Empirical Evidence of the Lending Channel of Monetary Policy under Negative Interest Rates

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Abstract

Does the lending channel of monetary policy operate under a negative interest rate policy (NIRP)? The purpose of this study is to shed light on the existence of a lending channel of monetary policy under NIRP. To do so, we aim to provide an in-depth analysis of the relationship between NIRP and bank-lending behavior. To achieve this, we employ a large panel dataset of 4072 banks operating in 54 countries over the period 2009-2018 and a Difference-in-Differences methodology. We find that banks located in countries affected by negative interest rates have adjusted their bank-lending behavior by increasing lending activities. Our findings suggest that in response to negative interest rates, banks have reduced their lending cost, and increased lending supply, particularly loans with maturities ranging from 3 to 12 months and those over 5 years. Finally, we also find that the transmission of monetary policy under negative interest rates to the real economy depends on banks' specific characteristics such as reliance on retail deposits and size.

JEL codes**:** E43, E51, E52, F34, G21.

Keywords**:** Negative interest rates, Lending cost, Lending supply, Lending maturity, Difference-in-Differences estimation.

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« *The use of interest rates […] has been quite efficient in order to lower the financing costs. […] We are still seeing credit expansion.* »
(Christine Lagarde)[1]

1. Introduction

In response to the Great Financial Crisis of 2007-2009, several central banks have implemented unprecedented monetary policy measures, so-called unconventional monetary policies (UMPs). These new measures, mainly focused on banks, aim to stimulate post-crisis economies characterized by low growth and low inflation.

Since 2012, in addition to existing UMPs measures, seven central banks in Europe as well as the Bank of Japan have moved one of their main policy rates into negative territory.[2] The introduction of a negative interest rate policy (NIRP) aims to tax banks' excess reserves so that they can be used to increase the lending supply. Indeed, NIRP has been implemented to improve banks' funding and liquidity conditions, and ultimately increase the supply and demand for credit. Moreover, Schwaab (2017) argues that this accommodative monetary policy gives banks an incentive to lend to the real sector, and as a result support growth and a return of inflation to levels that are consistent with the central banks' objective of price stability. A crucial question then arises: Does the lending channel of monetary policy operate under a negative interest rate policy? In other words, how do banks change their lending-behavior in a negative interest rate environment?

The conventional view is that in normal times the central bank remunerates banks' excess reserves in order to regulate the liquidity in circulation, in line with its objective of price stability. However, in times characterized by low economic growth and low inflation, the central bank takes decisions to support economic activity, for example, through the lending channel. To this end, the taxation of reserves aims to increase the cost of holding reserves with the central bank, and thus encourages an increase in the supply of credit by reducing both bank and borrower financing costs (Coeuré, 2016). However, credit expansion depends on the transmission of negative interest rates to the lending rate and the retail deposit rate (Brunnermeier and Koby, 2018). Indeed, if the transmission of negative interest rate is not perfect, it would squeeze banks' interest margins (Boungou, 2019, Lopez et al. 2020, Molyneux et al. 2019) and thus reduce their incentive to lend to the real economy (Hannoun, 2015).

The assumption that NIRP could reduce the banks' interest margins (NIM) is based on the fact that the increase in the lending supply, linked to excess reserves, is not accompanied by a reduction in both the rate on loans and the rate on retail deposits. Indeed, as noted by Jobst and Lin (2016), banks' NIM compresses as rates on new

[1] ECB Press Conference at Frankfurt am Main on 12 December 2019.
[2] Bulgaria (in January 2016), Denmark (July 2012), Euro area (June 2014), Hungary (March 2016), Japan (January 2016), Norway (September 2015), Sweden (February 2015), Switzerland (January 2015).

loans decline and existing (variable rate) loans are reduced, while deposit rates remain downward sticky. In fact, several empirical studies argue that negative interest rates reduce banks' net interest margins. Using data of 7359 banks from 33 OECD countries over the period 2012-2016, Molyneux et al. (2019) find that negative interest rates have reduced the NIM of banks located in countries that have adopted this policy.[3]

According to Scheiber et al. (2016), there are at least two reasons why banks are reluctant to lower deposit rates below zero: (i) legal constraints; (ii) the risk of substitution of savings deposits by banknotes ("*rush to cash*"). Through the lending channel, banks can mitigate the compression of net interest margins due to NIRP in several ways: (i) increase (or reduce) the cost of lending; (ii) increase the supply of credit (if the demand is strong); (iii) if banks decide to increase the supply of credit, they would adjust their portfolio by shifting from short-term to long-term loans (see Black and Rosen, 2016).[4] Taking this body of work one step further, we analyze empirically how banks' lending behavior has changed in the presence of negative interest rates.

Using the Difference-in-Differences method, we conduct an in-depth analysis of the effects of negative interest rates on bank-lending behavior. We capture banks' lending behavior through changes in the cost, volume and maturity of loans. In addition, we examine how bank-specific characteristics can amplify or weaken the lending channel of monetary policy under negative interest rates. In other words, we investigate whether the effects of NIRP differ across bank-specific characteristics. Indeed, the transmission of monetary policy to the real economy through the lending channel under negative interest rates may differ according to bank-specific characteristics such as size and deposits (see Schelling and Towbin, 2018; Heider et al. 2019; Molyneux et al. 2020).

Our main contribution is the growing literature on how negative interest rates influence bank behavior. Despite a several number of empirical studies on this topic, there is no paper that provides cross-country evidence. To our knowledge, this is the second paper (after Molyneux et al. 2020) that provides cross-country evidence on how negative policy rates affect the lending behavior using a large sample of banks operating in 54 countries over the period 2009-2018. This goes beyond existing analysis on bank-lending behavior which typically look at single countries in domestic context (Arce et al. 2018; Basten and Mariathasan, 2018; Schelling and Towbin, 2018; Bottero et al. 2019; Eggertsson et al. 2019; Gunji, 2018; Heider et al. 2019; Hong and Kandrac, 2018). This undoubtedly explains the divergence of results found in this literature. Indeed, two results generally emerge from this literature. On the one hand, some studies support the presence of a lending channel for monetary

[3] Based on 5200 banks operating in the 27 advanced European and Asian countries over the period 2010-2017, Lopez et al. (2019) find similar results.

[4] Other studies indicate that in order to maintain profitability, banks can also: (i) increase fees and commissions (Lopez et al. 2020; Molyneux et al. 2019); reduce personnel expenses (Boungou and Hubert, 2020); (iii) invest more in risky securities (Bubeck et al. 2020).

policy under negative interest rates (Basten and Mariathasan, 2018; Schelling and Towbin, 2018; Bottero et al. 2019; Gunji, 2018; Hong and Kandrac, 2018). On the other hand, analyses suggest that negative interest rates have not encouraged banks to lend more (Arce et al. 2018; Eggertsson et al. 2019; Heider et al. 2019).

Besides, while some studies have focused only on the effects of NIRP on the volume of credit (among others, Molyneux et al. 2020; Bottero et al. 2019; Basten and Mariathasan, 2018; Hong and Kandrac, 2018) or on a specific type of loans, such as syndicated loans (Heider et al. 2019), we complement these studies by conducting an in-depth analysis of the effects of NIRP on bank-lending behavior, namely on cost, supply, and maturity of lending. Finally, this paper is also the first to show how the maturity of loans influences the transmission of monetary policy in the context of negative interest rates.

To measure bank-lending behavior, we use three proxies: (i) lending cost; (ii) lending supply; (iii) lending maturity. While lending cost refers to interest income paid on loans, lending supply is measured as the total of gross loans. Lending maturity refers to the volume of credit of different maturities, i.e. loans with a maturity of less than 3 months, those between 3 and 12 months and finally those with a maturity above 5 years. Using gross lending with different maturities, allows us to distinguish loans by maturity that may have different relationships with negative interest rates. Employing a large panel dataset of 4072 banks operating in 54 countries over the period 2009-2018 and the Difference-in-Differences methodology, we show that banks located in NIRP-affected countries have reduced the cost of credit, thereby increasing the supply of credit. Our findings also highlight that negative interest rates have had a significant effect on lending maturity by favoring, notably, an expansion of loans with maturities of more than 3 months for banks located in NIRP-affected countries, compared to those that did not adopt this policy. Overall, these results support the presence of a lending channel of monetary policy under negative interest rates, and stresses above all that short-term loans become less attractive than others in an environment of low or even negative interest rates.

Finally, we show that the effectiveness of this monetary policy transmission channel depends on bank-specific characteristics such as size and deposits. Specifically, we find that large and high-deposits banks reacted more strongly to negative interest rates by adjusting their lending activity. These conclusions remain valid even when we combine the Difference-in-Differences methodology with Propensity Score Matching, and when we consider the other unconventional monetary policies that were conducted in conjunction with the introduction of NIRP.

The remainder of the paper is organized as follows. Section 2 briefly reviews the related literature on negative interest rates and bank-lending behavior. Section 3 describes our data and empirical approach. Section 4 documents the effects of NIRP on bank-lending behavior, including several robustness checks. Section 5 concludes.

2. Related literature

Since 2012, several banks have introduced a new unconventional monetary policy tool: negative policy interest rates. By introducing negative interest rates, central banks want banks to use their excess reserves to lend to the real economy and thus support economic activity. Central banks then support the presence of a lending channel for monetary policy under negative interest rates to boost economic activity. In doing so, a question emerges: Does this lending channel operate under negative interest rates? To answer that, we analyze in depth the effects of NIRP on bank-lending behavior, considering the cost, volume and maturity of loans. In this context, we provide a first cross-country evidence of the role played by loan maturity in the transmission of negative interest rates.

The recent literature has tried to provide some answers to this question by analyzing the relationship between negative interest rates and bank-lending behavior. Meanwhile, there is no consensus on the effects of negative interest rates on lending activities. Indeed, this lack of consensus is undoubtedly linked to the samples used (mostly focused on single countries), ignoring the cross-country dimension.[5] This lack of consensus may also stem from the difference between the characteristics of the banks, and the failure to take into account the maturity of the loans (Black and Rosen, 2016). As a result, two results are highlighted in this literature.

On the one hand, some studies show that the introduction of negative interest rates has led to an increase in the supply of credit by banks. Schelling and Towbin (2018) have provided empirical evidence by analyzing the effects of the introduction of negative interest rates by the Swiss National Bank (SNB) on individual Swiss corporate loans. Using a Difference-in-Differences approach, they find that banks, with a lot of deposits, try to offset their relatively higher funding costs by offering more generous lending terms and thereby capturing market shares. Also analyzing the Swiss banking market, Basten and Mariathasan (2018) find similar results. They show that the introduction of negative interest rates by the SNB has led to an increase in the supply of loans by Swiss banks. In particular, they find an expansion of banks' activities in the mortgage market. In the same vein, Hong and Kandrac (2018) investigate how negative interest rate policy introduced in January 2016 by the Bank of Japan affected Japanese banks' lending behavior. They highlight that credit supply increased more for banks that were more affected by NIRP. Similarly, using the experience in Japan, Gunji (2018) also find that the loan rates of banks to which negative interest rates were levied declined compared to those of the banks that were not subject to NIRP. Another study, Bottero et al. (2019), examines the transmission of

[5] Euro area (Arce et al. 2018; Heider et al. 2019); Italy (Bottero et al. 2019); Japan (Gunji, 2018; Hong and Kandrac, 2018); Spain (Arce et al. 2018); Sweden (Eggertsson et al. 2019); Switzerland (Schelling and Towbin, 2018; Basten and Mariathasan, 2018).

negative interest rates through the Italian banking system. They note an increase in the growth rate of total bank credit after the introduction of NIRP.

On the other hand, other studies examining the effects of NIRP, find that negative interest rates did not encourage an increase in the supply of bank loans. Using a Difference-in-Differences framework, Heider et al. (2019) estimate the effects of the introduction of negative interest rates by the European Central Bank on the credit supply of euro area banks.[6] They show that in response to negative interest rates, euro area banks have on the whole lent less to the real economy. They also find that these effects depend on the reliance on deposits. Indeed, their results suggest that banks with high deposits lend more to risky firms, which could pose a risk to financial stability. Focusing on the Swedish banking system, Eggertsson et al. (2019) also show that once the policy rate turns negative, the usual transmission mechanism of monetary policy through the bank sector breaks down in Sweden. They find that Swedish banks that rely more heavily on deposit financing also have lower credit growth in a negative interest rate environment. Based on data from 6675 banks in 33 OECD countries over 2012-2016 and a Difference-in-Differences method, Molyneux et al. (2020) find similar results. Indeed, the authors show that after the introduction of negative interest rates bank lending was weaker in NIRP-adopter countries than in countries that did not adopt the policy.

To date, Molyneux et al. (2020) is the only study that analyses the effects of negative interest rates on the volume of credit by considering several countries. However, our approach differs from that of Molyneux et al. (2020) on two respects. First, Molyneux et al. (2020) study the relationship between negative interest rates and loan volume, we go even further by considering the cost of credit and the volume of loans with different maturities. Second, while the study by Molyneux et al. (2020) covers 33 OECD countries and the period 2012-2016, we go further by analyzing the effects of NIRP on the lending behavior of 4072 banks located in 54 countries over a 10-year period from 2009 to 2018. In doing so, we complement the previous literature by detailing how banks' lending behavior evolves in the presence of negative interest rates.

3. Data and empirical methodology

3.1. Data

In order to assess the effects of negative interest rates on bank-lending behavior, we extract data from 5454 banks located in 122 countries around the world over a ten-year period from 2009 to 2018. The data used for our estimates come from four sources: Fitch Connect, IMF, Datastream and central banks. Our main source is Fitch Connect, which contains detailed information on the composition of banks assets and

[6] Other evidence in the euro area (and Spain) shows that negative interest rate had no significant impact on banks' credit standards, which suggests that banks did not expand their loan supply (Arce et al. 2018).

liabilities.[7] Using the Difference-in-Differences method, we ensure that banks unaffected by NIRP (control group) have a similar trend before the implementation of NIRP with banks affected by this policy (treated group), in order to respect the requirement of a parallel trend between our two groups. To do so, we use the holdings of liquid assets and market structure (measured with the Herfindahl-Hirschman Index) as a selection criterion to determine the control group that is as close as possible to the treated group. This shows that the banks not affected by NIRP, with similar lending behavior to the group treated before NIRP was set up, are those with a ratio of liquid assets to total assets above the 90th percentile and with a HHI index above the 40th percentile. Figure 1 illustrates this parallel evolution between our two groups before the introduction of negative interest rates.

We have sorted our database by winsorizing the data at the 1st and 99th percentile level to ensure that outliers do not bias our estimates (e.g., when assets are less than zero or customer deposits are below zero). Our final database includes a large unbalanced dataset of 4072 banks in 54 low-, middle-, and high-income countries over the period 2009-2018, consisting of 25175 annual observations. While the treatment group consists of 3128 banks operating in 23 countries adopting NIRP[8], the control group consists of 944 banks located in 31 countries not affected by negative interest rates.[9]

Table A1 displays the descriptive statistics of bank-specific control prior to the implementation of negative interest rates for the treated and control groups. We measure bank-lending behavior ($Lending_{i,k,t}$) using lending cost, lending supply, and lending maturity. As a proxy for lending cost, we use interest income on loans to gross loans (Int_inc). We use the gross loans to total assets as a proxy of lending supply (Lend_ta).[10] To measure lending maturity, we use loans of different maturities (as % of total assets) such as loans less than 3 months (Three_months), loans between 3 months and 12 months (Twelve_months), and loans above 5 years (Five_years).[11] In terms of the specific variables required for our estimates, we include control variables related to bank and country-specific characteristics.

The bank-specific controls ($\beta_{i,k,t}$). According to the previously mentioned literature on banking, we use four specific characteristics of banks' balance sheets that can influence bank-lending behavior. First, we use the ratio of liquid assets to total assets (Liquidity) as proxy for bank liquidity. Second, we include capitalization, defined as

[7] Fitch Connect is a commercial database.

[8] Denmark, 18 EMU member countries (without Estonia), Hungary, Japan, Sweden, Switzerland.

[9] Argentina, Australia, Belarus, Bosnia and Herzegovina, Brazil, Canada, Croatia, Czech Republic, Egypt El Salvador, Iceland, Indonesia, Kazakhstan, Korea (South), Kyrgyzstan, Malaysia, Mauritius, Morocco, New Zealand, Panama, Peru, Poland, Romania, Russia, Singapore, South Africa, Thailand, Tunisia, Turkey, Ukraine, United Kingdom.

[10] The advantage of considering gross loans is that it takes into account the entire lending activity of banks and not just one type of loan. In their analysis, Heider et al. (2019), for example, considered only syndicated loans, which is only a fraction of what all banks do. Moreover, only the large banks are generally involved in syndicated loans.

[11] It might have been interesting to also examine the effects of NIRP on the supply of loans with maturities between 1 and 5 years. Unfortunately, we do not have this information in our database.

equity to assets ratio (Capitalization). Third, we use customer deposits to total assets (Deposits), as a proxy for the bank funding. Finally, we proxy bank size with the logarithm of the bank's total assets (Size).

The country-specific controls ($Y_{k,t}$). In our empirical exercises we also consider country-specific controls. We employ the Herfindahl-Hirschman Index (HHI) to reflect the market concentration. It can take values between 0 (perfect competition) and 1 (monopoly). In addition, to account for macroeconomic heterogeneities between countries and demand of credit, we include inflation rate, unemployment rate, fiscal policy[12], and real GDP growth rate.

3.2. Empirical methodology

To examine the effect of negative interest rates on bank-lending behavior, we use the Difference-in-Differences (DiD) methodology. We compare the effects of negative interest rates on bank-lending behavior for a treatment group of banks (Treated) with a control group of banks (Control) unaffected by NIRP.[13] The empirical strategy is based on a series of panel regressions. Equation (1) summarizes our baseline model:

$$Lending_{i,k,t} = c + \alpha_1(Treated_{i,t} * Post_{k,t}) + \alpha_2\beta_{i,k,t} + \alpha_3 Y_{k,t} + \theta_t + \lambda_i + \varepsilon_{i,k,t} \quad (1)$$

where $Lending_{i,k,t}$ is the bank-lending behavior (proxy with lending cost, lending supply, and lending maturity) for the bank i in country k at year t. $Treated_{i,t}$ is a dummy variable equal to 1 if bank i in country k is affected by NIRP, and 0 otherwise. $Post_{k,t}$ is a dummy variable equal to 1 in years following implementation of NIRP by country k and 0 before. The coefficient of α_1 is our DiD estimator in average of $Lending_{i,k,t}$ between Treated and Control groups. Using the Variance Inflation Factor (VIF), we test the control variables for multicollinearity. A mean VIF of 1.26 suggests that our control variables are not highly correlated (see Table A2 for the correlation matrix). In addition, the descriptive statistics in Table A1 display that the bank-specifics of the two groups are close prior to the implementation of treatment.[14] While $\beta_{i,k,t}$ refers to bank-specific controls, $Y_{k,t}$ refers to country-specific controls. θ_t, λ_i and $\varepsilon_{i,k,t}$ are respectively time fixed-effects, bank fixed-effects, and idiosyncratic error.[15] As suggested by Bertrand et al. (2004), we use robust and clustered standard errors at the bank level to control for heteroscedasticity and dependence between observations.

[12] General government structural balance as a percentage of potential GDP.

[13] Following Jobst and Lin (2016), we use the real interest rate as a robustness test. Indeed, a decline in the nominal interest rate could also reduce its real component, allowing inflation expectations to strengthen and boost aggregate demand. We find similar results to our baseline (not reported, but available on request).

[14] Although our two groups have close characteristics prior to treatment (see Figure 1), we use the Propensity Score Matching in robustness to build our treatment and control groups. We obtain similar results to our baseline (see Section 4.3).

[15] Although previous studies on negative interest rates also include bank fixed effects in their estimates (e.g. Boungou, 2020; Lopez et al. 2020), we re-estimate Equation (1) by including country fixed effects. Our main results do not change even when considering country fixed effects (not reported but available on request).

The Difference-in-Differences method is widely used in the literature analyzing the effects of negative interest rates on bank behavior (among others, Basten and Mariathasan 2018; Heider et al. 2019; Lopez et al. 2020; Molyneux et al. 2019; Boungou 2020). As noted by Molyneux et al. (2019), the advantage of using this method is that it reduces potential endogeneity bias by controlling for omitted variable bias and reverse causality. Indeed, the objective of NIRP is to support economic activity through the lending channel. The taxation of banks excess reserves by the central bank is intended to encourage banks to take up such liquidity to improve the supply of loans. Therefore, this new policy should impact bank-lending behavior (to a lesser extent at least) and not vice versa.

4. Empirical Findings

4.1. Baseline results

Table 1 presents the results of the effects of negative interest rates on lending cost (column I), and on lending supply (column II) based on Equation (1). While interest income on loans (Int_inc) is our proxy for lending cost, gross loans to total assets is the proxy of lending supply (Lend_ta). Estimations are performed with fixed effects and standard errors are robust and clustered at bank level.

Looking at column I of Table 1, negative interest rates (denoted in Tables as NIRP-Effect) have the expected sign and magnitude. In the year following the introduction of negative interest rates, banks reduced the lending cost by 0.344 percentage points (pp). This result argues that the transfer of excess reserves from the central bank to the banks was accompanied by a reduction in the lending cost due to a large supply of liquidity. In the same vein, previous studies also find similar results, focusing on individual countries, namely Italy (Bottero et al. 2019) and Japan (Gunji, 2018).[16] Indeed, they also find that credit supply has increased for banks affected by negative interest rates, compared to those unaffected by NIRP. This result is consistent with the NIRP's objective of bringing inflation closer to its target. Indeed, by taxing excess bank reserves, central banks aim to increase the share of liquidity held by banks and thus reduce both bank and borrower financing costs (Coeuré, 2016). Estimates of bank-specific and country-specific controls are also in line with standard results (see Hong and Kandrac, 2018; Abuka et al. 2019).

Column II of Table 1 reports the results for the lending supply. The coefficient estimate on NIRP-Effect indicates a 0.022pp expansion of lending supply in countries affected by negative interest rates.[17] This result validates the presence of a monetary policy lending channel under negative interest rates (Gunji 2018; Basten and

[16] Boungou and Mawusi (2021) also find a reduction in the cost of lending in countries affected by negative interest rates.

[17] Using the experience in Japan, Hong and Kandrac (2018) find that credit supply increased more for banks that were more affected by NIRP.

Mariathasan, 2018; Bottero et al. 2019). Conversely, Arce et al. (2018) and Molyneux et al. (2020) find different effects of negative interest rates on the supply of loans (reduced or no effect). These different effects may stem from bank-specific characteristics (see Bottero et al. 2019; Heider et al. 2019) or the duration of the loans (Black and Rosen, 2016). In Section 4.2, we verify this hypothesis by investigating whether the characteristics of banks influence their lending behavior.

Finally, we analyze whether the effects of interest rates on credit volume differ according to the maturity of the loans to the real economy. To test this channel, we proxy lending maturity by using credit volumes with different maturities: loans with a maturity of less than 3 months (Three_months), loans with a maturity of between 3 and 12 months (Twelve_months) and finally loans with a maturity of more than 5 years (Five_years). Table 2 details the results based on lending maturity.

Column I of Table 2 presents the results of the estimates when the dependent variable is the total credits of less than 3 months duration. Our DiD estimator has the expected sign but the effect is statistically non-significant. We find that negative interest rates did not favor an increase in the supply of very short-term credit. One explanation for this would be that central banks, by introducing negative interest rates, would like banks to move toward a supply of credit of a longer duration, which has a greater effect on the real economy. In addition, medium-, and long-term loans are attractive options for borrowers with weaker credit histories or limited repayment capacity. Indeed, earlier studies have argued that an accommodative monetary policy encourage banks to shift short-term loans with long-term loans (among others, Berger et al. 2005; Black and Rosen, 2016). Columns II and III of Table 2 report the results for loans with maturities between 3 and 12 months and over 5 years, respectively. The results show that banks located in countries that adopted negative interest rates increased the volume of loans with terms between 3 and 12 months by 0.023pp. These results corroborate the previous ones by highlighting the effectiveness of the transmission of monetary policy to the real economy under negative interest rates. For loans over 5 years, the coefficient associated with our DiD estimator is positive and significant at 5% level. To sum up, these results show that negative interest rates have favored the increase in the supply of credit, precisely loans with maturities of more than 3 months.

Our previous results highlight the importance of the maturity of loans contracted in the transmission of monetary policy under negative interest rates. We can then assume that bank-specific characteristics would influence the impact of NIRP on lending activity. The coefficients associated with bank-specific and country-specific controls are consistent with the banking literature, which analyzes the relationship between monetary policy and lending channel.

4.2. The issue of bank heterogeneity

Our previous results highlight the presence of a lending channel of monetary policy under negative interest rates. Indeed, we show that in response to the introduction of NIRP, banks have reduced the cost of credit and increased the volume of loans, especially loans with terms between 3 months and 12 months and those over 5 years. It seems important to understand whether the increase in lending activity is homogeneous across all banks or whether the increase has been greater for some banks. If we consider that the composition of banks' balance sheets provides an essential piece of information on lending decisions, then one would expect that individual bank characteristics would have a significant impact on the performance of the lending channel. For example, banks depending on their size and dependence on retail deposits potentially face different changes in their investment opportunities (Heider et al. 2019).

Therefore, in this section we focus on two key characteristics of banks: size and deposits, which are important for the following reasons. First, small banks with lower deposits tend to be more limited in terms of expanding the supply of credit. In addition, larger banks with higher deposits would respond more strongly to the introduction of NIRP by increasing their lending activity (Heider et al., 2019). Second, analyzing the effects of negative interest rates as a function of bank characteristics allows us to better document the relationship between NIRP and banks' lending behavior, but more importantly, to define the channel that guides our results (Bottero et al. 2019). In doing so, we create a smaller number of peer groups using the median. For example, for size, a bank is considered small if its logarithm of total assets is below the median (6.30) and conversely it is large if its assets exceed the median.[18] Tables 3 shows the results of the impact of negative interest rates on bank-lending behavior across different type of banks.

In Table 3, columns I and II present the results according to bank size (small or large) and columns III and IV present results based on the reliance on deposits (low- or high-deposits). The results reported in Table 3 show that the reduction in the cost of lending was greater for large banks (-1.566pp) and for high-deposits (-1.493pp) compared to other banks affected by NIRP. However, we find that the increase in the supply of credit differs according to the characteristics of the banks. Indeed, our results highlight that small and low-deposit banks reduced the supply of credit in the year following the implementation of interest rates by 0.015pp and 0.011pp, respectively. In addition, we show that the characteristics of banks influence the supply of credit with different maturities. Indeed, while small and low-deposit banks have reduced the share of loans with maturities of less than 3 months, large and high-deposit banks have rather increased the share of loans with maturities of more than 5 years. Overall, banks affected by negative interest rates increased their lending activity to the economy, focusing more on long-term loans rather than on the supply of short-term loans. These results underline the importance of loan maturity in the

[18] We proceed in the same way for deposits (73%).

transmission of monetary policy. In particular, the effectiveness of the transmission of monetary policy through the lending channel varies according to the maturity of the loans (see, Black and Rosen, 2016).

4.3. Further robustness checks

In this sub-section, we establish three robustness tests to our baseline results. First, based on the analysis of Rosenbaum and Rubin (1983), we check the robustness of our baseline results by combining Difference-in-Differences and Propensity Score Matching (PSM). Precisely, we use the Kernel Matching algorithm (Behejia and Wahba, 1999; Becker and Ichino, 2002). The results of this first robustness test are reported in Tables A3.[19] As a second robustness check, we perform sub-sample analysis, assessing the effects of NIRP in OECD member countries (see Table A4). Indeed, the Treated and Control groups are made up solely of banks located in OECD member countries. Finally, as we know, negative interest rates were implemented as a complement to (un)conventional monetary policies, with the aim of providing more stimulus to economic growth. Therefore, to dissociate the effects of other monetary policy tools on bank-lending behavior, we (alternatively) use the three monetary aggregates (M1, M2, M3). These aggregates allow us to capture the evolution of other monetary policy tools, such as the various asset purchase programmes that boost the real economy through the (mostly) lending channel. The results of this last robustness test are reported in Tables A5 and A6. In summary, our main results remain robust after a series of tests, even taking into account the other monetary policy tools.

5. Conclusion

Since 2012, several central banks have introduced negative interest rates to reduce financing costs and thus promote credit expansion, with a view to boosting economic activity. This article documents how negative interest rates can impact bank-lending behavior. To this end, using Difference-in-Differences framework, we exploit balance sheet data from 4072 banks located in 54 countries over the period 2009-2018. To get better understanding about how negative interest rate policy affects bank-lending behavior, we empirically assess the effects of negative interest rates on: (i) lending cost; (ii) lending supply; (iii) lending maturity.

Our results highlight that negative interest rates have favored a reduction in the lending cost of banks located in countries affected by negative interest rates. This reduction in financing costs has been accompanied by an increase in the lending supply in the year following the introduction of negative interest rates. Moreover, our findings provide further evidence of the link between negative interest rates and bank lending maturity. Negative interest rates have fostered an increase in the supply of credit, particularly loans with maturities ranging from 3 to 12 months and those over 5 years. We also find that these results depend on bank-specific characteristics such as

[19] We use a probit model to generate propensity scores (not reported, but available on request).

reliance on retail deposits and size. In addition, large and high-deposits banks reacted more strongly to negative interest rates by adjusting their lending behavior. Our results are consistent with previous studies analyzing the effects of negative interest rates on the bank lending channel. Finally, these results remain robust by: (i) combining the Difference-in-Differences methodology and Propensity Score Matching; (ii) controlling the effects of other unconventional monetary policies; (iii) conducting sub-sample analysis.

The findings of this study show that negative interest rates have a significant impact on bank-lending behavior. They also indicate that the transmission of monetary policy under negative interest rates to the real economy depends on banks' specific characteristics. We believe that our study contains interesting insights for monetary policy, which might be useful when considering the effectiveness of negative interest rates. However, further research is needed to investigate the impact of negative interest rates on banks' credit risk. This extension of our study will allow us to understand how changes in bank lending activity (related to NIRP) impacts risk-taking.

Formatting of funding sources

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Table 1. Negative interest rate policy, lending cost and lending supply

	Int_inc	Lend_ta
	(I)	(II)
NIRP-Effect	-0.344**	0.022**
	(0.15)	(0.01)
Liquidity	0.042***	-0.003***
	(0.01)	(0.00)
Capitalization	-0.026	-0.000
	(0.02)	(0.00)
Deposits	-0.379	0.026
	(0.99)	(0.02)
Size	-0.142	0.007
	(0.30)	(0.01)
HHI	3.044	-0.027
	(2.08)	(0.09)
Inflation	0.008	0.000
	(0.02)	(0.00)
Unemployment	0.089**	-0.005***
	(0.04)	(0.00)
Fiscal	-0.116***	0.004
	(0.03)	(0.00)
GDP	-0.002	-0.002
	(0.02)	(0.00)
Constant	4.764**	0.406***
	(2.33)	(0.05)
Observations	25175	25175
Number of banks	4072	4072
R2 (within)	0.157	0.008
Year FE	Yes	Yes
Bank FE	Yes	Yes

Note: NIRP-Effect is our Difference-in-Differences estimator. It takes the value 1 for bank *i*, the year after country *k* implements NIRP and 0 before. Liquidity is the ratio of bank liquid assets to total assets. Capitalization is the ratio of bank equity to total assets. Deposits is the ratio of customer deposits to total assets. Size is the natural logarithm of bank total assets. HHI is the Herfindahl-Hirschman Index. Inflation is the yearly Consumer Price Index in percentage. Unemployment is the unemployment rate. Fiscal is the fiscal policy measured as general government structural balance as a percentage of potential GDP. GDP is the real GDP growth rate. Robust standard errors clustered by banks in parenthesis. ***, **, and * indicate statistical significance at 1%, 5%, and 10%, respectively.

Table2. Negative interest rate policy and lending maturity

	Lending maturity:		
	Three_months	Twelve_months	Five_years
	(I)	(II)	(III)
NIRP-Effect	-0.009	0.023***	0.008**
	(0.01)	(0.01)	(0.00)
Liquidity	-0.001	-0.001***	-0.001***
	(0.00)	(0.00)	(0.00)
Capitalization	0.000	-0.001***	0.001*
	(0.00)	(0.00)	(0.00)
Deposits	0.002	0.011	0.013
	(0.01)	(0.01)	(0.01)
Size	-0.007*	0.000	0.014***
	(0.00)	(0.00)	(0.00)
HHI	0.207**	-0.079***	-0.155***
	(0.09)	(0.02)	(0.04)
Inflation	0.000	-0.001*	0.001***
	(0.00)	(0.00)	(0.00)
Unemployment	-0.004***	-0.001*	0.001
	(0.00)	(0.00)	(0.00)
Fiscal	0.006***	0.001	-0.003***
	(0.00)	(0.00)	(0.00)
GDP	-0.001	-0.002*	0.000
	(0.00)	(0.00)	(0.00)
Constant	0.149***	0.082***	0.175***
	(0.04)	(0.03)	(0.04)
Observations	25175	25175	25175
Number of banks	4072	4072	4072
R2 (within)	0.005	0.003	0.080
Year FE	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes

Note: NIRP-Effect is our Difference-in-Differences estimator. It takes the value 1 for bank *i*, the year after country *k* implements NIRP and 0 before. Liquidity is the ratio of bank liquid assets to total assets. Capitalization is the ratio of bank equity to total assets. Deposits is the ratio of customer deposits to total assets. Size is the natural logarithm of bank total assets. HHI is the Herfindahl-Hirschman Index. Inflation is the yearly Consumer Price Index in percentage. Unemployment is the unemployment rate. Fiscal is the fiscal policy measured as general government structural balance as a percentage of potential GDP. GDP is the real GDP growth rate. Robust standard errors clustered by banks in parenthesis. ***, **, and * indicate statistical significance at 1%, 5%, and 10%, respectively.

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Table3. Negative interest rate policy, lending and bank-specific characteristics

	Int_Inc			
	Small	Large	Low-deposits	High-deposits
NIRP-Effect	-1.062***	-1.566***	-1.273***	-1.493***
	(0.24)	(0.29)	(0.45)	(0.15)
R2(within)	0.191	0.256	0.134	0.310
	Lend_ta			
	Small	Large	Low-deposits	High-deposits
NIRP-Effect	-0.015**	-0.004	-0.011*	-0.015
	(0.01)	(0.01)	(0.01)	(0.03)
R2(within)	0.198	0.005	0.232	0.007
	Three_months			
	Small	Large	Low-deposits	High-deposits
NIRP-Effect	-0.036***	-0.030**	-0.030***	-0.042
	(0.01)	(0.01)	(0.01)	(0.03)
R2(within)	0.179	0.005	0.126	0.007
	Twelve_months			
	Small	Large	Low-deposits	High-deposits
NIRP-Effect	0.001	0.001	0.001	0.001
	(0.00)	(0.00)	(0.00)	(0.00)
R2(within)	0.062	0.063	0.082	0.052
	Five_years			
	Small	Large	Low-deposits	High-deposits
NIRP-Effect	0.021***	0.025***	0.018***	0.026***
	(0.00)	(0.00)	(0.00)	(0.00)
R2(within)	0.071	0.129	0.107	0.098
Observations	9144	11288	6786	13646
Nbr.of banks	1498	1607	1251	1854

Note: NIRP-Effect is our Difference-in-Differences estimator. It takes the value 1 for bank *i*, the year after country *k* implements NIRP and 0 before. All estimates include bank-specific controls (i.e. liquid assets to total assets, equity to total assets, customer deposits to total assets, is the natural logarithm of bank total assets), country-specific controls (i.e., Herfindahl-Hirschman Index, yearly Consumer Price Index, unemployment rate, fiscal policy, real GDP growth rate), year- and bank-fixed effects. Robust standard errors clustered by banks in parenthesis. ***, **, and * indicate statistical significance at 1%, 5%, and 10%, respectively.

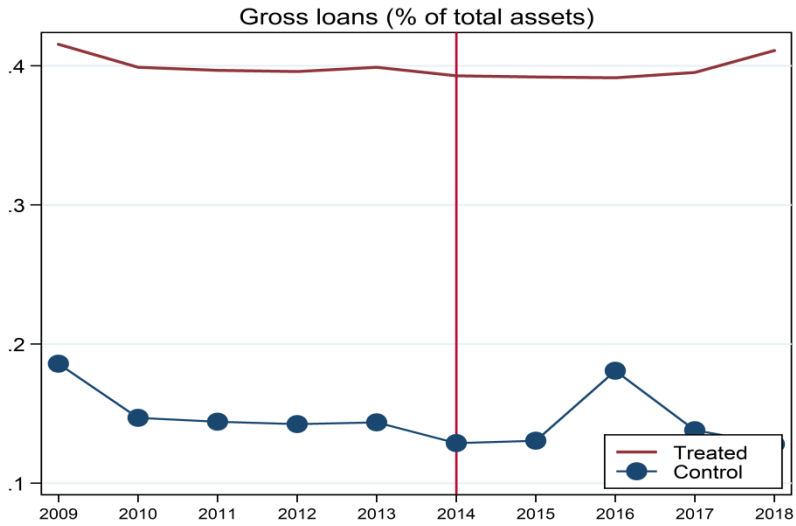

Figure 1. Average of gross loans (% of total assets) among treated banks (red line) and control banks (blue line) from 2009-2018. Following Molyneux et al. (2019, 2020), we consider 2014 as the year of implementation of NIRP for ease of interpretation.

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Appendix

Table A1. Descriptive statistics before NIRP

Variable	Obs	Mean	Std. Dev.	Min	Max
			Treated group		
Liquidity	10538	18.82	16.95	.51	98.45
Capitalization	10538	10.94	9.47	.02	98.77
Deposits	10538	61.53	15.26	1	98.02
Size	10538	6.44	1.79	-2.21	14.49
			Control group		
Liquidity	2287	19.01	13.83	.08	96.17
Capitalization	2287	11.22	7.66	.01	92.85
Deposits	2287	59.06	35.28	0.4	95.93
Size	2287	8.30	2.88	.29	20.13

Note: Liquidity is the ratio of bank liquid assets to total assets. Capitalization is the ratio of bank equity to total assets. Deposits is the ratio of customer deposits to total assets. Size is the natural logarithm of bank total assets.

Table A2. Correlation matrix

	L1.	L2.	L3.	L4.	L5.	L6.	L7.	L8.	L9.
L1.Liquidity	1								
L2. Capitalization	0.1787*	1							
L3.Deposits	-0.1008*	-0.3288*	1						
L4.Size	0.0698*	-0.1196*	-0.1956*	1					
L5.HHI	0.0792*	0.0100	0.0646*	-0.0546*	1				
L6.Inflation	0.0820*	0.1799*	-0.1315*	0.1123*	-0.0099	1			
L7.Unemployment	0.0838*	0.0761*	-0.2388*	0.0778*	0.0614*	0.082*	1		
L8.Fiscal	-0.1397*	-0.0892*	0.3279*	-0.2133*	-0.0614*	-0.258*	-0.522*	1	
L9.GDP	0.0298*	0.0859*	0.0266*	0.1621*	-0.0183*	0.018*	-0.180*	-0.005	1

Note: This table represents the correlation matrix among the variables used in the baseline regression. Correlations that are significant at least at 5% level are reported using star (*).

Table A3. Difference-in-Differences and PSM results

	Int_inc	Lend_ta	Lending maturity:		
			Three_months	Twelve_months	Five_years
	(I)	(II)	(III)	(IV)	(V)
NIRP-Effect (PSM)	-2.245***	0.065***	-0.019***	-0.060***	0.143***
	(0.16)	(0.01)	(0.00)	(0.00)	(0.00)
Observations	25175	25175	25175	25175	25175

Note: This table presents the results by combining the Difference-in-Differences with Propensity Score Matching (PSM). NIRP-Effect is our Difference-in-Differences estimator. It takes the value 1 for bank *i*, the year after country *k* implements NIRP and 0 before. All estimates include fixed effects and bootstrapped standard errors are in parentheses. ***, **, and * indicate statistical significance at 1%, 5%, and 10%, respectively.

Table A4. NIRP and lending behavior: Evidence from OECD member countries

	Int_inc	Lend_ta	Lending maturity:		
			Three_months	Twelve_months	Five_years
	(I)	(II)	(III)	(IV)	(V)
NIRP-Effect	-0.653***	0.010	-0.001	0.008**	0.002
	(0.17)	(0.01)	(0.01)	(0.00)	(0.01)
Liquidity	0.043***	-0.003***	-0.001	-0.001***	-0.002***
	(0.02)	(0.00)	(0.00)	(0.00)	(0.00)
Capitalization	-0.020	-0.000	0.000	-0.001**	0.000
	(0.03)	(0.00)	(0.00)	(0.00)	(0.00)
Deposits	-0.732	0.037	0.018	0.016*	0.002
	(1.11)	(0.02)	(0.02)	(0.01)	(0.02)
Size	-0.195	-0.002	-0.007	-0.005*	0.010
	(0.38)	(0.01)	(0.01)	(0.00)	(0.01)
HHI	-0.921	0.001	0.267**	-0.064***	-0.202***
	(1.25)	(0.13)	(0.13)	(0.02)	(0.05)
Inflation	0.081*	0.007*	0.007*	0.001	-0.001
	(0.04)	(0.00)	(0.00)	(0.00)	(0.00)
Unemployment	0.153***	-0.005***	-0.005***	-0.001*	0.000
	(0.05)	(0.00)	(0.00)	(0.00)	(0.00)
Fiscal	-0.109***	0.005	0.012***	-0.002***	-0.006***
	(0.03)	(0.00)	(0.00)	(0.00)	(0.00)
GDP	0.015	0.001	0.002	-0.001***	-0.000
	(0.02)	(0.00)	(0.00)	(0.00)	(0.00)
Constant	4.538*	0.450***	0.088*	0.100***	0.261***
	(2.74)	(0.06)	(0.05)	(0.02)	(0.05)
Observations	21639	21639	21639	21639	21639
Number of banks	3329	3329	3329	3329	3329
R2 (within)	0.181	0.011	0.006	0.049	0.088
Year FE	Yes	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes	Yes

Note: NIRP-Effect is our Difference-in-Differences estimator. It takes the value 1 for bank *i*, the year after country *k* implements NIRP and 0 before. Liquidity is the ratio of bank liquid assets to total assets. Capitalization is the ratio of bank equity to total assets. Deposits is the ratio of customer deposits to total assets. Size is the natural logarithm of bank total assets. HHI is the Herfindahl-Hirschman Index. Inflation is the yearly Consumer Price Index in percentage. Unemployment is the unemployment rate. Fiscal is the fiscal policy measured as general government structural balance as a percentage of potential GDP. GDP is the real GDP growth rate. Robust standard errors clustered by banks in parenthesis. ***, **, and * indicate statistical significance at 1%, 5%, and 10%, respectively.

Table A5. NIRP, lending cost, and supply and unconventional monetary policies (UMPs)

	int_inc			Lend_ta		
	(I)	(II)	(III)	(IV	(V)	(VI)
NIRP-Effect	-0.359**	-0.548***	-0.491***	0.022**	0.018**	0.020**
	(0.16)	(0.16)	(0.16)	(0.01)	(0.01)	(0.01)
M1	-0.006**			-0.001		
	(0.00)			(0.00)		
M2		0.013**			-0.000	
		(0.01)			(0.00)	
M3			0.033***			0.000
			(0.01)			(0.00)
Observations	25008	23784	24677	25008	23784	24677
Number of banks	4030	3773	3969	4030	3773	3969
R2 (within)	0.158	0.191	0.159	0.009	0.012	0.008
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes

Note: NIRP-Effect is our Difference-in-Differences estimator. It takes the value 1 for bank *i*, the year after country *k* implements NIRP and 0 before. Controls include bank-specific characteristics (the ratio of bank liquid assets to total assets, the ratio of bank equity to total assets, the ratio of customer deposits to total assets and the natural logarithm of bank total assets) and country-specific characteristics (the Herfindahl-Hirschman Index, the yearly Consumer Price Index in percentage, the unemployment rate, the fiscal policy measured as general government structural balance as a percentage of potential GDP and the real GDP growth rate). ***, **, and * indicate statistical significance at 1%, 5%, and 10%, respectively.

Table A6. NIRP, lending maturity and unconventional monetary policies (UMPs)

	Three_months			Twelve_months			Five_years		
	(I)	(II)	(III)	(IV)	(V)	(VI)	(VII)	(VIII)	(IX)
NIRP-Effect	-0.009	-0.007	-0.011	0.023***	0.016***	0.022***	0.008**	0.009*	0.009**
	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)
M1	0.001*			-0.001***			-0.001***		
	(0.00)			(0.00)			(0.00)		
M2		0.000			-0.000			-0.000***	
		(0.00)			(0.00)			(0.00)	
M3			0.001*			0.000			-0.001***
			(0.00)			(0.00)			(0.00)
Observations	25008	23784	24677	25008	23784	24677	25008	23784	24677
Number of banks	4030	3773	3969	4030	3773	3969	4030	3773	3969
R2 (within)	0.005	0.005	0.005	0.004	0.059	0.003	0.083	0.087	0.084
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: NIRP-Effect is our Difference-in-Differences estimator. It takes the value 1 for bank *i*, the year after country *k* implements NIRP and 0 before. Controls include bank-specific characteristics (the ratio of bank liquid assets to total assets, the ratio of bank equity to total assets, the ratio of customer deposits to total assets and the natural logarithm of bank total assets) and country-specific characteristics (the Herfindahl-Hirschman Index, the yearly Consumer Price Index in percentage, the unemployment rate, the fiscal policy measured as general government structural balance as a percentage of potential GDP and the real GDP growth rate). ***, **, and * indicate statistical significance at 1%, 5%, and 10%, respectively.