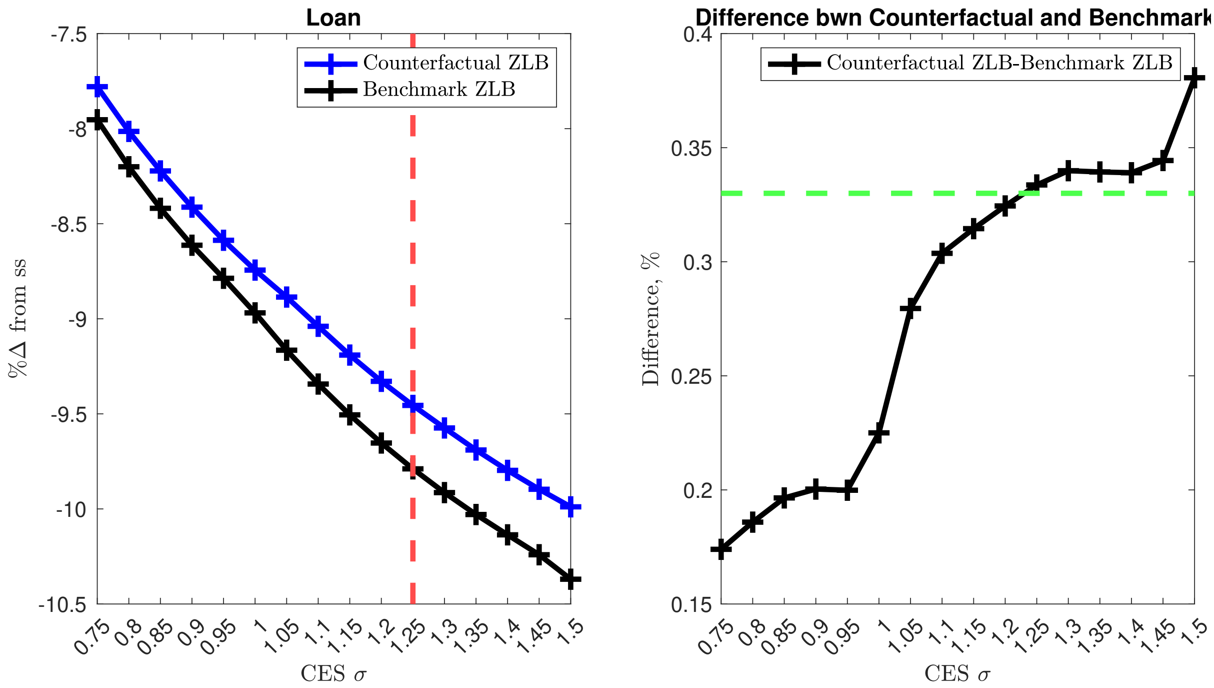


Figure 2: Calibrating CES σ to match the empirical estimates based on lending.

Notes: The figure on the left depicts the on-impact percentage deviation of lending from its steady-state level for both the Benchmark scenario (in black line) and the Counterfactual scenario (in blue line), plotted as a function of the elasticity of substitution between capital and labor. The figure on the right depicts the on-impact difference between these two lines as a function of the elasticity of substitution between capital and labor.

5.2 Evaluating negative interest rate policies

In this section, I evaluate the aggregate effects of negative interest rate policies and conduct a welfare analysis using the calibrated model. Subsequently, I compare the responses of the Benchmark ZLB scenario to the Traditional ZLB scenario.

Figure 4 shows the impulse response functions of the most important variables in the model to the shock to capital productivity under two scenarios. The Benchmark ZLB scenario is plotted in the blue line and the Traditional ZLB scenario is plotted in the red line. The impulse response function for the policy rate, the deposit rate, and the loan spread defined as the spread between the expected loan rate and the policy rate are plotted in annualized levels in percentage points. The rest of the impulse response functions are plotted as percent deviations from their steady states.

Figure 4 shows that in the Benchmark ZLB scenario, the policy rate is stuck at its limit of –50 basis points, while in the Traditional ZLB scenario, it remains at the zero lower bound. Due to this, output in the Benchmark ZLB scenario drops less than in the Traditional ZLB scenario because the central bank stimulates the economy by reducing the policy rate. Although the consumption response between these two scenarios

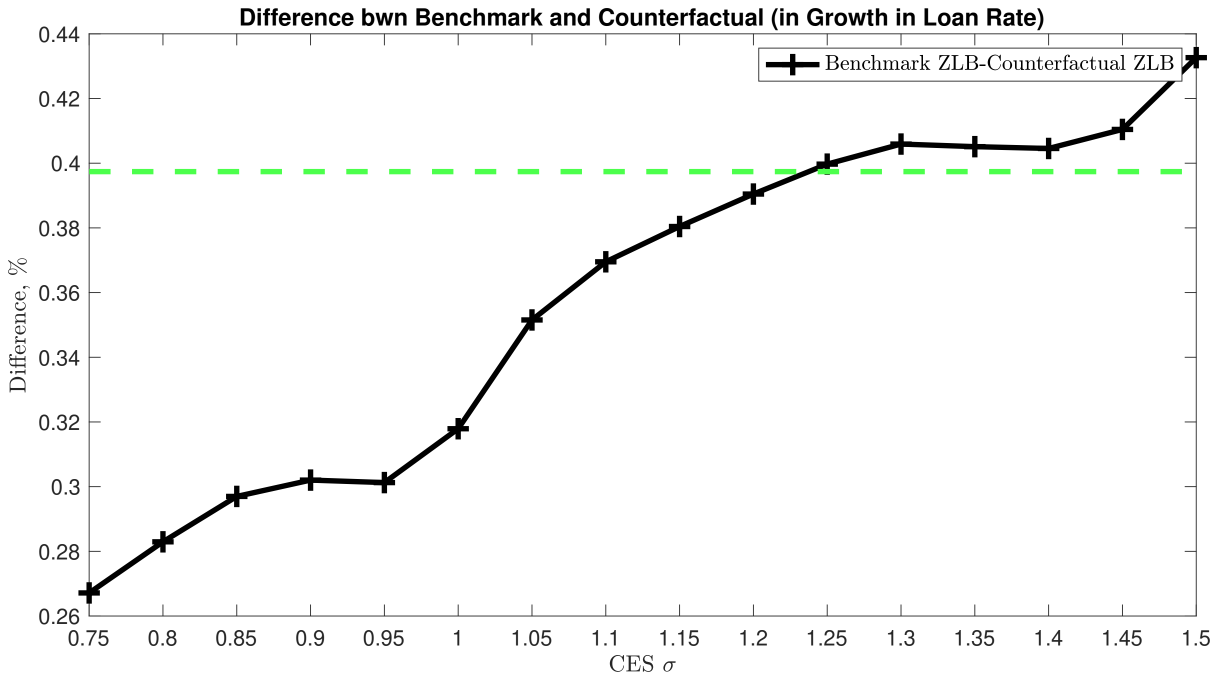


Figure 3: Calibrating CES σ to match the empirical estimates based on the interest rate.

Notes: The figure depicts the on-impact difference as percentage deviation of interest rate from its steady-state level between the Benchmark scenario and the Counterfactual scenario, plotted as a function of the elasticity of substitution between capital and labor.

does not show a vast difference like in the output, it is worth noting that consumption is slightly lower in the Traditional ZLB scenario.

When examining bank results, it is observed that bank equity declines more significantly in the Traditional ZLB scenario. The extra decrease is approximately equal to 1.5 percent. This is due to banks charging higher loan spreads, resulting in decreased lending. Consequently, their profitability suffers, leading to reduced equity.

5.2.1 Welfare implications

I evaluate the welfare implications of two scenarios in terms of consumption equivalent units, relative to steady-state allocations. These allocations correspond to a situation where there is no shock to capital productivity in the first quarter.

I calculate λ_j, which represents the percent deviation from consumption without the shock, where $j \in \{\textit{Benchmark ZLB}, \textit{Traditional ZLB}\}$.

$$\text{Welfare}_j = \sum_{t=0}^{\infty} \beta^t \left[\ln((1-\lambda_j)C_{ss} - (1-\lambda_j)hC_{ss}) - \chi \frac{N_{ss}^{1+\frac{1}{\eta}}}{1+\frac{1}{\eta}} \right] \tag{36}$$

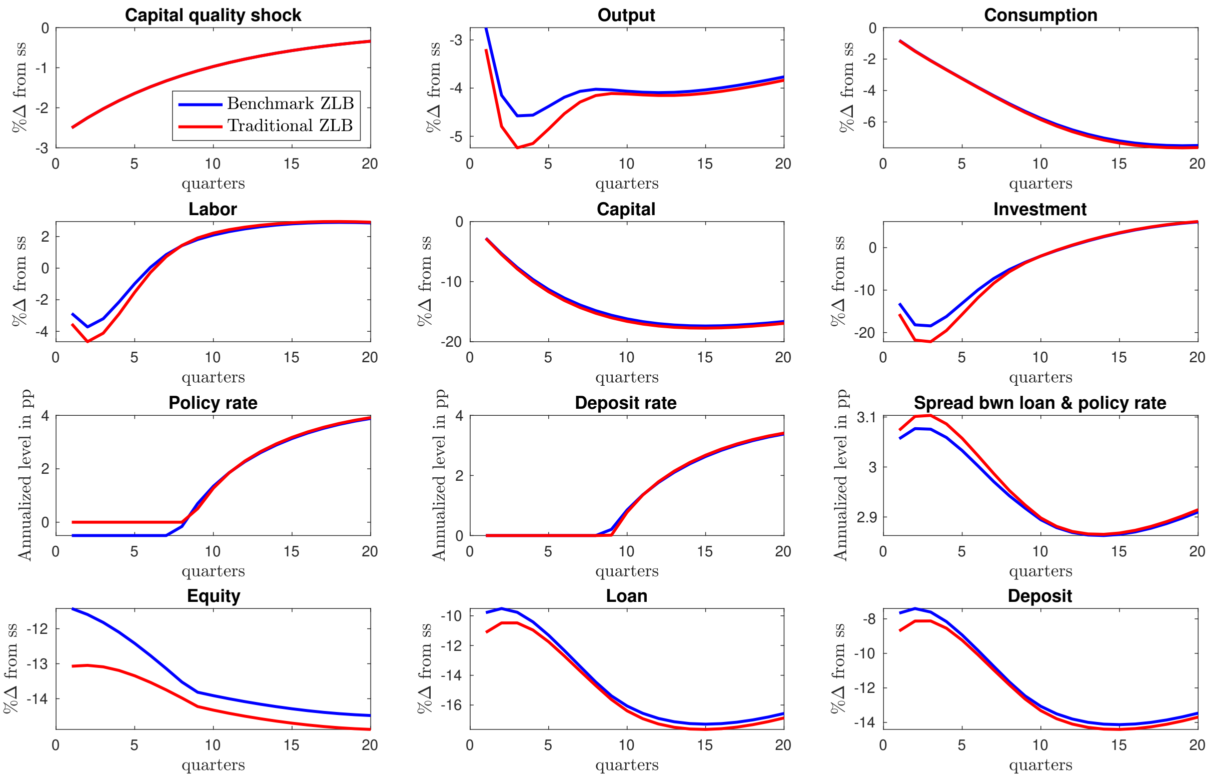


Figure 4: IRFs to capital quality shock.

Notes: The figure depicts the IRFs of some of the main variables in the model to a capital productivity shock under the Benchmark ZLB scenario (in blue line) and the Traditional ZLB scenario (in red line) with the calibrated model where CES $\sigma = 1.25$. The x–axis is in quarters and y–axis is percent deviation from the steady state for capital quality shock, output, consumption, labor, capital, equity, loan, and deposit, and in annualized percentage points for policy rate, deposit, and spread between loan rate and policy rate.

where C_{ss} (N_{ss}) is the consumption (labor) at steady-state.

$$\text{Welfare}_j = \sum_{t=0}^{\infty} \beta^t \left[\ln(C_{j,t} - hC_{j,t-1}) - \chi \frac{N_{j,t}^{1+\frac{1}{\eta}}}{1+\frac{1}{\eta}} \right] \tag{37}$$

where $C_{j,t}$ ($N_{j,t}$) is the consumption (labor) in scenario j at period t.

I find that $\lambda_{Benchmark\ ZLB} = 2.43\%$ and $\lambda_{Traditional\ ZLB} = 2.45\%$. The difference between these two is equal to 0.2 basis points.

I also conduct a welfare analysis in util terms, expressing the results as percent deviation relative to a situation without the shock. I find that the deviation is 101.7 basis points under the Traditional ZLB scenario, while it is 100 basis points in the Benchmark ZLB scenario.

Based on the welfare analysis, both in terms of consumption equivalent and utils measures, it is evident that negative interest rate policies result in a smaller drop in welfare. While the difference is not substantial, this still underscores the effectiveness of negative interest rate policies as a tool for central banks, leading to notable welfare improvements.

5.3 Role of elasticity of substitution between capital and labor in production

In this section, I examine how the elasticity of substitution between capital and labor in the production function impacts the economy under the Benchmark ZLB scenario, considering various levels of elasticity parameters. I keep the size of the shock and its persistence as in the previous section.

Figure 5 below presents the impulse response functions of key variables in the model, responding to the shock to capital productivity, across three different elasticity parameters. CES σ takes the following three values: $\sigma \in \{0.75, 1.00, 1.25\}$. The first case, CES $\sigma = 0.75$, indicates that capital and labor are gross complements. The second corresponds to a Cobb Douglas production function. The third represents my estimate, which served as the benchmark used in the previous section, and in this case, capital and labor are gross substitutes.

5.3.1 Results and mechanism behind them

Figure 5 shows that when there is a negative shock to capital quality, making capital less productive, a higher elasticity of substitution between capital and labor magnifies labor market outcomes in equilibrium. Specifically, this higher elasticity leads to a more pronounced decline in labor and a correspondingly higher wage rate at equilibrium. This amplified response arises due to two key reasons. First, when there is an increased elasticity of substitution, the marginal product of capital decreases more substantially. This affects households' intertemporal decisions between current consumption and savings. As the return on capital drops more sharply (and savings yield less), households choose to consume more and save less. This decision leads to a more pronounced decrease in labor supply with a higher elasticity of substitution, as households work fewer hours. Second, an increase in the elasticity of substitution allows firms to more easily substitute labor for capital. This leads to a lesser decrease in the marginal product of labor, resulting in a less significant reduction in labor demand.

A higher elasticity of substitution results in a more pronounced drop in both labor and investment, which subsequently leads to a more pronounced decrease in output.

After a negative shock to capital productivity, the marginal product of capital declines more sharply if the elasticity of substitution is high. This is because firms can more easily substitute capital with labor under these conditions. The return on bank

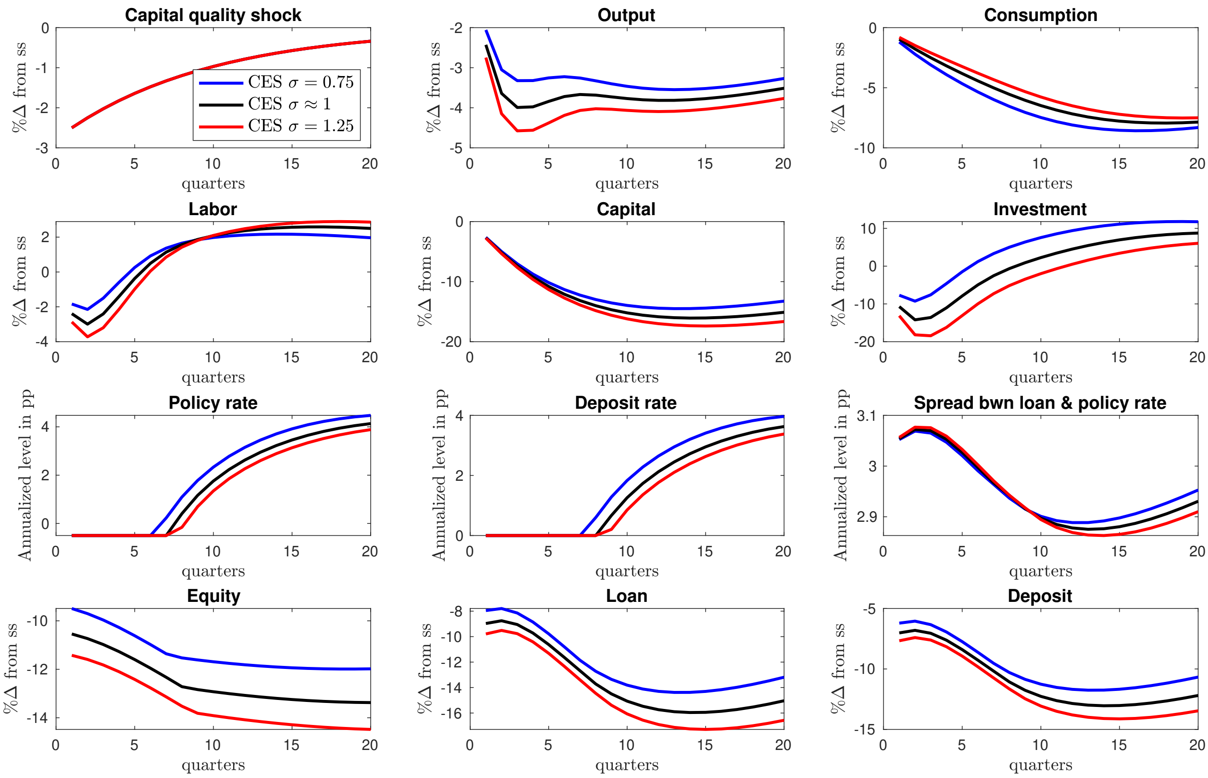


Figure 5: IRFs to capital productivity shock with different substitution elasticity.

Notes: The figure depicts the IRFs of some of the main variables in the model to a capital productivity shock under the Benchmark ZLB scenario for when CES σ = 0.75 (in blue line), CES $\sigma \approx$ 1.00 (in black line), and CES σ = 1.25 (in red line). The x–axis is in quarters and y–axis is percent deviation from the steady state for capital quality shock, output, consumption, labor, capital, equity, loan, and deposit, and in annualized percentage points for policy rate, deposit, and spread between loan rate and policy rate.

loans, which are stochastic and tied to the marginal product of capital, also faces a more pronounced drop. This results in banks experiencing a steeper decrease in their profitability. In turn, this leads to a more substantial decrease in bank equity and a larger deviation from its steady state.

In essence, a higher elasticity of substitution in the production function amplifies banks' vulnerability. This stems from firms' ability to easily switch between capital and labor, leading to a more pronounced reduction in capital demand and, consequently, a decreased demand for bank loans when there is a negative shock to capital productivity.

Shocks to capital productivity are highly persistent, with an autocorrelation of 0.90. This means that capital remains less productive for a prolonged period compared to its steady state level. Consequently, the demand for capital remains lower over an extended period. As a result, the gap in bank equity between a model with high elasticity and one with low elasticity remains significant and elevated.

With high elasticity, bank equity and, consequently, profitability drop more significantly. In response to this, banks increase their loan spread, charging firms higher loan rates to regain some of their equity losses. This leads to a more pronounced decrease in the amount of loans banks provide when elasticity is high. Additionally, banks collect fewer deposits because they offer lower rates on these deposits. This results in a more pronounced decrease in the volume of deposits banks collect when elasticity is high.

In Figure 6, I highlight the effect of elasticity on the on-impact (the effect in the first quarter) rather than over all 20 quarters in the impulse response function. This is shown using various sigma values, $\sigma \in \{0.75, \dots, 1.00, \dots, 1.50\}$.

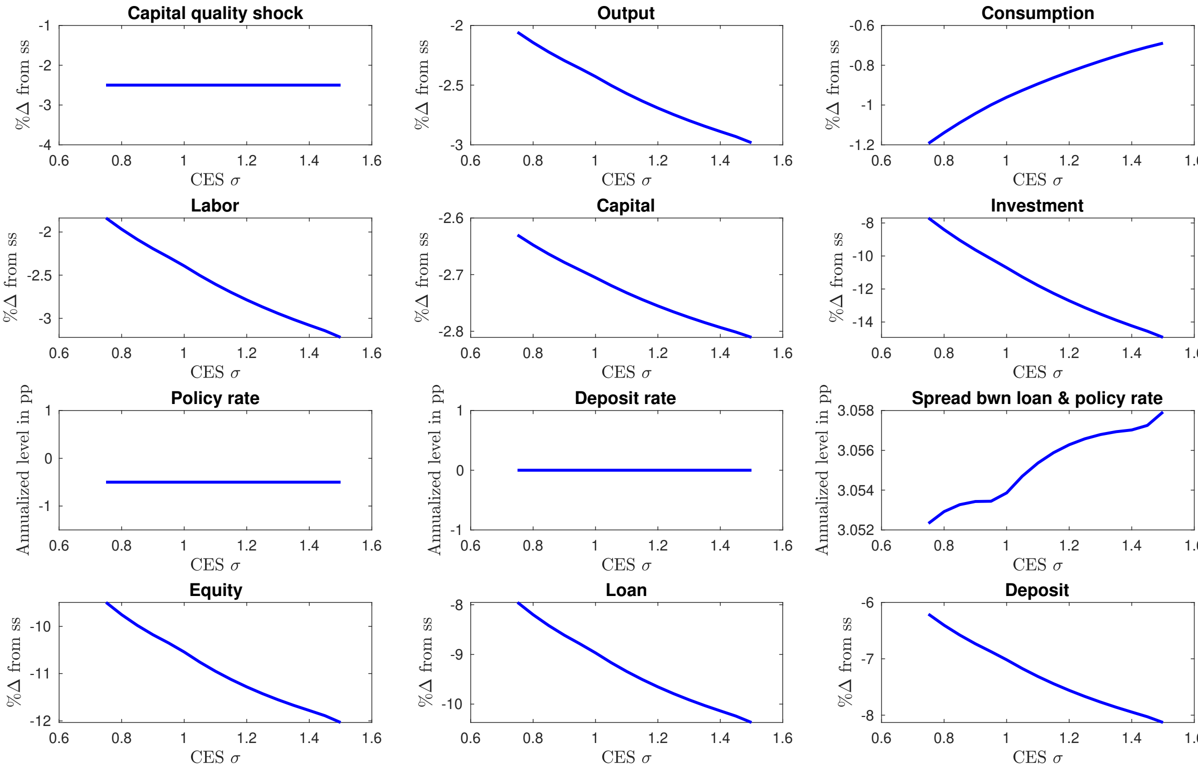


Figure 6: On-impact responses to capital productivity shock with different substitution elasticity.

Notes: The figure depicts the on-impact response of some of the main variables in the model to a capital productivity shock under the Benchmark ZLB scenario for CES $\sigma \in \{0.75, \dots, 1.00, \dots, 1.50\}$. The x–axis is in quarters and y–axis is percent deviation from the steady state for capital quality shock, output, consumption, labor, capital, equity, loan, and deposit, and in annualized percentage points for policy rate, deposit, and spread between loan rate and policy rate.

5.3.2 Effects of elasticity of substitution between capital and labor in production on banks

In this section, I aim to explore the implications of different elasticity of substitution parameters on banks. Specifically, I will compare CES $\sigma = 1$, which corresponds to

Cobb Douglas production function prevalent in the literature, against CES σ = 1.25, the estimate derived from my empirical work using a moment-matching exercise consistent with the methodology of Nakamura and Steinsson (2018).

Figure 7 plots the bank leverage following the shock to capital productivity. In response to the same negative shock to capital productivity, banks in an economy with the elasticity of substitution of 1.25 experience an additional 26 basis points drop in their capital ratio compared to banks in an economy with the elasticity of substitution of 1. While this finding is based on the model, I will now explore its broader implications using external estimates outside of the model to offer a more tangible interpretation of the results.

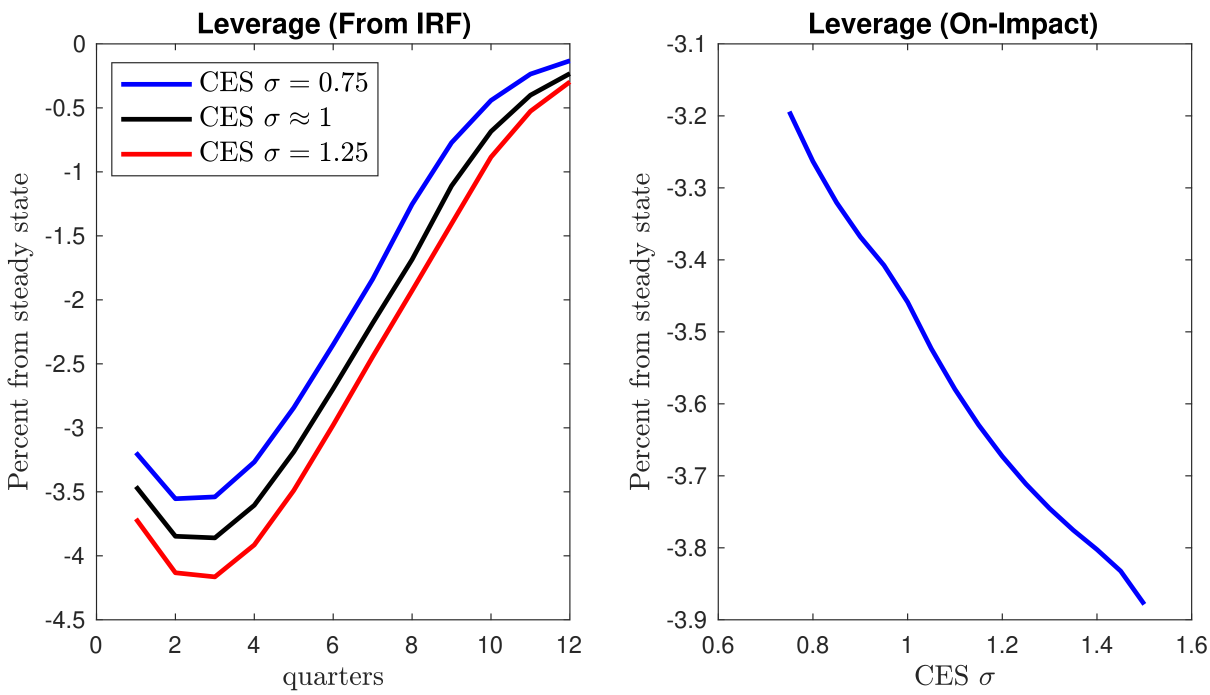


Figure 7: Bank leverage to response to capital productivity shock.

Notes: The figure on the left depicts the IRFs of bank leverage in the model to a capital productivity shock under the Benchmark ZLB scenario for CES σ ∈ {0.75, 1.00, 1.25}. The figure on the right is the on-impact percentage deviation of bank leverage from its steady state level for CES σ ∈ {0.75, . . . , 1.00, . . . , 1.50}.

Using Berger and Bouwman (2013) estimates, this additional decrease in capital ratio (or increase in leverage) significantly amplifies the probability of default across various economic situations—an 8.15% surge during a banking crisis, 11.38% during a market crisis, and 10.72% in normal times. Additionally, drawing insights from Laeven et al. (2016), the leverage increase also increases the dollar value of bank losses during crises. It amounts to an increase of US$0.91 billion for a bank with total assets of $100 billion. Lastly, when examining the effect on bank stock returns according to the findings of Demirgunc-Kunt et al. (2013), there is an additional decrease of 14.3 basis points in stock returns each quarter. This corresponds to roughly 3% of the median quarterly decrease of 4.7% observed during crisis periods. These sizable bank effects underscore that even slight deviations from the prevailing assumption in the production function, like the one presented in my paper, can lead to substantial consequences with important implications for both banks and central banks.

5.3.3 Effects of elasticity of substitution between capital and labor in production on welfare

Figure 8 plots the deviation in consumption relative to the case without the shock to capital productivity for the Benchmark ZLB scenario (in blue line) and the Traditional ZLB scenario (in red line), as a function of the elasticity of substitution between capital and labor. This is similar to the exercise in Section 5.2.1. The figure shows that welfare gains from implementing negative interest rate policies, measured as the difference between the Benchmark ZLB scenario and the Traditional ZLB scenario increases in CES σ because the economic downturn is larger when the substitution between capital and labor in production is higher.

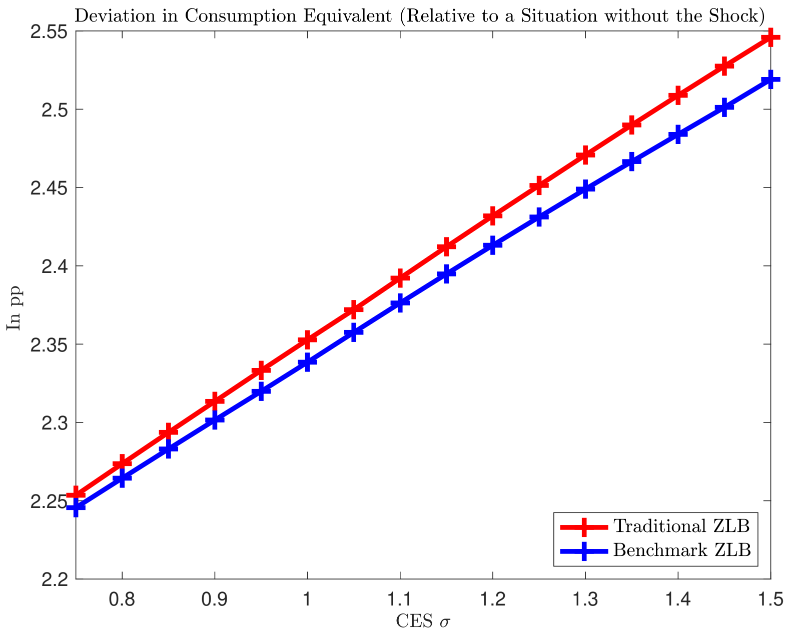


Figure 8: Deviation in consumption equivalent terms relative to situation without shock to capital productivity.

Notes: The figure depicts the percent deviation from consumption without shock to capital productivity for the Benchmark ZLB scenario (in blue line) and the Traditional ZLN scenario (in red line), plotted as a function of the elasticity of substitution between capital and labor.

6 Conclusion

In this paper, I present both empirical evidence and theoretical analyses on the effects of negative interest rate policies. Using matched firm-bank level data that I construct from seven euro area countries, I document that banks with higher deposit ratios supply less credit to firms relative to those with lower deposit ratios after the introduction of these policies. The dataset enables more precise identification of the effects compared to other studies. This precision arises because I can construct four-digit-industry-country-year and firm fixed effects, which allow for more comprehensive control of the demand for bank credit. I then show that, while firms linked to banks with higher deposit ratios invest less in response to lending contractions, they tend to hire more relative to firms associated with banks with lower deposit ratios, especially in industries with high capital-labor substitution.

Motivated by my empirical analysis, I utilize my cross-sectional estimates, serving as well-identified macro moments, in a moment-matching exercise to inform the production block of the DSGE model. I then use this model to examine the impact of negative interest rate policies on aggregate variables and welfare over time. My analysis underscores that negative interest rate policies are effective in stimulating the economy. Additionally, my findings indicate that higher capital-labor substitution in production surprisingly leads to a larger economic downturn when there is a negative shock to capital productivity. Furthermore, my findings emphasize that even minor variations in the elasticity of substitution can have significant implications for the economy, banks, and welfare.

References

Abadi, Joseph, Markus Brunnermeier, and Yann Koby (2023) "The Reversal Interest Rate," *American Economic Review*, 113 (8), 2084–2120.

Almeida, Heitor, Murillo Campello, Bruno Laranjeira, and Scott Weisbenner (2012) "Corporate Debt Maturity and the Real Effects of the 2007 Credit Crisis," *Critical Finance Review*, 1 (1), 3–58.

Altavilla, Carlo, Miguel Boucinha, José-Luis Peydró, and Frank Smets (2020) "Banking Supervision, Monetary Policy and Risk-Taking: Big Data Evidence from 15 Credit Registers," Working Papers 1137, Barcelona School of Economics, https://ideas.repec.org/p/bge/wpaper/1137.html.

Altavilla, Carlo, Lorenzo Burlon, Mariassunta Giannetti, and Sarah Holton (2022) "Is There a Zero Lower Bound? The Effects of Negative Policy Rates on Banks and Firms," *Journal of Financial Economics*, 144 (3), 885–907.

Ampudia, Miguel and Skander J. Van den Heuvel (2022) "Monetary Policy and Bank Equity Values in a Time of Low and Negative Interest Rates," *Journal of Monetary Economics*, 130 (C), 49–67.

Amzallag, Adrien, Alessandro Calza, Dimitris Georgarakos, and João Sousa (2019) "Monetary Policy Transmission to Mortgages in a Negative Interest Rate Environment," Working Paper Series 2243, European Central Bank, https://EconPapers.repec.org/RePEc:ecb:ecbwps:20192243.

Arce, Oscar, Miguel Garcia-Posada, Sergio Mayordomo, and Steven Ongena (2021) "Adapting Lending Policies in a "Negative-for-Long" Scenario," Swiss Finance Institute Research Paper Series 21-75, Swiss Finance Institute, https://ideas.repec.org/p/chf/rpseri/rp2175.html.

Balloch, Cynthia, Yann Koby, and Mauricio Ulate (2022) "Making Sense of Negative Nominal Interest Rates," Working Paper Series 2022-12, Federal Reserve Bank of San Francisco.

Balloch, Cynthia Mei and Yann Koby (2019) "Low Rates and Bank Loan Supply: Theory and Evidence from Japan."

Basten, Christoph and Mike Mariathasan (2018) "How Banks Respond to Negative Interest Rates: Evidence from the Swiss Exemption Threshold,"Technical report.

Berger, Allen N. and Christa H.S. Bouwman (2013) "How Does Capital Affect Bank Performance During Financial Crises?" *Journal of Financial Economics*, 109 (1), 146–176.

Bittner, Christian, Diana Bonfim, Florian Heider, Farzad Saidi, Glenn Schepens, and Carla Soares (2022) "The Augmented Bank Balance-Sheet Channel of Monetary Policy," Working Paper Series 2745, European Central Bank, https://ideas.repec.org/p/ecb/ecbwps/20222745.html.

Bottero, Margherita, Camelia Minoiu, José-Luis Peydró, Andrea Polo, Andrea F. Presbitero, and Enrico Sette (2022) "Expansionary yet different: Credit supply and real effects of negative interest rate policy," *Journal of Financial Economics*, 146 (2), 754–778.

Boungou, Whelsy (2020) "Negative interest rates policy and banks' risk-taking: Empirical evidence," *Economics Letters*, 186, 108760.

Cantore, Cristiano, Miguel Leon-Ledesma, Peter McAdam, and Alpo Willman (2014) "Shocking Stuff: Technology, Hours, and Factor Substitution," *Journal of the European Economic Association*, 12 (1), 108–128, https://EconPapers.repec.org/RePEc:bla:jeurec:v:12:y:2014:i:1:p:108-128.

Cantore, Cristiano and Paul Levine (2012) "Getting Normalization Right: Dealing with 'Dimensional Constants' in Macroeconomics," *Journal of Economic Dynamics and Control*, 36 (12), 1931–1949, https://EconPapers.repec.org/RePEc:eee:dyncon:v:36:y:2012:i:12:p:1931-1949.

de Groot, Oliver and Alexander Haas (2023) "The Signalling Channel of Negative Interest Rates," *Journal of Monetary Economics*.

Degryse, Hans, Olivier De Jonghe, Sanja Jakovljević, Klaas Mulier, and Glenn Schepens (2019) "Identifying Credit Supply Shocks with Bank-Firm Data: Methods and Applications," *Journal of Financial Intermediation*, 40 (C).

Demiralp, Selva, Jens Eisenschmidt, and Thomas Vlassopoulos (2021) "Negative interest rates, excess liquidity and retail deposits: Banks' reaction to unconventional monetary policy in the euro area," *European Economic Review*, 136, 103745.

Demirgunc-Kunt, Asli, Enrica Detragiache, and Ouarda Merrouche (2013) "Bank Capital: Lessons from the Financial Crisis," *Journal of Money, Credit and Banking*, 45 (6), 1147–1164.

Eggertsson, Gauti B, Ragnar E Juelsrud, Lawrence H Summers, and Ella Getz Wold (2023) "Negative Nominal Interest Rates and the Bank Lending Channel*," *The Review of Economic Studies*, rdad085.

Eisenschmidt, Jens and Frank Smets (2019) "Negative Interest Rates: Lessons from the Euro Area," in Álvaro Aguirre, Markus Brunnermeier, and Diego Saravia eds.

Monetary Policy and Financial Stability: Transmission Mechanisms and Policy Implications, 26 of Central Banking, Analysis, and Economic Policies Book Series, Chap. 2, 013–042: Central Bank of Chile, https://ideas.repec.org/h/chb/bcchsb/v26c02pp013-042.html.

Gerali, Andrea, Stefano Neri, Luca Sessa, and Federico M. Signoretti (2010) "Credit and Banking in a DSGE Model of the Euro Area," *Journal of Money, Credit and Banking*, 42 (s1), 107–141.

Gertler, Mark and Peter Karadi (2011) "A model of unconventional monetary policy," *Journal of Monetary Economics*, 58 (1), 17–34, Carnegie-Rochester Conference Series on Public Policy: The Future of Central Banking April 16-17, 2010.

Giannetti, Mariassunta and Steven Ongena (2012) ""Lending by example": Direct and indirect effects of foreign banks in emerging markets," *Journal of International Economics*, 86 (1), 167–180, https://EconPapers.repec.org/RePEc:eee:inecon:v:86:y:2012:i:1:p:167-180.

Girotti, Mattia, Guillaume Horny, and Jean-Guillaume Sahuc (2022) "Lost in Negative Territory? Search for Yield!,"Technical report.

Grandi, Pietro and Marianne Guille (2023) "Banks, deposit rigidity and negative rates," *Journal of International Money and Finance*, 133, 102810.

de la Grandville, O. and R.M. Solow (2009) *Economic Growth: A Unified Approach*: Cambridge University Press, https://books.google.com/books?id=0maXETIw5LQC.

Guerrieri, Luca and Matteo Iacoviello (2015) "OccBin: A toolkit for solving dynamic models with occasionally binding constraints easily," *Journal of Monetary Economics*, 70, 22–38.

Heider, Florian, Farzad Saidi, and Glenn Schepens (2019) "Life below Zero: Bank Lending under Negative Policy Rates," *The Review of Financial Studies*, 32 (10), 3728–3761.

——— (2021) "Banks and Negative Interest Rates," *Annual Review of Financial Economics*, 13 (1), 201–218, https://EconPapers.repec.org/RePEc:anr:refeco:v:13:y:2021:p:201-218.

Herrendorf, Berthold, Christopher Herrington, and Ákos Valentinyi (2015) "Sectoral Technology and Structural Transformation," *American Economic Journal: Macroeconomics*, 7 (4), 104–33.

Hong, Gee Hee and John Kandrac (2022) "Pushed Past the Limit? How Japanese Banks Reacted to Negative Rates," *Journal of Money, Credit and Banking*, 54 (4), 1027–1063, https://EconPapers.repec.org/RePEc:wly:jmoncb:v:54:y:2022:i:4:p:1027-1063.

Hubmer, Joachim (2023) "The Race Between Preferences and Technology," *Econometrica*, 91 (1), 227–261.

Kalemli-Ozcan, Sebnem, Bent Sorensen, Carolina Villegas-Sanchez, Vadym Volosovych, and Sevcan Yesiltas (2015) "How to Construct Nationally Representative Firm Level Data from the Orbis Global Database: New Facts and Aggregate Implications," Working Paper 21558, National Bureau of Economic Research.

Kalemli-Ozcan, Sebnem, Bent Sorensen, and Sevcan Yesiltas (2012) "Leverage across firms, banks, and countries," *Journal of International Economics*, 88 (2), 284–298, NBER Global.

Kalemli-Özcan, Sebnem, Luc Laeven, and David Moreno (2022) "Debt Overhang, Rollover Risk, and Corporate Investment: Evidence from the European Crisis," *Journal of the European Economic Association*, 20 (6), 2353–2395, https://ideas.repec.org/a/oup/jeurec/v20y2022i6p2353-2395..html.

Karabarbounis, Loukas and Brent Neiman (2014) "The Global Decline of the Labor Share*," *The Quarterly Journal of Economics*, 129 (1), 61–103.

Klump, Rainer, Peter McAdam, and Alpo Willman (2012) "The Normalized Ces Production Function: Theory And Empirics," *Journal of Economic Surveys*, 26 (5), 769–799.

Knoblach, Michael and Fabian Stöckl (2020) "What Determines The Elasticity Of Substitution Between Capital And Labor? A Literature Review," *Journal of Economic Surveys*, 34 (4), 847–875.

Kopecna, Vedunka, Milan Scasny, and Lukas Recka (2020) "Estimating Elasticity of Substitution in CES Production Function: Examining Different Nesting Structures and EU Regions," Working Papers IES 2020/43, Charles University Prague, Faculty of Social Sciences, Institute of Economic Studies, https://ideas.repec.org/p/fau/wpaper/wp2020_43.html.

Kwan, Simon H., Mauricio Ulate, and Ville Voutilainen (2023) "The Transmission of Negative Nominal Interest Rates in Finland," Working Paper Series 2023-11, Federal Reserve Bank of San Francisco, https://EconPapers.repec.org/RePEc:fip:fedfwp:96029.

Laeven, Luc, Peter McAdam, and Alexander Popov (2023) "Credit shocks, employment protection, and growth:firm-level evidence from spain," *Journal of Banking Finance*, 152, 106850.

Laeven, Luc, Lev Ratnovski, and Hui Tong (2016) "Bank size, capital, and systemic risk: Some international evidence," *Journal of Banking Finance*, 69, S25–S34, Bank Capital.

León-Ledesma, Miguel A., Peter McAdam, and Alpo Willman (2010) "Identifying the Elasticity of Substitution with Biased Technical Change," *American Economic Review*, 100 (4), 1330–57.

Lopez, Jose A., Andrew K. Rose, and Mark M. Spiegel (2020) "Why have negative nominal interest rates had such a small effect on bank performance? Cross country evidence," *European Economic Review*, 124, 103402.

Nakamura, Emi and Jón Steinsson (2018) "Identification in Macroeconomics," *Journal of Economic Perspectives*, 32 (3), 59–86.

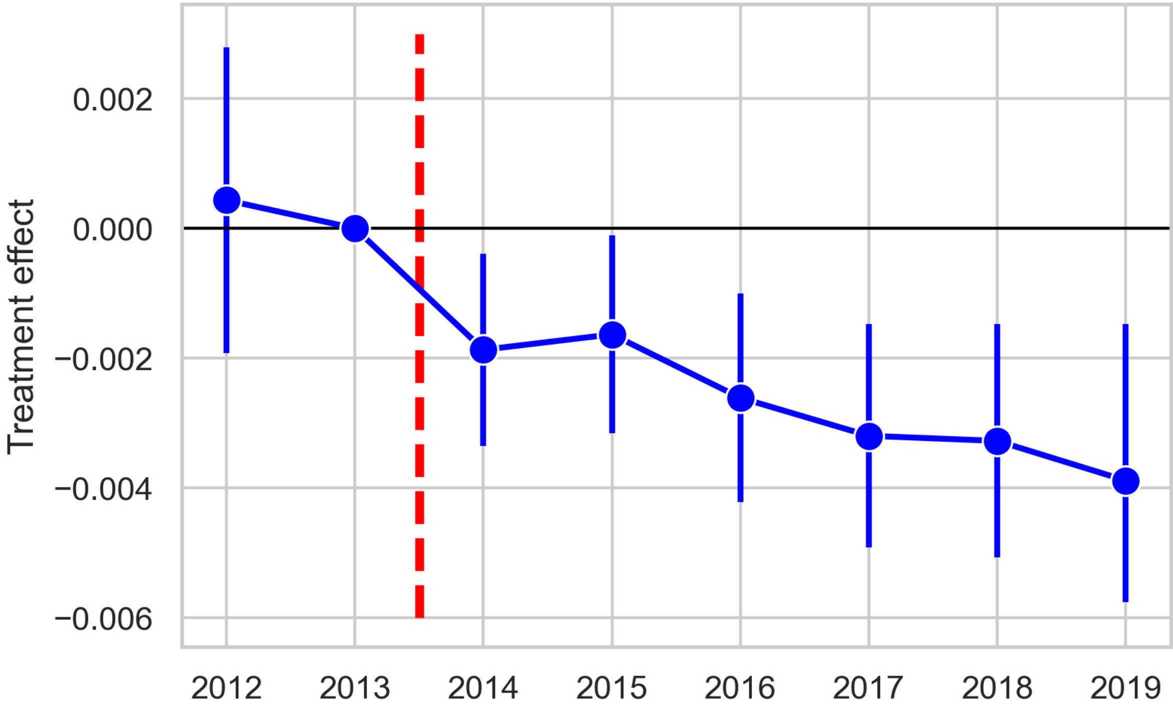
Ongena, Steven, Jose-Luis Peydro, and Neeltje Van Horen (2015) "Shocks Abroad, Pain at Home? Bank-Firm-Level Evidence on the International Transmission of Financial Shocks," *IMF Economic Review*, 63 (4), 698–750, http://www.jstor.org/stable/24738123.

Onofri, Marco, Gert Peersman, and Frank Smets (2023) "The effectiveness of a negative interest rate policy," *Journal of Monetary Economics*.

Schelling, Tan and Pascal Towbin (2022) "What lies beneath—Negative interest rates and bank lending," *Journal of Financial Intermediation*, 51, 100969.

Ulate, Mauricio (2021) "Going Negative at the Zero Lower Bound: The Effects of Negative Nominal Interest Rates," *American Economic Review*, 111 (1), 1–40.

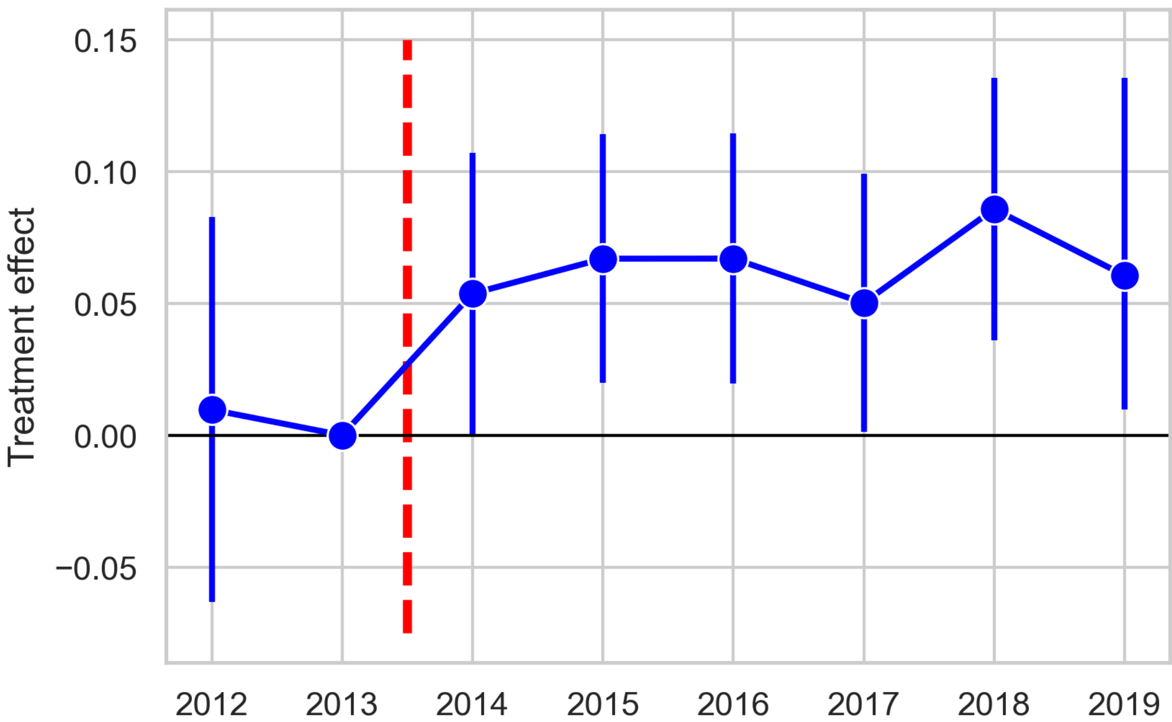
A Checking parallel trends



Note: This figure plots the coefficient estimates $\hat{\beta}_t$ of the following model at the bank-firm level.

$$\text{Leverage}_{isct} = \sum_{t=2012}^{2019} \beta_t D_{Year=t} \times \text{Deposit ratio}_b + \alpha_b + \delta_{sct} + \gamma' X_{isct-1} + \epsilon_{isct}$$

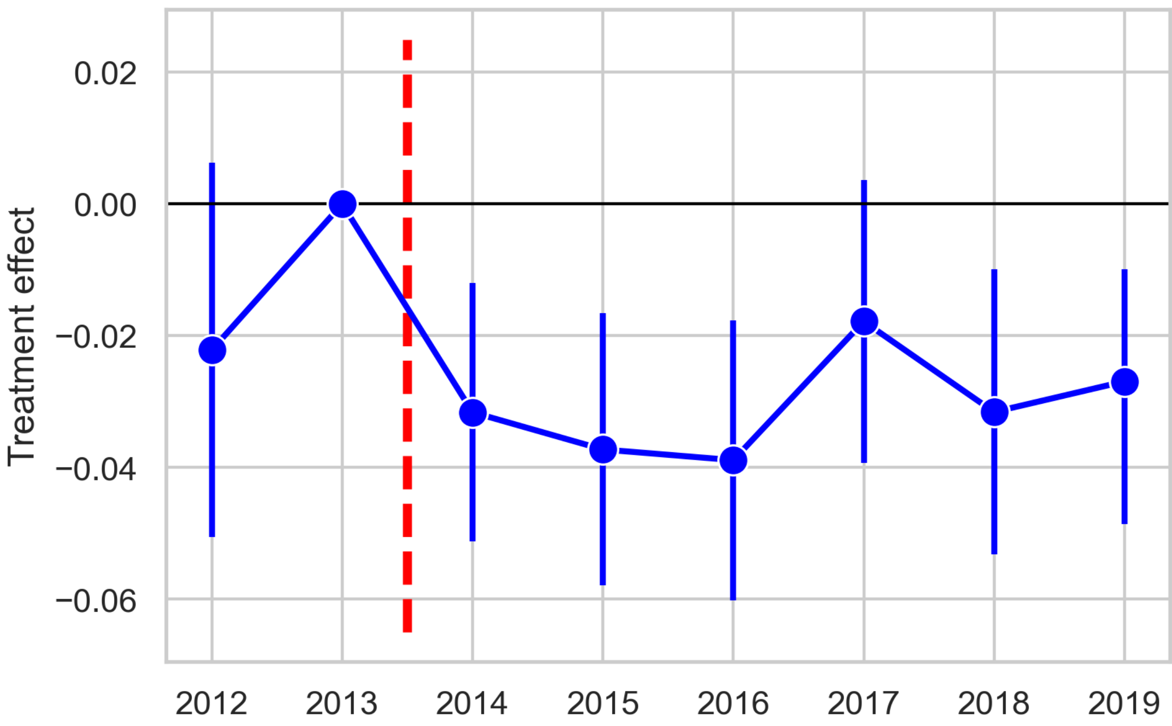
$\hat{\beta}_t$ is time-varying treatment effect of negative rates on loan growth. Vertical bars correspond to 90% confidence intervals. $D_{Year=t}$ is dummy variable taking the value one if the year is equal to t, where $t = \{2012, \ldots, 2019\}$. The year 2013 is the reference year. The dependent variable is leverage at the firm level and is calculated as the ratio of total liabilities to total assets in period t. The deposit ratio denotes the ratio of deposits over total assets (in %) for the year 2013. The set of firm control variables (not reported) includes i) size, measured as the logarithm of total assets, ii) leverage, defined as the ratio of total liabilities to total assets, iii) sales growth, measured as the annual change in the natural logarithm of sales, iv) cash, defined as the ratio of cash and cash equivalents to total assets. Bank fixed effects are included. Country-Industry-Time fixed effects are based on four-digit NACE Rev.2 codes. Robust standard errors are clustered at the bank level.



Note: This figure plots the coefficient estimates $\hat{\beta}_t$ of the following model at the bank-firm level.

$$\text{Cash growth}_{isct} = \sum_{t=2012}^{2019} \beta_t D_{Year=t} \times \text{Deposit ratio}_b + \alpha_b + \delta_{sct} + \gamma' X_{isct-1} + \epsilon_{isct}$$

$\hat{\beta}_t$ is time-varying treatment effect of negative rates on loan growth. Vertical bars correspond to 90% confidence intervals. $D_{Year=t}$ is dummy variable taking the value one if the year is equal to t, where $t = \{2012, \ldots, 2019\}$. The year 2013 is the reference year. The dependent variable is cash growth at the firm level and is calculated as the difference in the natural logarithm of cash and cash equivalent between periods t and $t-1$. The deposit ratio denotes the ratio of deposits over total assets (in %) for the year 2013. The set of firm control variables (not reported) includes i) size, measured as the logarithm of total assets, ii) leverage, defined as the ratio of total liabilities to total assets, iii) sales growth, measured as the annual change in the natural logarithm of sales, iv) cash, defined as the ratio of cash and cash equivalents to total assets. Bank fixed effects are included. Country-Industry-Time fixed effects are based on four-digit NACE Rev.2 codes. Robust standard errors are clustered at the bank level.



Note: This figure plots the coefficient estimates $\hat{\beta}_t$ of the following model at the bank-firm level.

$$\text{Net investment}_{isct} = \sum_{t=2012}^{2019} \beta_t D_{Year=t} \times \text{Deposit ratio}_b + \alpha_b + \delta_{sct} + \gamma' X_{isct-1} + \epsilon_{isct}$$

$\hat{\beta}_t$ is time-varying treatment effect of negative rates on loan growth. Vertical bars correspond to 90% confidence intervals. $D_{Year=t}$ is dummy variable taking the value one if the year is equal to t, where $t = \{2012, \ldots, 2019\}$. The year 2013 is the reference year. The dependent variable is net investment at the firm level and is calculated as the difference in the natural logarithm of tangible fixed assets between periods t and $t-1$. The deposit ratio denotes the ratio of deposits over total assets (in %) for the year 2013. The set of firm control variables (not reported) includes i) size, measured as the logarithm of total assets, ii) leverage, defined as the ratio of total liabilities to total assets, iii) sales growth, measured as the annual change in the natural logarithm of sales, iv) cash, defined as the ratio of cash and cash equivalents to total assets. Bank fixed effects are included. Country-Industry-Time fixed effects are based on four-digit NACE Rev.2 codes. Robust standard errors are clustered at the bank level.

B Robustness

Table 10: Negative Interest Rates and Output

Dependent variable:	Material expenses growth		Sales growth	
	(1)	(2)	(3)	(4)
Deposit ratio × Post	0.000885		0.00170	
(%)	(0.00899)		(0.00589)	
Deposit ratio × Post		0.000382		0.000551
(0/1)		(0.00319)		(0.00219)
Firm Control	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Country-Industry-Time FE	Yes	Yes	Yes	Yes
Observations	776848	776848	969229	969229
R^2	0.179	0.179	0.243	0.243

Notes: The table presents OLS estimates of the following model at the bank-firm level.

$$\text{Material expenses growth}_{isct} = \beta \text{Deposit ratio}_b \times \text{Post}_t + \alpha_i + \delta_{sct} + \gamma' X_{isct-1} + \epsilon_{isct}$$
$$\text{Sales growth}_{isct} = \beta \text{Deposit ratio}_b \times \text{Post}_t + \alpha_i + \delta_{sct} + \gamma' X_{isct-1} + \epsilon_{isct}$$

The dependent variable in Columns (1) and (2) is material expenses growth at the firm level and is calculated as the difference in the natural logarithm of material expenses between periods t and $t-1$. The dependent variable in Columns (3) and (4) is sales growth at the firm level and is calculated as the difference in the natural logarithm of sales between periods t and $t-1$. The deposit ratio, presented in Columns (1) and (3), denotes the ratio of deposits over total assets (in %) for the year 2013. In Columns (2) and (4), the deposit ratio is assigned a value of one if the ratio of deposits to total assets in 2013 is above the median of its respective country's distribution. Post is a dummy variable representing the period from 2014 onward. The set of firm control variables (not reported) includes i) size, measured as the logarithm of total assets, ii) leverage, defined as the ratio of total liabilities to total assets, iii) sales growth, measured as the annual change in the natural logarithm of sales, iv) cash, defined as the ratio of cash and cash equivalents to total assets. Bank fixed effects are included. Country-Industry-Time fixed effects are based on four-digit NACE Rev.2 codes. Robust standard errors, clustered at the bank level, are in parentheses. ***, **, and * indicate significance at 1%, 5%, and 10%, respectively.

Table 11: Negative Interest Rates and Small and Large Firms - Loan Growth

Dependent variable:	Loan growth			
	(1)	(2)	(3)	(4)
Sample:	Small to large firms		Very large firms	
Deposit ratio × Post	-0.0537**		-0.0193	
(%)	(0.0253)		(0.119)	
Deposit ratio × Post		-0.0192**		-0.0336
(0/1)		(0.00764)		(0.0503)
Firm Control	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes
Country-Industry-Time FE	Yes	Yes	Yes	Yes
Observations	713065	713065	19489	19489
R^2	0.0279	0.0279	0.197	0.197

Notes: The table presents OLS estimates of the following model at the bank-firm level.

$$\text{Loan growth}_{isct} = \beta \text{Deposit ratio}_b \times \text{Post}_t + \alpha_b + \delta_{sct} + \gamma' X_{isct-1} + \epsilon_{isct}$$

The dependent variable is loan growth at the firm-bank level and is calculated as the difference in the natural logarithm of credit between periods t and $t-1$. The sample is restricted to small, medium-sized, and large firms in Columns (1) and (2). The sample is restricted to very large firms in Columns (3) and (4). Credit refers to the sum of long- and short-term financial debt recorded in Orbis. The deposit ratio, presented in Columns (1) and (2), denotes the ratio of deposits over total assets (in %) for the year 2013. In Columns (3) and (4), the deposit ratio is assigned a value of one if the ratio of deposits to total assets in 2013 is above the median of its respective country's distribution. Post is a dummy variable representing the period from 2014 onward. The set of firm control variables (not reported) includes i) size, measured as the logarithm of total assets, ii) leverage, defined as the ratio of total liabilities to total assets, iii) sales growth, measured as the annual change in the natural logarithm of sales, iv) cash, defined as the ratio of cash and cash equivalents to total assets. Bank fixed effects are included. Country-Industry-Time fixed effects are based on four-digit NACE Rev.2 codes. Robust standard errors, clustered at the bank level, are in parentheses. ***, **, and * indicate significance at 1%, 5%, and 10%, respectively.

Table 12: Negative Interest Rates and Small and Large Firms - Interest Rate Growth

Dependent variable:	Interest rate growth			
	(1)	(2)	(3)	(4)
Sample:	Small to large firms		Very large firms	
Deposit ratio × Post	0.0853**		-0.276*	
(%)	(0.0354)		(0.154)	
Deposit ratio × Post		0.0241**		-0.0611
(0/1)		(0.0102)		(0.0720)
Firm Control	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes
Country-Industry-Time FE	Yes	Yes	Yes	Yes
Observations	558844	558844	18447	18447
R^2	0.0305	0.0305	0.209	0.209

Notes: The table presents OLS estimates of the following model at the bank-firm level.

$$\text{Interest rate growth}_{isct} = \beta \text{Deposit ratio}_b \times \text{Post}_t + \alpha_b + \delta_{sct} + \gamma' X_{isct-1} + \epsilon_{isct}$$

The dependent variable is interest rate growth at the firm-bank level and is calculated as the difference in the natural logarithm of interest rate between periods t and $t-1$. Interest rate refers the ratio of interest expenses to the sum of both long- and short-term financial debt as recorded in Orbis. The sample is restricted to small, medium-sized, and large firms in Columns (1) and (2). The sample is restricted to very large firms in Columns (3) and (4). Credit refers to the sum of long- and short-term financial debt recorded in Orbis. The deposit ratio, presented in Columns (1) and (2), denotes the ratio of deposits over total assets (in %) for the year 2013. In Columns (3) and (4), the deposit ratio is assigned a value of one if the ratio of deposits to total assets in 2013 is above the median of its respective country's distribution. Post is a dummy variable representing the period from 2014 onward. The set of firm control variables (not reported) includes i) size, measured as the logarithm of total assets, ii) leverage, defined as the ratio of total liabilities to total assets, iii) sales growth, measured as the annual change in the natural logarithm of sales, iv) cash, defined as the ratio of cash and cash equivalents to total assets. Bank fixed effects are included. Country-Industry-Time fixed effects are based on four-digit NACE Rev.2 codes. Robust standard errors, clustered at the bank level, are in parentheses. ***, **, and * indicate significance at 1%, 5%, and 10%, respectively.

Table 13: Negative Interest Rates and Small and Large Firms - Investment

Dependent variable:	Net investment			
	(1)	(2)	(3)	(4)
Sample:	Small to large firms		Very large firms	
Deposit ratio × Post	-0.0264***		0.0170	
(%)	(0.0101)		(0.0421)	
Deposit ratio × Post		-0.00619**		0.0213
(0/1)		(0.00304)		(0.0165)
Firm Control	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Country-Industry-Time FE	Yes	Yes	Yes	Yes
Observations	927521	927521	24435	24435
R^2	0.211	0.211	0.329	0.330

Notes: The table presents OLS estimates of the following model at the bank-firm level.

$$\text{Net investment}_{isct} = \beta \text{Deposit ratio}_b \times \text{Post}_t + \alpha_i + \delta_{sct} + \gamma' X_{isct-1} + \epsilon_{isct}$$

The dependent variable is net investment at the firm level and is calculated as the difference in the natural logarithm of tangible fixed assets between periods t and $t-1$. The sample is restricted to small, medium-sized, and large firms in Columns (1) and (2). The sample is restricted to very large firms in Columns (3) and (4). The deposit ratio, presented in Columns (1) and (2), denotes the ratio of deposits over total assets (in %) for the year 2013. In Columns (3) and (4), the deposit ratio is assigned a value of one if the ratio of deposits to total assets in 2013 is above the median of its respective country's distribution. Post is a dummy variable representing the period from 2014 onward. The set of firm control variables (not reported) includes i) size, measured as the logarithm of total assets, ii) leverage, defined as the ratio of total liabilities to total assets, iii) sales growth, measured as the annual change in the natural logarithm of sales, iv) cash, defined as the ratio of cash and cash equivalents to total assets. Bank fixed effects are included. Country-Industry-Time fixed effects are based on four-digit NACE Rev.2 codes. Robust standard errors, clustered at the bank level, are in parentheses. ***, **, and * indicate significance at 1%, 5%, and 10%, respectively.

Table 14: Negative Interest Rates and Small and Large Firms - Employment

Dependent variable:	Employment growth		Employee expenses growth	
	(1)	(2)	(3)	(4)
Sample:	Small to large	Very large	Small to large	Very large
Deposit ratio × Post	0.00224	-0.0163	0.00332	-0.0261
(%)	(0.00783)	(0.0355)	(0.00571)	(0.0234)
Firm Control	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Country-Industry-Time FE	Yes	Yes	Yes	Yes
Observations	679484	19008	834027	24084
R^2	0.187	0.358	0.223	0.324

Notes: The table presents OLS estimates of the following model at the bank-firm level.

$$\text{Employment growth}_{isct} = \beta \text{Deposit ratio}_b \times \text{Post}_t + \alpha_i + \delta_{sct} + \gamma' X_{isct-1} + \epsilon_{isct}$$
$$\text{Employee expenses growth}_{isct} = \beta \text{Deposit ratio}_b \times \text{Post}_t + \alpha_i + \delta_{sct} + \gamma' X_{isct-1} + \epsilon_{isct}$$

The dependent variable in Columns (1) and (2) is employment growth at the firm level and is calculated as the difference in the natural logarithm of number of employees between periods t and $t-1$. The sample is restricted to small, medium-sized, and large firms in Columns (1) and (3). The sample is restricted to very large firms in Columns (2) and (4). The dependent variable in Columns (3) and (4) is employee expenses growth at the firm level and is calculated as the difference in the natural logarithm of employee expenses between periods t and $t-1$. Employee expenses refer to the employees costs of the company (including pension costs) in Orbis. The deposit ratio denotes the ratio of deposits over total assets (in %) for the year 2013. Post is a dummy variable representing the period from 2014 onward. The set of firm control variables (not reported) includes i) size, measured as the logarithm of total assets, ii) leverage, defined as the ratio of total liabilities to total assets, iii) sales growth, measured as the annual change in the natural logarithm of sales, iv) cash, defined as the ratio of cash and cash equivalents to total assets. Bank fixed effects are included. Country-Industry-Time fixed effects are based on four-digit NACE Rev.2 codes. Robust standard errors, clustered at the bank level, are in parentheses. ***, **, and * indicate significance at 1%, 5%, and 10%, respectively.

Table 15: Negative Interest Rates and France

Dependent Variable:	Loan growth	
	(1)	(2)
Sample:	Firms in France	
Deposit ratio × Post	-0.0631**	-0.0639**
(%)	(0.0308)	(0.0308)
Firm Control	No	Yes
Bank FE	Yes	Yes
Industry-Time FE	Yes	Yes
Observations	308422	308422
R^2	0.0156	0.0166

Notes: The table presents OLS estimates of the following model at the bank-firm level.

$$\text{Loan growth}_{isct} = \beta \text{Deposit ratio}_b \times \text{Post}_t + \alpha_b + \delta_{sct} + \gamma' X_{isct-1} + \epsilon_{isct}$$

The dependent variable is loan growth at the firm-bank level and is calculated as the difference in the natural logarithm of credit between periods t and $t-1$. Credit refers to the sum of long- and short-term financial debt recorded in Orbis. The sample is restricted to firms in France. The deposit ratio, presented in Columns (1) and (2), denotes the ratio of deposits over total assets (in %) for the year 2013. Post is a dummy variable representing the period from 2014 onward. The set of firm control variables (not reported) includes i) size, measured as the logarithm of total assets, ii) leverage, defined as the ratio of total liabilities to total assets, iii) sales growth, measured as the annual change in the natural logarithm of sales, iv) cash, defined as the ratio of cash and cash equivalents to total assets. Bank fixed effects are included. Industry-Time fixed effects are based on four-digit NACE Rev.2 codes. Robust standard errors, clustered at the bank level, are in parentheses. ***, **, and * indicate significance at 1%, 5%, and 10%, respectively.

Table 16: Negative Interest Rates and Other Loan Growth Measures

Dependent Variable	ln Loan		Loan-to-Asset	
	(1)	(2)	(3)	(4)
Deposit ratio × Post	-0.0600**		-0.00985**	
(%)	(0.0290)		(0.00427)	
Deposit ratio × Post		-0.0164*		-0.00322***
(0/1)		(0.00954)		(0.00103)
Firm Control	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes
Country-Industry-Time FE	Yes	Yes	Yes	Yes
Observations	780287	780287	1020109	1020109
R^2	0.484	0.484	0.343	0.343

Notes: The table presents OLS estimates of the following model at the bank-firm level.

$$\ln \text{Loan}_{isct} = \beta \text{Deposit ratio}_b \times \text{Post}_t + \alpha_b + \delta_{sct} + \gamma' X_{isct-1} + \epsilon_{isct}$$
$$\text{Loan-to-Asset}_{isct} = \beta \text{Deposit ratio}_b \times \text{Post}_t + \alpha_b + \delta_{sct} + \gamma' X_{isct-1} + \epsilon_{isct}$$

The dependent variable in Columns (1) and (2) is the natural logarithm of credit at the firm-bank level in period t. The dependent variable in Columns (3) and (4) is the ratio of credit-to-asset at the firm-bank level in period t. Credit refers to the sum of long- and short-term financial debt recorded in Orbis. The deposit ratio, presented in Columns (1) and (3), denotes the ratio of deposits over total assets (in %) for the year 2013. In Columns (2) and (4), the deposit ratio is assigned a value of one if the ratio of deposits to total assets in 2013 is above the median of its respective country's distribution. Post is a dummy variable representing the period from 2014 onward. The set of firm control variables (not reported) includes i) size, measured as the logarithm of total assets, ii) leverage, defined as the ratio of total liabilities to total assets, iii) sales growth, measured as the annual change in the natural logarithm of sales, iv) cash, defined as the ratio of cash and cash equivalents to total assets. Bank fixed effects are included. Country-Industry-Time fixed effects are based on four-digit NACE Rev.2 codes. Robust standard errors, clustered at the bank level, are in parentheses. ***, **, and * indicate significance at 1%, 5%, and 10%, respectively.