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Inside the Black Hole: Does Negative Interest Rate Policy Enhance Bank Lending? Evidence from the Portuguese Experience

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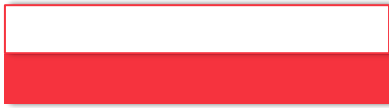

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INSIDE THE BLACK HOLE: DOES NEGATIVE INTEREST RATE POLICY ENHANCE BANK LENDING? EVIDENCE FROM THE PORTUGUESE EXPERIENCE

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Abstract

The implications of Negative Interest Rate Policy (NIRP) for banks' lending behavior have been at the forefront of academic and policy debates in recent years, with little consensus achieved thus far. Adding to the theoretical discomfort among policymakers, the absence of clear-cut empirical support is plausibly the main reason why NIRP has not been broadly adopted. The debate is a critical one to settle, as evidence shows that real interest rates can remain low for a prolonged period, and estimates suggest that the Zero Lower Bound will often constrain the conduct of monetary policy in most advanced economies. The present work aims to contribute to this debate. Exploring confidential bank-level data from Banco de Portugal, we employ a difference-in-differences methodology to estimate the impact of negative interest rates on Portuguese banks' lending behavior. We focus on two potential determinants of banks' exposure to NIRP, namely the liquidity of banks' assets and banks' reliance on deposit funding, captured by two treatment variables: (1) interbank liquidity and (2) deposit ratio, respectively. Our results suggest that, after NIRP, banks with higher *ex-ante* liquidity increase the share of corporate credit in their balance sheets by more than other banks. The average treatment effect of the policy is economically relevant, and the impact found becomes statistically significant just 3 months after the initial impulse. However, this adjustment in banks' portfolio composition does not seem to translate into an increase in the overall supply of credit, as we do not find evidence of changes in the volumes of credit granted by differently exposed banks (neither via liquidity nor deposit reliance). Moreover, we investigate changes in fees and commissions income, as well as in interest rates charged on loans, but once again do not uncover changes between differently exposed banks.

JEL codes: E43, E44, E52, E58, G21

Keywords: Bank Lending, Monetary Policy, Negative Interest Rates, Banks, Liquidity, Deposits, Difference-in-Differences, Banco de Portugal

Resumo

As implicações da Política de Taxas de Juro Negativas (NIRP) para a concessão de crédito bancário têm estado no centro do debate político e académico dos últimos anos, com pouco consenso alcançado até agora. Para além do desconforto teórico por parte dos decisores de política, a falta de suporte empírico inequívoco é plausivelmente a principal razão pela qual este instrumento não foi amplamente adotado. A resolução deste debate é importante, pois a experiência demonstra que as taxas de juro reais podem permanecer baixas por um período prolongado, e estimativas sugerem que o *Zero Lower Bound* restringirá frequentemente a condução da política monetária em economias avançadas. O presente trabalho visa contribuir para este debate. Explorando dados confidenciais do Banco de Portugal, aplicamos uma metodologia de diferenças-em-diferenças para estimar o impacto das taxas de juro negativas no comportamento dos bancos portugueses. Focamo-nos em dois potenciais determinantes da exposição dos bancos a NIRP, nomeadamente a liquidez dos seus ativos e a sua dependência de depósitos, capturados por duas variáveis de tratamento: (1) liquidez interbancária e (2) rácio de depósitos, respetivamente. Os resultados sugerem que os bancos *ex-ante* mais líquidos aumentam a proporção de crédito a empresas no seu balanço comparativamente com outros bancos, após a NIRP. O efeito médio do tratamento é economicamente relevante, e o impacto encontrado torna-se estatisticamente significativo apenas 3 meses após o impulso inicial. No entanto, este ajustamento na composição do balanço dos bancos não parece traduzir-se num aumento da oferta de crédito, uma vez que não encontramos indícios de alterações no volume de crédito concedido por bancos com diferentes exposições (nem via liquidez nem via dependência de depósitos). Além disso, investigamos alterações em receitas de comissões bancárias, assim como nas taxas de juro cobradas sobre empréstimos, mas uma vez mais não encontramos diferenças entre bancos com diferentes exposições.

Códigos JEL: E43, E44, E52, E58, G21

Palavras-chave: Empréstimos Bancários, Política Monetária, Taxas de Juro Negativas, Bancos, Liquidez, Depósitos, Diferenças-em-Diferenças, Banco de Portugal

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1. Introduction

With the onset of the Great Recession, the advent of the Zero Lower Bound (ZLB) imposed binding constraints on the usual conduct of monetary policy, as it was thought that nominal interest rates could not, for pragmatic reasons, fall beneath zero (Lombardi et al., 2018). Since 2012, however, several central banks, including the European Central Bank (ECB), have reduced their main policy rates into negative territory for the first time in history, as part of a stimulus package aimed at averting the perils of deflation. Long believed to be unfeasible, the implementation of negative interest rate policy (NIRP) has caused extensive controversy as to whether it ultimately overturns the conventional mechanisms of monetary policy transmission.

Moreover, given the steady decline in nominal interest rates for the past four decades and due to concerns of secular stagnation, Kiley and Roberts (2017) estimate that the ZLB may be binding up to 40% of the time in the future for most advanced economies. Therefore, examining the consequences of cutting policy rates below zero is of utmost importance when preparing for upcoming recessions. As the world withstood the downturn induced by the COVID-19 pandemic crisis, the viability and the broader implications of NIRP were at the focal point of the ongoing policy and academic debate in recent years.

There are several mechanisms through which the monetary stimulus provided by NIRP can support economic growth. In this regard, to the extent that negative rates may increase the amount of credit available to the real economy, the credit channel of monetary policy stands out (Hannoun, 2015). Within the former, the bank lending channel has received particular attention, since NIRP was introduced with the explicit intent of enhancing banks' incentives for granting loans. Nonetheless, systematic evidence on how negative policy rates affect banks' lending behavior is *a priori* unclear.

The blossoming research on this topic has focused on the interactions between NIRP and banks' balance sheets while pointing out some bank-specific characteristics that make these interactions unique. On the one hand, banks' asset composition – and particularly the *liquidity* of banks' assets – has been greatly emphasized. Since NIRP typically takes the form of a negative rate of remuneration on excess reserve balances held by commercial banks at the central bank, it implies a *direct* cost for banks holding excess liquidity. Moreover, by breaking through the ZLB, negative policy rates relax the non-negative constraint on current and

future expected short-term interest rates, which induces a decline in the returns of all liquid assets in banks' balance sheets. Therefore, NIRP should encourage liquid banks to protect profitability by curtailing not only their holdings of excess reserves, but also other liquid assets in general, and by procuring higher earning, less liquid assets, such as loans (Bottero et al., 2021). This conjecture is commonly referred to as the *banks' portfolio rebalancing hypothesis*.

On the other hand, a different strand of this literature emphasizes the role played by banks' funding structure, and particularly, banks' reliance on *deposit funding*. Indeed, NIRP may work differently from standard positive rate cuts because banks are unwilling (and sometimes unable) to pass on negative rates to their clients' deposits, *i.e.*, there may be a ZLB on banks' retail deposit rates. Numerous studies report a complete pass-through of negative policy rates to money market and interbank rates, but not to banks' retail deposit rates (Eggertsson et al., 2019; Eisenshmidt & Smets, 2019), which may be due to forces of competition within the banking sector, legal constraints, or to the existence of physical currency (Scheiber et al., 2016). Hence, NIRP results in cheaper market-based (non-deposit) financing, but not in cheaper deposit financing, and this is expected to affect banks differently, depending on the role played by deposits on the liability side of their balance sheets. It remains to be seen, then, how banks may react. Some researchers have argued that this friction tightens the intermediation margins of deposit-dependent banks, which may discourage them from lending. Contrastingly, others have claimed that these banks may attempt to restore earnings and returns by granting more credit and extending more favorable lending terms, thus increasing the supply of credit to the real economy.

The fact that this topic remains inadequately explored in the existing literature motivates the present work. Indeed, the acknowledgment of unique interactions between negative interest rates and banks' balance sheets raises two main questions: First, does NIRP enhance bank lending? Second, does banks' balance sheet structure influence their lending behavior in a negative rate environment? And if so, how?

The present work aims to provide coherent answers to these questions while focusing on the Portuguese banking system. In a nutshell, the purpose of this dissertation is to examine how Portuguese banks' balance sheet composition – with a focus on asset liquidity and funding structure – influences their response to NIRP, thereby realizing its effects on credit availability in Portugal. To this end, we employ a Difference-in-Differences estimation methodology and use measures of bank liquidity (interbank liquidity ratio) and reliance on

deposit funding (deposit ratio) as treatment variables that may determine banks' exposure to NIRP. Portugal offers an appropriate testing ground for our analysis, as the banking system provides the bulk of the financing to the Portuguese economy. Moreover, the availability of well-supplied datasets on Portuguese banks held by Banco de Portugal allows us to conduct meticulous empirical tests.

This dissertation is organized as follows. The next chapter briefly outlines the theoretical foundations and empirical research on the bank lending channel of monetary policy in conventional times. Subsequently, chapter 3 addresses the advent of negative policy rates, as well as its implications for bank lending and the related channel of monetary policy transmission. By acknowledging the relationship between NIRP and banks' balance sheets, this chapter describes how banks' asset and funding structure may determine their response to negative policy rates. An overview of the recent empirical literature on this subject is provided as well. Chapter 4 lays out the empirical contribution of the present dissertation. The chapter begins with a description of the institutional context in the Euro Area and Portugal. Then, it exposes the empirical strategy employed, as well as the data on all the variables used in different regressions. Lastly, this chapter presents and discusses the main findings, along with results from additional tests and robustness checks. Finally, chapter 5 concludes.

2. Bank Lending in Conventional Times: A Literature Review

This chapter aims to present a brief overview of the literature on the relationship between monetary policy and the supply of bank credit in conventional times, *i.e.*, when policy rates prevail in positive territory. In so doing, it will lay the groundwork for the analysis of this relationship when policy rates become negative – the gist of this dissertation, to be developed in subsequent chapters. First, it will shed some light on the original mechanism that grounded this relationship, *viz.*, the bank lending channel, while providing an outline of its theoretical foundations. Then, it will address how the conceptual formulation of this channel evolved to keep up with changes in the conduct of monetary policy and financial market trends. A review of the most relevant threads of empirical research will be presented as well.

2.1 The Bank Lending Channel of Monetary Policy

The textbook AD/AS view of the economy establishes the traditional interest-rate channel as the primary monetary policy transmission mechanism. From a Keynesian perspective, and in line with the expectations hypothesis of the term structure, expansionary monetary policy leads to a decline in short-term, as well as long-term real interest rates, thus lowering the real cost of borrowing. This, in turn, encourages business inventory and fixed investment, residential housing investment, and consumer durable expenditure, which generates a rise in aggregate demand that is ultimately reflected in output and the price level (Mishkin, 1996).

Taylor (1995) provides a thorough review of the research on interest-rate channels and claims that sound empirical evidence has proved its prominent effects on consumption and investment spending. This standpoint was, nonetheless, a deeply controversial one, since several other economists argued that empirical research had great difficulty in finding meaningful effects of interest rates through the real cost of borrowing (Bernanke & Gertler, 1995; Blinder & Stiglitz, 1983).[1] Hence, the widespread dissatisfaction with the traditional narrative of monetary policy transmission stimulated the search for alternative explanations.

Against this background, the blossoming research on the principal-agent theory pioneered by Nobel Prize laureates George Akerlof and Joseph Stiglitz provided economists with the intuition to contemplate the major role played by financial markets in the transmission of

[1] Economic theorists had long struggled with the perception that rises in short-term interest rates were frequently associated with lingering declines in aggregate demand, even when long-term rates (the proxies for the cost of borrowing) were not significantly affected.

monetary policy.[2] Scholars began examining how frictions in credit markets, such as asymmetric information problems between borrowers and lenders, might account for the observed impact of monetary policy on economic activity. This extension to the existing literature gave rise to what became collectively known as "the credit channel".

According to Bernanke and Gertler (1995), the credit channel of monetary policy should not be taken as an autonomous, independent substitute for the conventional interest-rate/money channel. Instead, it should be understood as an enhancement mechanism that magnifies and propagates the traditional interest-rate effects through two subchannels, namely, the Balance Sheet Channel and the Bank Lending Channel. While the former is closely related to the financial accelerator concept and highlights the effects of monetary policy decisions on firms' and households' balance sheets, the latter underscores the influence of monetary policy on the supply of loans by banks.[3] This is where we will focus our attention.

The Bank Lending Channel (BLC) is grounded on the pivotal role that banks play in the financial system. Within this framework, bank lending is information-intensive, requiring specialized knowledge and information-acquiring endeavors such as *ex-ante* screening and *ex-post* monitoring, which places banks in an optimal position to survey credit risk, insure against illiquidity and exploit economies of scale and scope through the combination of services in accounting, transfers of payments and portfolio management (Trautwein, 2000).

In this context, through the process of screening borrowers and monitoring loans' performance, banks develop an *expertise* that makes them especially well-suited for solving asymmetric information problems in credit markets (Blinder & Stiglitz, 1983). Moreover, the proficiency that banks acquire through their regular activity is what allows them to grant loans to customers who would otherwise find it difficult, if not impossible, to secure credit. As a result, whenever the supply of loans by banks is disturbed, bank-dependent borrowers will incur substantial costs to build new credit relationships with different lenders, which in turn affects their consumption and investment decisions. In short, to the extent that monetary policy may affect banks' loan supply, it will impact economic activity, even in the absence of significant changes in long-term interest rates (Bernanke & Gertler, 1995).

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[2] This perspective was at odds with the established interest-rate/money view, which often assumed that financial markets were complete and frictionless, and thus played no special role.

[3] Since the purpose of the present work is to examine banks' lending behavior, a comprehensive review of the balance sheet channel would be too far off focus and is, for this reason, unwarranted. For a survey of this literature see *e.g.*, Bernanke and Gertler (1989); Bernanke et al. (1999); Gertler and Gilchrist (1993).

2.1.1 The Traditional Bank Lending Channel

The seminal contribution of Bernanke and Blinder (1988) paved the way for the "*bank lending view*", according to which monetary policy partly unfolds by influencing banks' portfolio composition through a solid link between bank liabilities (deposits) and assets (loans). This point is further developed by Bernanke and Blinder (1992), who claim that restrictive monetary policy, accomplished by a decline in banks' reserves, causes a decrease in deposits as the main source of loanable funds, which in the long-run forces banks to terminate old loans and turn down new ones.[4] Insofar as some borrowers depend on bank lending for credit, the scarce supply of loans will dampen economic activity.

Early skeptics of this framework (see Romer & Romer, 1990) claimed that banks could easily counter the shortfall in deposits with alternative sources of funds, thus avoiding being forced to forfeit lucrative lending opportunities. However, as pointed out by Stein (1998), for the bank lending channel to be operative, it suffices that these other sources of funding are more expensive due to market frictions at the level of depository institutions themselves.

All in all, the original formulation of the BLC suggests that monetary policy affects the supply of bank credit, and thus the real economy, because banks finance most of their lending activity with liabilities that entail reserve requirements (deposits). Hence, through a decrease in the amount of bank reserves, a monetary tightening reduces the extent to which banks may take reservable deposits, which prevents them from granting loans (Boivin et al., 2010).[5]

Nevertheless, since the seminal depiction of the *bank lending view* by Bernanke and Blinder (1988), a lot has changed in the way central banks conduct monetary policy, which raised important objections to the prevailing theory. To be specific, under the operational framework of major central banks, monetary policy is primarily focused on achieving a target for short-term interest rates, which implies that reserves are not directly controlled.[6] Furthermore, within a fractional reserve banking system, commercial banks cannot operate

[4] This line of reasoning hinges on the assumption of imperfect substitutability between loans and securities in banks' portfolios (see Kashyap and Stein (1994) for a thorough review).

[5] An alternative description of this mechanism is rooted in portfolio substitution effects (see *e.g.*, Ehrmann et al., 2001; Kishan & Opiela, 2000). According to this perspective, monetary policy innovations change the yields on deposits relative to other assets, which in turn influences households' willingness to hold them. In any case, the intrinsic mechanism implies that a monetary contraction causes a decline in deposits that ultimately forces banks to reduce the supply of loans.

[6] The supply of CB reserves varies with the need to balance the money market at the desired level of short-term interest rates, and not with the pretension of the monetary authority to steer the supply of bank credit.

in the absence of guaranteed recourse to "cash on demand" at a foreseeable interest rate (Goodhart, 2009), which means the central bank ought to accommodate any amount of reserves that is required by the system.

At the same time, some developments in financial markets, such as the proclivity toward deregulation and the outstanding progress in financial innovation seem to have a major influence on the way bank lending reacts to monetary policy (Gambacorta et al., 2011). This is not to say, however, that the bank lending channel has ceased to operate. In fact, given the central role that banks play in the financial system, economic theorists have soon attempted to reconcile the gist of this channel with an appropriate theoretical framework.

Before delving further into this topic, it is important to note that there is some diversity in the mechanisms proposed to recast the traditional BLC. Notwithstanding, the main differences are mostly a matter of emphasis rather than substance. Indeed, the crux of the various interpretations of this channel lies invariably in the description of how central banks' policy is able to influence the supply of bank credit.

2.1.2 Recasting the Bank Lending Channel

Recent trends within the banking sector, including the deepening of wholesale funding markets, along with extended bank holdings of market-sensitive assets and enlarged trading books (which are marked to market), suggest that banks' balance sheets are increasingly sensitive to changes in interest rates (Adrian & Shin, 2008) as well as to markets' perceptions and investors' risk assessments (Altunbas et al., 2010; Disyatat, 2011; Gambacorta et al., 2011). In view of this, alternative formulations to the traditional BLC have been put forward, claiming that policy-induced variations in banks' balance sheet *strength* drive the most relevant mechanisms through which monetary policy is transmitted across the banking system.[7]

Fundamentally, the core premise of these formulations has two major elements. First, monetary policy affects banks' earnings and net worth, both directly and indirectly. More directly, interest rate changes not only influence the valuation of banks' assets through the discount factor effect, but they also have a significant impact on cash flows and net interest

[7] This intuition is related to the financial accelerator and the balance sheet channel concepts. However, while the balance sheet channel addresses the ultimate borrowers in the economy, *i.e.*, households and firms, depository institutions are the protagonists in the bank lending channel thesis (Bernanke, 2007).

margins due to maturity mismatches in banks' balance sheets.[8] Less directly, policy-induced changes in borrowers' balance sheets and creditworthiness affect the quality of banks' assets.

The second element of this argument lies in the existence of a binding constraint for banks' external finance, which typically derives from information problems in the market for bank funding. In this context, following a monetary tightening, rising interest rates cause a deterioration in banks' profits and net worth that impairs their ability to attract funds, and consequently their capacity to grant loans. Intuitively, for a given amount of loans contracted, a decline in banks' net worth entails less protection for potential providers of external funds, for which they require a higher compensation (Disyatat, 2011). The resulting increase in banks' funding costs, combined with the decline in net interest margins, implies that lending becomes less profitable, which leads to a reduction in the supply of bank credit (Kishan & Opiela, 2012).[9] Furthermore, if higher interest rates are perceived to be accompanied by abnormal impairments on banks' pending loans, this may trigger the coalescence of a pessimistic consensus among investors regarding the soundness of the banking sector, potentially reinforcing the initial contraction in the supply of bank credit.[10]

In a slightly different rendition of this mechanism, the external finance constraint may instead be derived from the existence of binding capital regulation (Van den Heuvel, 2002a). From this perspective, policy-induced declines in banks' profits and net worth ultimately deteriorate their capital adequacy. If capital is sufficiently low, banks will be deterred from lending because agency costs prevent them from readily issuing new equity (see Calomiris & Hubbard, 1995; Cornett & Tehranian, 1994; Stein, 1998), while prudential regulation requires capital to be at least a minimum percentage of loans (see Bolton & Freixas, 2000; Gambacorta & Mistrulli, 2004; Thakor, 1996).[11]

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[8] An inherent feature of bank intermediation is the maturity transformation performed by banks, who invest in long-term claims issued by borrowers, *viz.*, loans, while providing separate short-term claims to individual savers. As a result, at any given time, a lower fraction of banks' assets can be renegotiated with respect to liabilities, which means banks' margins and profitability tend to be at risk from rising interest rates.

[9] Disyatat (2011) refers to this mechanism as the *Revisited Bank Lending Channel*. However, alternative terminologies have been used, *e.g.*, *Risk-Pricing Channel* (Kishan & Opiela, 2012) and *Bank Balance Sheet Channel* (Halvorsen & Jacobsen, 2016; Jiménez et al., 2012; Schelling & Towbin, 2022).

[10] The connection between monetary policy and financial markets' perceptions has been widely analyzed (see *e.g.*, Bekaert et al., 2013; Bernanke & Kuttner, 2005; Borio & Zhu, 2012).

[11] This alternative mechanism is often referred to as the *Bank Capital Channel*.

2.2 Empirical Studies on the Bank Lending Channel

The first endeavor to empirically confirm the BLC is presented by Bernanke and Blinder (1992). Expanding on their previous contribution[12], they employ Vector Autoregression (VAR) techniques on U.S aggregate bank data to show that tight money reduces the amount of bank deposits, which in the long run is entirely reflected in a contraction of bank credit. However, while their findings were consistent with the BLC thesis, they also allowed for another interpretation: it could be the case that economic activity was dampened through the textbook interest-rate channel, and it was a decline in the *demand* for credit, rather than in the *supply* of credit, that was driving results. For instance, tight monetary policy raises interest rates and the cost of capital, which in turn dissuades investment and leads to a decline in the demand for credit. As a result, the total volume of credit granted falls, even if the supply of credit remains unchanged.[13]

After numerous attempts to overcome this challenge (see *e.g.,* Kashyap et al., 1993; Ludvigson, 1998; Oliner & Rudebusch, 1996), it became clear that the problem was unlikely to be settled using aggregate data. Thenceforward, econometric advances in panel estimation techniques and the increased availability of disaggregated data provided the means for scholars to prove the existence of the BLC while assessing its dependence on banks' characteristics. The intuition behind this approach is that some bank-specific characteristics can only affect movements in the supply of loans, whereas the demand for loans is independent of these (Gambacorta, 2005). Accordingly, cross-sectional differences between banks with respect to *liquidity* (Chatelain et al., 2003; De Santis et al., 2013; Kashyap & Stein, 2000), *size* (Kakes & Sturm, 2002; Kashyap & Stein, 1995) and *capital* (Jiménez et al., 2012; Kishan & Opiela, 2000; Van den Heuvel, 2002b) have been proposed as determining factors for the potency of the bank lending channel.

Most notably, Kashyap and Stein (2000) use data on every U.S. insured commercial bank from 1976-93 and find that a contractionary monetary shock has stronger effects on the lending behavior of smaller banks with less liquid portfolios. Under the auspices of the traditional BLC, the authors argue that these banks are forced to cut loans in order to refrain from reducing their liquid holdings to hazardously low levels. Similarly, using data on U.S.

[12] Bernanke and Blinder (1988).

[13] Disentangling the supply of credit from the demand for credit represents a major identification challenge, common to the entire empirical banking literature.

federally insured commercial banks from 1980-95, Kishan and Opiela (2000) show that, following tight monetary policy, small and undercapitalized banks reduce their loan supply by more, since these are unable to raise alternative funds to finance loan growth. In a similar vein, Jiménez et al. (2012) employ Linear Probability Models to explore a unique loan-level dataset from the Credit Register of Spain. Their results suggest that a monetary policy contraction reduces the probability of loan applications being granted, and this negative effect on credit availability is more severe for banks with low capital and liquidity ratios.

From the *traditional* BLC, these results are interpreted as distinguishing the characteristics that improve banks' capacity to counteract a policy-induced depletion of deposit funding: Liquid banks can shield their loan portfolio from a contractionary shock by liquidating part of their buffer of liquid assets, while larger, better-capitalized banks have easier access to the market for non-deposit funding. Nevertheless, in conformity with the *alternative* renditions of the BLC described above, one may argue that these characteristics mitigate the impact of monetary policy shocks on the supply of bank loans because they reduce the *sensitivity* of banks' external-financing constraint to changes in interest rates. In this regard, smaller, less liquid, and undercapitalized banks may be more vulnerable to monetary policy because these characteristics are closely tied to weaker balance sheets, heavier informational imperfections, and consequently higher variability in the cost of external finance (Disyatat, 2011).

3. The Monetary Response to the Great Recession: Negative Interest Rate Policy

Having outlined the most relevant literature on the BLC in conventional times, the purpose of this chapter is to address the advent of negative policy rates, as well as its implications for bank lending and that channel of monetary policy transmission. In so doing, it will first describe how the secular decline in natural interest rates makes a case for the use of NIRP in the foreseeable future. It will also shed some light on the polarized debate this policy tool has fueled since its debut. Then, the emphasis is placed on bank lending. By acknowledging the unique interactions between NIRP and banks' balance sheets, this chapter discusses how banks' asset and funding structure may determine their response to negative policy rates.

3.1 The New World of Negative Interest Rate Policy

Severe recessions usually require monetary policy accommodation provided by substantial policy rate cuts. Nonetheless, in an environment of near-zero interest rates and low inflation, as the one prevailing at the onset of the Great Recession in 2008, central banks were deemed unable to lower official policy rates further, since these were thought to be constrained by a "Zero Lower Bound" (ZLB) (Lombardi et al., 2018). Indeed, conventional macroeconomic theory assumes that every economic agent will require at least the nominal value of what they lend out to be returned to them.

Over the last few years, however, this macroeconomic tenet has been called into question, as several central banks, including the European Central Bank (ECB) and the central banks of Denmark, Switzerland, Sweden, and Japan, cut their key policy rates into negative territory for the first time in history. These central banks began charging, rather than paying, commercial banks for their excess reserves (Arteta et al., 2018). Hence the replacement of the concept of Zero Lower Bound with that of Effective Lower Bound (ELB).

Negative interest rate policy aimed to prove each central bank's resolve to achieve its policy targets, although the specific objectives were not entirely identical across jurisdictions (Arteta et al., 2018). Whereas the Danmarks Nationalbank (DNB) and the Swiss National Bank (SNB) introduced NIRP as a means to limit capital inflows and stabilize the exchange rate, the key motivation behind its implementation by the ECB, the Bank of Japan (BoJ) and the Swedish Riksbank was the need to stabilize inflation expectations and support economic growth. The common objective was, however, to promote economic recovery.

3.1.1 The Relevance of Analyzing Negative Policy Rates

To motivate the importance of studying NIRP, it is worth discussing why this policy instrument will presumably remain in central banks' toolbox in the foreseeable future. Before doing so, it is appropriate to describe the theoretical concept, controversial as it may be, of the natural or "equilibrium" interest rate. Originally proposed by Wicksell (1898), and central to modern macroeconomics, the natural interest rate portrays the equilibrium real short-term rate that would prevail if GDP reached potential output and inflation was equal to the inflation target of the central bank. This concept establishes a benchmark for assessing the stance of the monetary authority: whenever the short-term real interest rate lies below the natural rate, monetary policy is expansionary, and vice-versa.

One of the pressing challenges facing central bankers around the world is the long-term decline in natural interest rates. Projections by Holston et al. (2017), for instance, suggest that natural interest rates have dropped to near, and sometimes even below zero over the past quarter century in several advanced economies.[14] The causes of this phenomenon have been widely studied and include demographic factors such as lower fertility and increased life expectancy (see Carvalho et al., 2016; Gagnon et al., 2021), low productivity growth and "secular stagnation" (Summers, 2014), a slowdown in the rate of technological progress, global trends of investment and saving (Bernanke, 2005), and a growing demand for safe (and liquid) assets (Del Negro et al., 2017).

Since this trend will likely persist into the future, it will have far-reaching consequences on the conduct of monetary policy (see Blanchard et al., 2010; Laubach & Williams, 2016; Summers, 2014). To be specific, a declining trend in natural interest rates suggests that policy rates will need to be reduced further for monetary policy to be expansionary, which increases the likelihood that economies reach the ZLB more often. In fact, given the concerns of secular stagnation, Kiley and Roberts (2017) estimate that the zero lower bound will be binding up to 40% of the time in the future for most advanced economies.

Moreover, a recent inquiry based on a historical sample of pandemics presented by Jordà et al. (2022) indicates that pandemics are usually followed by a sustained period of depressed economic activity and a persistent decline in the real natural rate of interest. As the world

[14] Beyer and Wieland (2019) conducted a similar study using a different methodology and found assenting results.

withstood the downturn induced by the COVID-19 pandemic crisis, these findings pointed to the imperative need for a forceful policy response on all fronts, including the monetary one. Therefore, the viability and the broader implications of NIRP have remained at the focal point of the ongoing policy and academic debate in recent years.

3.1.2 The Controversial Nature of NIRP

Although negative policy rates have been adopted in countries accounting for more than one-quarter of the world GDP, this unprecedented policy move did not come without contention. Most notably, the Federal Reserve and the Bank of England have refrained from the implementation of NIRP due to skepticism regarding its effectiveness in stimulating economic activity, and particularly bank lending (see Carney, 2016; Waller, 2016).[15]

For the most part, opponents to this policy innovation allege concerns about detrimental effects on the stability of the financial system and argue that NIRP may reduce banks' willingness to lend, aggravate financial markets' frictions and distortions, inflate asset prices, and postpone the enactment of urgent macroeconomic and structural policies (Arteta et al., 2018; McAndrews, 2015). Other arguments commonly cited relate to the unpredictability of NIRP's signaling effects. These include the possibility that the public misinterprets negative policy rates as evidence that the central bank is "running out of ammunition" (Bernanke & Reinhart, 2004), or even that the central bank itself has low expectations for inflation – thus thwarting the intended effect of stabilizing these expectations.[16]

The standpoint of researchers and academics is no less divergent. Krugman (2013) claimed that "the zero lower bound isn't a theory, it's a fact" and Summers (2019) describes negative interest rates as the "monetary black hole". Opposingly, other well-known economists, such as Buiter (2009), Agarwal and Kimball (2015), Rogoff (2017), and Lilley and Rogoff (2019) advocated the use of negative rates as the preferable long-term solution to the binding limitations of standard monetary policy tools since the Global Financial Crisis (GFC). At a midpoint is Bernanke (2016), who provides a more balanced perspective, while claiming that the nervousness around negative interest rate policy is "overdone".[17]

[15] From a policy perspective, some renowned economists have leaned in favor of the implementation of negative policy rates in the United States (see Blinder, 2010; Kocherlakota, 2016; Mankiw, 2009).

[16] While most of these fears were present to some extent at very low rates, they are amplified by NIRP.

[17] In the words of Bernanke (2016), negative interest rates appear to have both modest benefits and manageable costs.

Another bone of contention is the extent to which NIRP fits into the unconventional monetary policy (UMP) box. According to Bernanke (2019), unconventional policies may be categorized into four groups, namely, forward guidance, quantitative easing (QE), negative interest rates, and yield curve control (the management of long-term yields). While this nomenclature has been largely adopted in the existing literature, the inclusion of NIRP in this group is not unanimous. The gist of the objections, as put forth by Albertazzi et al. (2021) and Lombardi et al. (2018), is that unconventional tools can only include policy instruments, *other than the setting of short-term interest rates*, specifically tailored to stimulate the economy or alleviate shocks to the financial system in times of strong financial strains. From this perspective, NIRP should be understood as a conventional instrument used in an unconventional way, as it represents a mere extension of short-term interest rate policies.

Despite these protracted and polarized debates on the significance and implications of NIRP, little consensus has been reached since its groundbreaking enactment. Importantly, however, the failure of this policy to be broadly embraced should not be entirely ascribed to theoretical discomfort among academics and policymakers, as it has also suffered until very recently from a shortage of clear-cut, unequivocal empirical support.

3.2 The Bank Lending Channel under Negative Interest Rate Policy

Having laid out the dual foundation of the present dissertation, *i.e.*, the bank lending channel and negative interest rate policy, now is the time to relate the two and address the leading question: Does the bank lending channel survive under NIRP? Differently put: *Does Negative Interest Rate Policy enhance bank lending?* Before taking matters into one's hands, however, it is of the utmost importance to discuss the possible mechanisms that may be at work, a subject to which this section now turns. In so doing, it will first address the interactions between negative interest rates and banks' balance sheets from a theoretical standpoint, and the extent to which these interactions are unique. Building on the blossoming research on the importance of banks' reserve holdings and liquidity, this section describes why a heterogeneous transmission of NIRP depending on banks' asset composition seems plausible. Then, it discusses how the observation of a *sui generis* friction associated with NIRP, *i.e.*, the ZLB on banks' retail deposits, points to the importance of banks' funding structure

in a negative rate environment. An overview of the growing empirical evidence on these matters will be presented as well.[18]

3.2.1 Bank Lending and Asset Composition

Setting negative policy rates was meant to encourage banks to lend out the deposits they were holding at the central bank, hence increasing the supply of credit to the real economy. However, the extent to which different banks are exposed to NIRP is not homogeneous. Reminiscent of the conventional BLC described earlier, some bank-specific characteristics seem to heighten the sensitivity of banks' balance sheets, and therefore their lending behavior, to negative interest rates. In this regard, the composition of banks' assets, and particularly their liquidity has been greatly emphasized in the maturing literature, as we will now discuss.

3.2.1.1 The Direct Cost of NIRP: A Tax on Excess Reserves

Banks' holdings of reserves above the regulatory requirement are an obvious aspect to consider when assessing the impact of NIRP on lending behavior. Indeed, a negative policy rate usually refers to the rate remunerating excess reserve balances held by commercial banks at the central bank (Basten & Mariathasan, 2018, 2020; Demiralp et al., 2021).[19] And while a few decades ago most banks held mandatory reserves for the sole purpose of compliance with the official requirement of the central bank, this pattern was revoked with the GFC and, most recently, with the COVID-19 pandemic crisis.

Focusing on the Euro Area experience, due to massive liquidity injections into the banking sector, the amount of reserves held by commercial banks at the ECB escalated from around EUR 10 billion in 1999 (representing 0.7% of Euro Area banks' total assets) to more than EUR 4 trillion in April 2021 (comprising 11.3% of total assets) (Clayes, 2021). Therefore, the direct cost for banks detaining excess liquidity has increased substantially.

To avoid any misconception, it is important to clarify that the concurrence of these measures, *i.e.*, the negative DFR and the liquidity injections conducted by the ECB, was by no means a

[18] It is important to reiterate that the purpose of this section is not to redescribe the BLC mechanism, especially regarding those aspects which are common to its conventional formulation. Instead, the goal here is to discuss novel manifestations of this channel, which are to some extent distinctively related to NIRP.

[19] The technical aspects of the implementation of NIRP varied across jurisdictions (see Bech and Malkhozov (2016) for a comprehensive review). In the case of the ECB, which we emphasize, the negative policy rate is the DFR (Deposit Facility Rate), *i.e.*, the rate on the deposit facility that banks may utilize to make overnight deposits with the Eurosystem.

coincidence. Quite the opposite, these strategies are designed to positively interact with one another, so that the overall easing effect on credit conditions is larger than the sum of each measure individually (Constâncio, 2016). To be specific, while asset purchases and credit refinancing operations allow banks to obtain attractive funding conditions as well as the necessary liquidity to increase credit granted to the real economy, the negative DFR acts as an effective tax on that same excess liquidity (Arteta et al., 2018; Demiralp et al., 2021).

This additional burden is expected to encourage banks to get rid of costly reserves parked at the central bank and reallocate them via balance sheet adjustments.[20] Banks may carry out these adjustments by increasing debt securities purchases, paying down funding sources, or alternatively, by extending credit to households and non-financial firms, thus achieving the intended effect on credit creation.[21]

3.2.1.2 NIRP and the Yield Curve

There is another important way in which NIRP provides further stimulus to economic activity, particularly through the financial system. Negative interest rates relax the non-negativity constraint on current and future expected short-term interest rates, allowing monetary accommodation to proliferate through the entire yield curve (Boucinha & Burlon, 2020; Cœuré, 2017; Constâncio, 2016).

During normal times, whenever the central bank changes policy rates, it directly affects the short end of the yield curve, which is the footing of its expectations component: Insofar as market participants perceive a change in policy rates as the beginning of an incremental series of changes, longer-term rates vary in tandem (Bottero et al., 2021; Cœuré, 2017). Nonetheless, before the introduction of NIRP, the distribution of future expected short-term rates was truncated at zero, since market participants believed that, after reaching the ZLB, interest rates could only rise and would never drop further (Boucinha & Burlon, 2020; Constâncio, 2016). As a result, the response of long-term interest rates to shifts in the policy rate was impaired and the yield curve became steeper (Grisse, 2015; Ruge-Murcia, 2006).

[20] Ryan and Whelan (2021) refer to this phenomenon as the "hot potato effect".

[21] The banking system as a whole cannot curtail excess liquidity by granting more credit or purchasing securities, as these operations simply move liquidity from bank to bank within the self-contained, closed system in which it can circulate. Nonetheless, individual banks can orchestrate a decrease in their excess liquidity in this manner (Boucinha & Burlon, 2020).

By breaking through the ZLB, negative policy rates restored the monetary authority's ability to steer market expectations, enabling the full spectrum of interest rates to thrust into negative territory (Cœuré, 2017). As stated by Grisse et al. (2017), since NIRP moved the markets' believed location of the lower bound, it reduced long-term rates over and above the direct influence of the policy rate cut itself. At the same time, the negative remuneration of short-term holdings triggered an increase in the demand for longer-dated assets, which exerted further downward pressure on the term premia, *i.e.,* investors' required compensation for the uncertainty about the future path of interest rates (Boucinha & Burlon, 2020).

In fact, Christensen (2019) analyzed financial markets' reaction in five NIRP-adopting jurisdictions – Denmark, Sweeden, Switzerland, France, and Japan - and showed that the entire cross-section of sovereign bond yields displayed a swift and persistent response to this policy tool. Focusing on the Euro Area, Rostagno et al. (2021) found that negative rates influenced bond yields across the maturity spectrum, which amounted to a downward shift and a simultaneous flattening of the yield curve (see also Bottero et al., 2021). Importantly, the authors claim that the response of long-term rates to the NIRP impulse surpasses by a wide margin the response to regular policy rate cuts above but close to the lower bound.

As far as banks' balance sheets are concerned, the impact of negative interest rates on the yield curve induces a decline in the returns of all liquid assets. For this reason, liquid banks are encouraged to protect profitability by curtailing not only their holdings of excess reserves, but also other liquid holdings in general, and by procuring higher earning, less liquid assets (Bottero et al., 2021). In other words, negative rates incentivize banks to shift their portfolios' composition toward assets with longer maturities (and higher yields), propelling a variant of the *portfolio rebalancing mechanism* that is usually associated with other unconventional policy instruments and thus accentuating *yield-seeking* behavior (Demiralp et al., 2021).

From this perspective, policy rate cuts in negative territory diverge from conventional rate cuts above but close to the ZLB which, by influencing merely the short tail of the yield curve, cannot provide the same rebalancing stimulus (Bottero et al., 2021). Moreover, the fact that earnings on *all* liquid assets in banks' balance sheets fall compared to loans should offer them a powerful incentive to rebalance in favor of credit origination (Boucinha & Burlon, 2020).

3.2.2 Bank Lending and Funding Structure

Thus far, the discussion around bank lending in a negative rate environment has been centered on the composition of banks' assets and particularly, on the role played by liquidity.

However, given the emphasis placed on funding costs in the conventional BLC and taking on the evidence of a hard ZLB on banks' retail deposit rates, it is of the utmost importance to assess the role played by banks' funding structure for the transmission of NIRP.

3.2.2.1 The Zero Lower Bound on Banks' Retail Deposits

It seems plausible to assume that negative policy rates will work differently from standard positive rate cuts because NIRP is associated with a unique friction, *i.e.*, the existence of a zero lower bound on banks' retail deposits. Whereas banks are keen on lowering deposit rates after interest rate cuts in positive territory (Hannan & Berger, 1991), they seem unwilling, or even unable, to pass on negative rates to customers' deposits. Indeed, numerous studies report a complete pass-through of negative policy rates to money market and interbank lending rates, but not to banks' retail deposit rates (see Eggertsson et al., 2019; Eisenshmidt & Smets, 2019; Heider et al., 2019).

The most intuitive explanation for banks' reluctance to charge negative rates on retail deposits is the existence of physical currency, which provides a substitute store of value with 0% yield (Scheiber et al., 2016). Banks seem to fear large-scale withdrawals from their depositors, who may optimally prefer to hold banknotes and coins if the deposit rate were to become negative. However, several other explanations have been proposed.

One possibility is that banks are willing to charge negative rates on deposits in principle but are reluctant to be the first ones to attempt it in practice, due to forces of competition within the banking sector and fears of reputational damages connected to a "first-mover curse" (Grandi & Guille, 2021; IMF, 2017). Another possible reason may derive from the institutional features of the banking system. For instance, in some jurisdictions, there are legislative hurdles and litigation risks associated with the imposition of negative rates on bank customers, or at least some uncertainty concerning the legal framework around such arrangements (Boucinha & Burlon, 2020; Demiralp et al., 2021). Other examples of institutional constraints include the ambiguity regarding the taxation scheme of negative interest rate "income" and the inability of most IT systems to deal with negative rates (Cœuré, 2016; Demiralp et al., 2021).

Despite all these reasons, the fact that holding physical cash implies storage, transportation, and insurance costs suggests that, in theory, the effective lower bound could be below zero, which might allow banks to impose negative rates on *some* deposits. However, because the

estimation of these costs is arduous and mostly subjective, most banks were unwilling to test this boundary for some time (Beyer & Wieland, 2019; Heider et al., 2019).

A more granular analysis shows that households' deposit rates are constrained by a harder ZLB than nonfinancial corporations' deposits (Altavilla et al., 2022; Eisenshmidt & Smets, 2019). This is consistent with the observation that households typically own smaller bank deposit accounts, from which they may promptly draw back their money and switch to another bank or even hold physical cash. On the contrary, firms hold much larger deposit accounts and tend to rely on close, long-term relationships with their banks to preserve access to credit. Therefore, worries of having credit lines recalled or outstanding loans not refinanced if they move their deposits to a competitor bank are likely to raise firms' switching costs when compared to those of households (Altavilla et al., 2022).[22] Also, it must be borne in mind that the alternatives that most firms face to store their money usually consist of market-based assets such as government bonds and money market funds, which contrary to retail deposits, may be subject to negative rates (Heider et al., 2021). Accordingly, recent evidence suggests that a few banks began, in fact, charging negative rates on large deposit accounts from investment firms and other corporate clients (see Altavilla et al., 2022; Eisenshmidt & Smets, 2019; Heider et al., 2019; Schnabel, 2020), although this is not yet standard practice.

3.2.2.2 Banks' Response to the ZLB on Retail Deposits

A major debate among researchers and policymakers is whether the hindered pass-through of negative policy rates to deposit rates results in a compression of intermediation margins, thus lowering bank profitability and net worth. This debate becomes particularly relevant considering the detrimental effects that lower profitability and net worth may exert on banks' lending behavior and overall financial stability.

On the one hand, just as positive rate cuts, negative rates may improve bank value and net worth by raising asset prices and enhancing loan quality. Indeed, if NIRP fulfills its purpose of easing economic and financial conditions, the extent of banks' non-performing loans and loan-loss provisions should fall along with borrowers' improved creditworthiness. A similar

[22] Moreover, consumer protection regulation is often applicable to households' but not to nonfinancial firms' deposits (Boucinha & Burlon, 2020).

revaluation effect may arise for banks' tradable assets, which is then reflected in capital gains and hence, net worth (Brandão-Marques et al., 2021; Chodorow-Reich, 2014).

On the other hand, however, the ZLB on deposit rates suggests that most banks will no longer benefit from the standard decline in funding costs that takes place after policy rate cuts in positive territory. Meanwhile, competition in the banking system forces banks to continuously reduce lending rates (Scheiber et al., 2016), although they never reach the ZLB due to the premium for liquidity and credit risk (Heider et al., 2021).

As a result, one may expect banks' net interest margin (NIM) to tighten, as loan rates decline, while rates on deposits exhibit downward rigidity (Jobst & Lin, 2016). Moreover, to the extent that a decline in intermediation margins and profitability is known to erode net worth and equity, NIRP will tighten banks' external finance constraint until it inevitably binds. This, in turn, may discourage banks from lending or promote an increase in both lending rates and fees to cover losses, while causing contractionary effects on real economic activity (Eisenshmidt & Smets, 2019; Heider et al., 2019).

This hypothesis is in line with the theoretical model developed by Brunnermeier and Koby (2018), suggesting that there is a "reversal interest rate" at which further accommodation provided by policy rate cuts reverses its intended effect and becomes contractionary for lending.[23] [24] The reversal rate materializes when the positive influence of policy rate cuts on banks' balance sheets, *e.g.*, due to asset revaluation and borrowers' increased ability to reimburse their debts, is outweighed by its negative impact on net interest margins and net worth, thus leading to a contraction in bank lending.

From a theoretical stand view, the reversal rate hypothesis completely overturns the bank lending channel mechanism, according to which lower policy rates should *improve* banks' net worth and *relax* the external finance constraint, thus allowing banks to *expand* lending. In fact, this hypothesis justifies why several authors have claimed that the BLC collapses once the nominal bound on deposit rates is hit (Eggertsson et al., 2019; Heider et al., 2019).

[23] The model proposed by Brunnermeier and Koby (2018) does not explicitly mention negative interest rates, which means the reversal interest rate may be positive.

[24] The concepts "reversal interest rate" and ELB are frequently used interchangeably, although they portray different economic notions. The reversal rate might be either below or above the ELB.

3.2.3 Empirical Evidence

Anecdotal evidence suggests that bank lending has improved in most NIRP-adopting jurisdictions, both to households and non-financial corporations (see Cœuré, 2016; IMF, 2017; Schnabel, 2020). Nonetheless, the jury is still out on whether negative policy rates played a part in this credit expansion. Indeed, at the time of the introduction of NIRP, central banks carried out several other unconventional policies in an attempt to support the funding and liquidity position of the banking system, along with long-term credit conditions. Therefore, in order to unravel the causal nexus between negative rates and banks' lending behavior, empirical research has recently focused on comparing the response of banks that are heterogeneously impacted by the policy. With very few rare exceptions, most papers analyzing these matters employ a difference-in-differences (DiD) estimation methodology, which allows for exploring the variation in a chosen treatment variable between different banks, thereby identifying its impact on lending behavior following the introduction of NIRP. In other words, the treatment variable summarizes the degree of each bank's sensitivity (exposure) to NIRP.[25]

3.2.3.1 Banks' Asset Composition: Liquidity

Given the influence of NIRP on excess reserve holdings and the yield curve discussed above, some recent empirical contributions to this strand of the literature have employed variables capturing the liquidity of banks' assets as treatment variables in DiD settings.

Drawing on confidential bank-level datasets from the Euro Area, Demiralp et al. (2021) are the first to empirically verify the importance of banks' excess liquidity holdings, while pointing out a strong complementarity of NIRP with central bank liquidity injections, *e.g.* via asset purchases. Adding to the significance of banks' retail deposit intensity (as in Eggertsson et al., 2019; Grandi & Guille, 2021; Heider et al., 2019, among others), they show that higher levels of excess liquidity increase banks' sensitivity to NIRP, which in turn enhances loan granting through a "portfolio rebalancing" mechanism. By the same token, Basten and Mariathasan (2018) use detailed supervisory data from Switzerland to explore differences in banks' lending behavior stemming from the burden of holding excess reserves. Their study is more country-specific, however, as it accounts for the tiering mechanism adopted by the

[25] Table A13 (Annex) provides an overview of the empirical studies discussed throughout this section.

Swiss National Bank (SNB) together with the negative DFR.[26] Despite the different policy execution, the authors find that more affected banks reduce costly reserves in favor of higher mortgage and uncollateralized lending, which amounts to the same rebalancing effects uncovered by Demiralp et al. (2021).

In a similar vein, Bottero et al. (2021) and Arseneau (2020) examine the role played by banks' liquidity holdings more broadly in the transmission of negative policy rates. Arseneau (2020) uses confidential supervisory data gathered as part of the *Comprehensive Capital Analysis and Review (CCAR)* stress tests to empirically assess banks' perceptions of NIRP in the United States.[27] Surveying the stress-test data, the author claims that U.S. banks' exposure to NIRP is mostly driven by liquidity management concerns, as banks holding more short-term liquid assets anticipate the sharpest declines in net income if the federal funds rate dropped below zero (Arseneau, 2020). However, this paper does not cover the potential changes in U.S banks' lending behavior after NIRP, and thus cannot explicitly address the portfolio rebalancing hypothesis featured in the discussion of the studies presented above. Taking a step further, Bottero et al. (2021) employ two different variables capturing bank liquidity in a DiD setting, namely net interbank position and the liquid assets ratio. Exploring the Italian administrative credit register, along with firm and bank-level data, the authors present strong evidence suggesting that during NIRP, banks with higher *ex-ante* liquidity cut loan rates and expand their credit supply by more than other banks.

Noticeably, these findings contrast with previous contributions regarding conventional rate cuts above the ZLB (see Chatelain et al., 2003; Jiménez et al., 2012; Kashyap & Stein, 2000). Indeed, while the conventional BLC postulates a stronger responsiveness to policy changes for banks with lower liquidity ratios, in a negative rate environment, highly liquid banks appear to be the ones whose loan issuance is most affected by the policy. This is in line with the theoretical prediction of the interaction between negative rates and banks' asset composition: not only does NIRP act as a direct tax on excess liquidity, but it also broadens the spread between low-yield, liquid assets, and higher-yielding assets, especially loans. This is expected to incentivize liquid banks to reallocate their portfolios in favor of credit granting.

[26] As of January 2015, the Swiss National Bank cut its deposit facility rate from 0 to -0.75% but only imposed this rate on the fraction of each bank's central bank reserves that surpassed twenty times its minimum reserve requirement (Basten & Mariathasan, 2018).

[27] In the context of the CCAR, each bank was required to project its net income and profitability over a nine-quarter forward horizon conditional on a hypothetical negative policy rate scenario.

3.2.3.2 Banks' Funding Structure

Pursuant to the observation of a hard ZLB on deposit rates, recent contributions to the empirical literature have employed measures of banks' funding structure, namely banks' reliance on deposits, as treatment variables in DiD settings. The rationale for focusing on the share of deposit funding is straightforward: the fact that negative policy rates result in cheaper market-based (non-deposit) financing, but not in cheaper deposit financing implies that banks are heterogeneously affected by the policy, depending on the role played by deposits on the liability side of their balance sheets.[28]

Most notably, Heider et al. (2019) explore a transaction-level dataset on Euro Area syndicated loans from 2013-2015 to compare the volume and structure of syndicated lending by banks with different deposit ratios before and after NIRP. Their findings suggest that, following the implementation of negative policy rates by the ECB in June 2014, syndicated lending is significantly reduced by high-deposits banks relative to low-deposits banks.[29] Comparably, Eggertsson et al. (2019) use the Swedish mortgage market as a case study to show that, once banks run into the inevitable lower bound on deposits, the ones most dependent on deposit funding undertake a reduction in credit growth and are less prone to cut their lending rates, when compared to banks with little deposit funding. Arce et al. (2021) corroborate such findings with a unique dataset comprising the Credit Register of Banco de España as well as confidential survey data from the ECB's Bank Lending Survey (BLS). Based on the answers of Spanish banks to the BLS, they assume that a bank is adversely affected by NIRP when it reports that the negative DFR led to a decline in its net interest income. Once again, results indicate that reliance on deposit funding is the primary channel through which negative rates impact banks' margins and that adversely affected banks curtail their loan supply to firms and increase lending rates, relative to non-affected banks.

Surprisingly, a few studies have replicated the empirical approach employed by Heider et al. (2019) with different data and found contrasting results. For instance, Tan (2019) uses confidential bank-level data collected by the ECB on balance sheet items, lending volumes,

[28]Several studies find that banks relying mostly on deposit funding bear a relatively heavier impact on their net interest margins and profits when policy rates drop below zero, as they become unable to adjust a major portion of their funding expenses (Ampudia & Van den Heuvel, 2022; Heider et al., 2019; Urbschat, 2018).

[29] In their most comprehensive analysis, the authors find that their estimates are not only larger but are also more precisely estimated for banks with a greater reliance on *households'* deposits, which confirms the harder ZLB on households' deposit rates discussed earlier.

and interest rates, composing a baseline sample of 189 Euro Area banks. Unlike Heider et al. (2019), this sample is more representative (covering approximately 70% of EA banks' assets) and includes total lending rather than syndicated loans.[30] Contrary to previous findings, Tan (2019) claims that NIRP amplified the bank lending channel for banks most affected by the policy through the ZLB on retail deposits. To put it differently, despite a relative upsurge in the funding costs of high-deposits banks, the author shows that these banks increase the supply of credit by more than low-deposits banks and argues that greater lending volumes are enough to counteract the adverse impact of negative rates on intermediation margins. Importantly, however, these results are almost entirely driven by household mortgage lending, as there are no significant discrepancies found in lending to nonfinancial firms between high and low-deposits banks.

Focusing on country-specific analyses, Schelling and Towbin (2022) explore a transaction-level dataset on Swiss corporate loans, as well as bank-level data, while also using banks' deposit ratio as the treatment variable in their DiD framework. Their results suggest that after the implementation of NIRP, deposit-dependent banks not only relax their lending terms and conditions relative to other banks but also concede larger loan amounts. In the same vein, Grandi and Guille (2021) exploit a confidential dataset owned by Banque de France, including data from the French Credit Register, and find sound evidence that banks most reliant on deposit funding attempt to counteract the impact of NIRP by extending more corporate loans than other banks.

These findings suggest that an alternative response to the shrinkage of intermediation margins by high-deposits banks is also conceivable, which does not involve a decline in lending. Indeed, to restore their usual returns and earnings, thus maintaining profits and capturing market shares, deposit-reliant banks may react to the relative increase in their funding costs by granting *more* credit and extending more favorable lending terms, which may, in turn, generate an expansionary impact (Schelling & Towbin, 2022; Tan, 2019).

[30] Syndicated loans represent less than 5% of Euro Area lending and do not include loans to households (Tan, 2019).

4. Methodology

Considering the assorted theoretical conjectures described in the previous chapter, assessing the mechanisms that govern the relationship between NIRP and the bank lending channel of monetary policy is mostly an empirical matter. Throughout this chapter, we outline the framework for our empirical strategy. We start by briefly discussing the institutional context in the Euro Area and in Portugal (section 4.1) and by laying out the empirical model employed in the present study (section 4.2). Then, we describe the data and present summary statistics for banks with different characteristics relevant to our purposes, namely regarding liquidity and reliance on deposit funding (section 4.3). In section 4.4, we present and discuss our main findings, along with the results of some additional tests.

4.1 Institutional Background

4.1.1 The Implementation of NIRP by the ECB

The availability of reserves in the banking system seems to dictate which of the ECB's policy rates underpins short-term rates in the economy. Whenever the central bank supplies just the right amount of reserves to satisfy the demand brought about by reserve requirements or other autonomous factors, market participants set the cost of overnight funds in the vicinity of the rate on the Main Refinancing Operations (MRO) (Boucinha & Burlon, 2020). Indeed, during times of regular liquidity allotment, such as the one established by the liquidity framework of the Eurosystem prior to the GFC, the Euro Overnight Index Average (EONIA) hovered around the MRO, which was, therefore, the key policy rate for the transmission of monetary policy (Altavilla et al., 2022). Nevertheless, in times of abundant liquidity provision resulting from a policy of full allotment, overnight rates tend to be grounded by the Deposit Facility Rate (hereafter referred to as DFR), which is the rate on the deposit facility that banks may utilize to make overnight deposits with the Eurosystem. In such times, the DFR becomes the relevant variable in determining money market rates.

Bearing this in mind, the implementation of NIRP by the ECB refers to the initial cut in the DFR into negative territory, namely from 0 to −0.10%, on June 11, 2014. Subsequently, further cuts were made to −0.20% in September 2014, to −0.30% in December 2015, to −0.40% in March 2016, and finally to −0.50% in September 2019 (Altavilla et al., 2022).[31]

[31] As of July 2022, the ECB's Governing Council decided to raise its key interest rates by 50 bp. Accordingly, the rate on the MRO and the deposit facility (the DFR) increased to 0.50%, and 0.00%, respectively.

The declared goal of the ECB when implementing negative policy rates was to further ease credit conditions in response to rising deflationary risks (Bech & Malkhozov, 2016; Praet, 2014). However, NIRP was not introduced as a standalone measure. Instead, it was part of a comprehensive policy strategy aimed at averting the unprecedented consequences of the Global Financial Crisis and the ensuing Sovereign Debt Crisis for the European economy. This strategy consisted of a credit-easing package, which also involved targeted long-term refinancing operations (TLTROs) and a large-scale asset purchase program (APP) of private and public sector bonds across maturities and market segments (Arce et al., 2021).

4.1.2 The Portuguese Setting

Portugal offers a favorable testing ground for the analysis of bank lending under NIRP since the banking system provides the bulk of the financing to the Portuguese economy. Between 2001 and 2020, the average value for domestic bank credit to the private sector as a % of GDP in Portugal was above 127%. In 2014, when NIRP was first introduced by the ECB, this value amounted to 129,7% of GDP, which was well above the OECD members' average of 81,5% and the Euro Area average of 92,6%.[32]

In Portugal, banks are systematically the primary funding source of households, as well as of the corporate sector. This is especially true for small and medium-sized enterprises (SMEs), which represent a major portion of Portuguese firms. Indeed, despite a slight decrease over the last decade, the reliance of Portuguese firms on the banking sector as the main source of external finance, providing more than 40% of their funding, can be verified in Figure A3. Regarding the organization of the banking activity, traditional loan intermediation has always been the focus of the Portuguese banking sector, with loans and advances to customers representing around 50% of the sector's total assets in 2014 (Figure A4).

Within the Euro Area, Portugal is also a good experimental setting because the ECB's monetary policy is designed as a function of the macroeconomic conditions of the EA as a whole, and not in response to Portugal's domestic economic conditions. This mitigates potential endogeneity issues arising from the omission of variables that affect central banks' policies, as well as banks' credit supply decisions (Schelling & Towbin, 2022).

[32] The latest value from 2020 represents 101,1% of GDP, which is still considerably larger than the OECD members' average of 84,3%.

In this regard, there are several reasons to believe that the ECB's policies in mid-2014, including the introduction of NIRP, were exogenous to the Portuguese economic context. First, Portugal accounts for less than 3% of the Euro Area GDP, and as a peripheral country, its business cycle was not converging with those of the core countries (Giannone et al., 2009). Moreover, before the implementation of NIRP in June 2014, economic conditions were worse in Portugal than in most EA countries, as well as in the U.K and the U.S.[33] And while at that time the Bank of England and the U.S. Federal Reserve had their balance sheets growing with the implementation of large-scale asset purchase programs (LSAPs), the ECB had not yet launched its own rendition of Quantitative Easing (QE) and its balance sheet was even contracting. [34] [35] These developments support the view that the introduction of NIRP in June 2014 was not a response to the Portuguese situation but was instead tackling the downturn in economic recovery for the EA altogether.

4.2 Empirical Design

In our empirical analysis, we follow the bulk of the literature and adopt a Difference-in-Differences (DiD) methodology, while exploring cross-sectional variation in the two leading determinants of banks' response to NIRP – bank liquidity and reliance on deposit funding.

The DiD method is a quasi-experimental design that compares changes in outcomes over time between a population exposed to a treatment (the treated group) and a population that is not (the control group). In our setting, the "policy" corresponds to the first DFR cut below zero in June 2014, while the interbank liquidity and deposit ratios (the treatment variables), computed as of March 2014, measure bank-specific *ex-ante* exposure to the policy, *i.e.*, the treatment intensity.[36] It should be emphasized that we use continuous treatment variables because banks are impacted by NIRP to varying degrees, rather than in a binary fashion.

The appeal of the DiD approach comes not only from its robustness to omitted variables that identically affect the control and treated groups but also from its potential to circumvent

[33] In Portugal, annual GDP growth rates were already negative in 2012 and 2013.

[34] The decline in the ECB's balance sheet was mostly related to early repayments of funds raised through three-year longer-term refinancing operations (LTROs) (ECB, 2013).

[35] It was only in January 2015 that the Governing Council of the ECB decided to introduce the Expanded Asset Purchase Program (expanded APP), aiming to address the perils of Euro Area inflation remaining too low for a prolonged period (Gambetti & Musso, 2020).

[36] Studies employing DiD settings with proxies for bank liquidity as a treatment variable include Bottero et al. (2021) and Demiralp et al. (2021). Others measure treatment intensity using banks' reliance on deposit funding (see *e.g.*, Heider et al., 2019; Schelling & Towbin, 2022; Tan, 2019).

other endogeneity issues that frequently arise when making a comparison between heterogeneous entities (see Bertrand et al., 2004; Meyer, 1995). In the present study, we compare the lending behavior of banks with different characteristics (liquidity/deposit funding) before and after the implementation of NIRP by the ECB in mid-2014. The identifying assumption is that the control group (low-liquidity/low-deposits banks) offers a legitimate counterfactual for the behavior of the treated group (high-liquidity/high-deposits banks) had NIRP not been put into practice. The baseline regression is defined as follows:

$$Y_{i,t} = \sum_{t=1}^{n} \beta_{1,t} \times Period_t \times Interbank\ Liquidity_i + \sum_{t=1}^{n} \beta_{2,t} \times Period_t \times Deposit\ Ratio_i + \sum_{t=1}^{n} \theta_t \times Period_t \times Bank\ Char_i + \alpha_i + \lambda_t + \varepsilon_{i,t} \quad (4.1)$$

Where *i* denotes banks and *t* denotes months. $Y_{i,t}$ is the outcome variable of interest related to banks' response to negative policy rates, which for the core analysis represents banks' outstanding credit either to individuals or non-financial corporations (NFCs).

Among the independent variables, $Period_t$ is a time dummy variable indicating the period after the DFR cut in June 2014. This dummy is interacted with all other regressors, whether these are included as treatment variables or simply as controls.[37] In our simplest, *static* specification, $Period_t$ is replaced by $NIRP_t$, a dummy variable taking the value of 1 for every month from June 2014 onwards, and 0 otherwise. Then, in order to trace the impact of the treatment variables on banks' outcomes over time, we run a *dynamic* specification using separate indicator variables for each period relative to the enactment of the policy. The advantages of this alternative setup are twofold. First, it allows us to gauge changes in the effectiveness of the treatment throughout the time window employed. Second, it enables us to address the parallel trends assumption, which underlies any DiD specification and must be verified in depth.

[37] Most papers employing a DiD approach include lagged variables as controls, as opposed to interacting each variable with the time dummy. Although sometimes acceptable, the inclusion of lagged controls raises concerns about endogeneity, as these may be caused by the treatment (since they are measured after the treatment). To improve the validity of our study, we employ full interactions with both treatment variables, as well as with the control variables.

Regarding the treatment variables, $Interbank\ Liquidity_i$ measures banks' (net) interbank position, while the $Deposit\ Ratio_i$ corresponds to the share of short-term deposits over total assets. Additionally, $Bank\ Char_i$ is a vector containing other bank-level variables, which are included to control for time-varying characteristics that may affect the transmission of negative rates to the supply of bank credit. These include bank size, capitalization, the securities ratio, and the non-performing loans (NPLs) ratio.

Lastly, α_i and λ_t denote bank and time fixed effects, respectively, included to control for time-invariant, unobservable bank-specific characteristics as well as time-specific unobserved heterogeneity (*e.g.*, aggregate shocks). Regression (4.1) is estimated with OLS and standard errors ($\varepsilon_{i,t}$) are clustered at the bank level, hence allowing for correlation in the error terms over time within banks.

In recognition that banks may take some time to react to the NIRP impulse, we adopt a relatively large time window around its introduction, covering the period from October 2013 to December 2016. We argue that this time window is sufficient for banks' credit supply decisions to be affected by the policy. However, in view of reducing potentially confounding effects from concurrent events and policy measures, we further define a narrower time window that covers ±6 months around the enactment of the policy.

Some possible confounding, contemporary events include the first series of targeted longer-term refinancing operations (TLTROs) executed by the ECB, the Expanded Asset Purchase Program (expanded APP), and the introduction of the Basel III Liquidity Coverage Ratio (LCR). The first series of TLTROs, whereby the ECB provided long-term loans at a discount to banks that granted credit to businesses, was announced on the 5th of June 2014, and carried out between September 2014 and June 2016, through eight quarterly operations (Afonso & Sousa-Leite, 2020). The expanded APP, implemented to provide further monetary accommodation and ease borrowing conditions for households and businesses, was announced in January 2015, and started in March of the same year. Finally, the LCR was introduced on the 1st of January 2015 with a 4-year phasing-in period, aiming to ensure that banks hold a buffer of high-quality liquid assets (HQLA) against short-term outflows during times of significant liquidity stress.[38]

[38] It is important to reiterate that if these contemporary events affect differently exposed banks (via liquidity/ deposit funding) in the same way, they are differenced out by the DiD framework. However, if they somehow affect the treated and control groups differently, then our main findings could be biased.

Another potential confounder to our analysis is the resolution of a major Portuguese bank, Banco Espírito Santo (BES), which started in August 2014 and caused a disruption in the entire banking system – debts were restructured, and bad assets were sold. As this sort of event often affects both banks' credits and assets (Beck et al., 2021), it also motivates us to investigate potential adjustments in banks' balance sheet *structure,* rather than just assessing changes in credit volumes.

4.3 Data

A major advantage of using Portugal as a setting is the availability of well-supplied datasets, which allow researchers to conduct meticulous empirical experiments on several banking and policy topics. We use two confidential datasets on Portuguese banks held by Banco de Portugal Microdata Research Laboratory (BPLIM), namely the Monetary Financial Institutions (MFIs) Balance Sheet Database and the Historical Series of the Portuguese Banking Sector Database (SLB).

The MFIs Balance Sheet Database contains monthly information on the assets and liabilities of all the MFIs that were in operation in mainland Portugal and autonomous regions, Azores and Madeira, between September 1997 and December 2020 (BPLIM, 2021). The database is granular along numerous dimensions, as it includes details on the type and maturity of the different balance sheet items, as well as information regarding the classification and geography of each item's counterparty.[39]

The SLB Database provides yearly as well as quarterly information on banking groups and stand-alone institutions resident in Portugal between 1990 and 2019. This database is a great complement to the MFIs Database since it reports an inclusive range of series on banks' financial statements (*e.g.*, balance sheet, income statement, and solvency) as well as data on loans to customers and interest rates, human resources, branch networks, and payment systems (BPLIM, 2020). The main inconvenience of exploring the SLB database in the present study is that information is reported on a consolidated basis and includes operations outside Portugal. Moreover, the data period and the availability of the data frequency in the SLB are contingent upon the type of information reported, the variables, and the institutions under consideration, which gives rise to some breaks in the series. For these reasons, the

[39] Each observation in the MFIs Balance Sheet Database amounts to the book value held by each institution in each month of assets or liabilities in different categories, vis-à-vis all counterparties from a given institutional sector and geographical location (Crosignani et al., 2015).

data employed in the baseline specifications stem mostly from the MFIs Balance Sheet database, although alternative control variables and data used in auxiliary regressions (section 4.4.4) are drawn from the SLB database.

Our initial sample from the MFIs dataset contained balance sheet information on 82 MFIs operating in Portugal between October 2013 and December 2016. However, this sample had to be cleansed, as most of these institutions were not in effect banks. We first dropped all the institutions that did not take any type of deposit or did not grant loans to individuals nor NFCs during the pre-treatment period (2013m10-2014m6). These criteria led to the exclusion of 18 institutions. We then matched the remaining sample from the MFIs database with that from the SLB and kept only those institutions in both datasets, thereby removing 9 more institutions. Finally, institutions with multiple unreported/missing values in the main variables for the baseline regressions were also dropped, which led to a final sample consisting of 49 banks and 1796 observations.

4.3.1 Variables

4.3.1.1 Dependent Variables

As mentioned before, our main variables of interest represent banks' outstanding credit either to individuals or non-financial corporations (NFCs). To directly extrapolate percentage changes, the dependent variable is first used in the natural logarithm form. Then, with a focus on addressing potential adjustments in banks' balance sheet structure, the same variable is computed as a share of total assets. In this manner, we consider 4 alternative dependent variables in the baseline regressions: (1) *Log(NFCs Loans)*, (2) *Log(Loans to Individuals)*; (3) *NFCs Loans Ratio*; (4) *Individuals Loans Ratio.*

In section 4.4.4, we run additional regressions to test further hypotheses. First, we assess whether more exposed banks increase fees and commissions charged after NIRP by considering banks' net income from services and commissions (total amounts and as a share of total assets) as the dependent variable in regression (4.1). Second, to investigate changes in interest rate setting behavior between differently exposed banks, we use the interest rates on outstanding loan amounts as the dependent variable.[40]

Summary statistics for the dependent variables used in this study are presented in Table A8.

[40] These alternative dependent variables are drawn from the SLB dataset.

4.3.1.2 Independent Variables

Regarding the treatment variables, *Interbank Liquidity* represents banks' (net) position in the interbank market and is measured as the difference between interbank loans and interbank deposits divided by total assets, following Bottero et al. (2021). Specifically, this variable includes interbank notes and coins, as well as interbank credit with maturity up to 1 year (the shortest maturity available in the MFIs dataset) minus interbank demand deposits, deposits redeemable at notice, and interbank debt securities issued with a maturity up to 1 year. We adopt this rather confining measure of bank liquidity because interbank rates in the Euro Area were highly responsive to the negative DFR (Figure A6 and Figure A7). The EONIA, a proxy for borrowing costs in the interbank overnight market, dropped below zero in end-August 2014. Shortly after, the Euro Interbank Offered Rate (EURIBOR) also turned negative and remained so since then. Moreover, interbank operations are ample in Portugal (and in the EA) and are mostly concentrated in short-term maturities (Bottero et al., 2021). Contrary to other studies, *e.g.*, Demiralp et al. (2021) and Basten and Mariathasan (2018), we do not employ banks' holdings of excess reserves as a treatment variable. This is not only due to the lack of appropriate data in the available datasets, but also because excess reserves are insignificant in Portugal, much like in the entire EA periphery (Baldo et al., 2017).[41]

The *Deposit Ratio* is used as a proxy for banks' reliance on short-term deposit funding. This variable includes demand deposits, deposits redeemable at notice, and other deposits with maturity up to 1 year from individuals or non-financial corporations, as a share of total assets. The inclusion of this measure of banks' exposure to NIRP is grounded on the observation that in Portugal, contrary to what happens in other European countries, the regulatory and legal framework explicitly prohibits the rate of return on deposits from being negative, which implies a compulsory ZLB on banks' retail deposits.[42]

[41] Banks' holdings of excess reserves are asymmetrically allocated in the Euro Area and are mostly concentrated in countries such as Germany, France, the Netherlands, Luxembourg, and Finland (Clayes, 2021). A potential reason for this uneven distribution of excess liquidity, as put forth by Baldo et al. (2017), is that a large share of the ECB's APP portfolio has been bought from counterparties whose headquarters are outside the Euro Area, and whose euro liquidity is parked on accounts in a few Euro Area financial centers. This is also related to the TARGET2 system. To be specific, since TARGET2 balances stem from cross-border flows of liquidity, the factors that caused a build-up of excess liquidity in specific countries via such cross-border flows are the same factors explaining the accumulation of TARGET2 balances (see Baldo et al., 2017).

[42] According to Banco de Portugal Notice nº6/2009, whatever the method of determining the rate of return on a deposit account, it cannot, under any circumstances, be negative.

Furthermore, we include the following controls in the baseline specification. First, *Bank Size*, computed as the logarithm of total assets. Second, the *Capital Ratio*, which is the sum of capital and reserves divided by total assets. Third, the *Securities Ratio*, which represents the share of debt and equity securities, also scaled by total assets. The decision to add these variables as controls is rooted in the conventional BLC literature, which emphasizes the role played by bank-specific characteristics in the transmission of monetary policy (Chatelain et al., 2003; Jiménez et al., 2012; Kashyap & Stein, 1995, 2000). As a robustness test, we further include the *NPLs Ratio* from the SLB dataset, computed as the share of domestic overdue credit over total assets (in section 4.4.4.4, Table 7).[43]

Importantly, all the independent variables (treatment variables and controls) are measured as of March 2014, *i.e.*, 3 months prior to NIRP. Since these variables are not time-varying, potential endogeneity should be less of a concern. The choice to compute these variables in March 2014 also ensures compatibility with variables included in alternative specifications, which are drawn from the SLB dataset and thus are only available on a quarterly basis. Indeed, end-March 2014 is the nearest available quarter before the enactment of NIRP on June 11, 2014.[44] For robustness, we alternatively measure every variable as its average during the year before NIRP, and our results remain qualitatively similar (section 4.4.4.4, Table 7).

Summary statistics for the independent variables are presented in Table A9.[45]

4.3.2 Balance Checks

Banks with different treatment intensities are likely to face other *ex-ante* differences that may affect their lending behavior. To address this concern, Table A10 and Table A11 present summary statistics for the two groups of banks with reference to each treatment variable, *i.e.*, high and low liquidity banks (Table A10) as well as high and low deposits banks (Table A11). In each table, the banks are grouped according to whether their treatment variable is, respectively, above or below the cross-sectional median in March 2014.

The different groups of banks share some common features, as they exhibit a comparable size and have, on average, very similar capital ratios. However, they appear to be statistically

[43] In most recent studies, the NPLs ratio is used as an indicator of banks' health and efficiency.

[44] Alternatively, if the variables were computed as of end-June 2014 (the next feasible quarter), these would instead be *ex-post* measures of bank-level exposure, which means they might include any adjustment that occurred between June 11 and June 30.

[45] Also, Figure A5 (in the Annex) shows the kernel density distribution of both treatment variables, *i.e.*, interbank liquidity and the deposit ratio, as of end-March 2014.

different along important dimensions. First, both high-liquidity and high-deposits banks hold larger shares of securities than their counterparts (26% vs. 15% and 28% vs. 13%, respectively). Second, highly liquid banks have lower shares of NPLs in their portfolios than less liquid banks (2% vs. 8%), and the same holds for high- and low-deposits banks (2% vs. 7%). To ensure that the estimated effects of the treatment variables are not driven by differences in these bank characteristics, we explicitly include them as controls.[46] Last but not least, highly liquid banks are the ones most reliant on deposit funding. Differently put, high-deposits banks are more liquid. Although this was already implied by the observation that high-deposits banks tend to hold more securities, it is now reiterated by the stark differences in net interbank positions.[47] As we aim to explore the importance of both variables in determining banks' response to NIRP, this difference may be a cause for concern regarding identification. In Table A12, we present the correlation matrix for all the independent variables employed in the regressions. Considering 0.5 as a rule of thumb for the Pearson correlation coefficient, we can stave off fears of a strong correlation between the independent variables. Be that as it may, as a robustness check, we also modify the baseline specification by including the treatment variables separately, *i.e.*, just the interbank liquidity ratio or just the deposit ratio (Table 6). Our main results are robust to this change.

4.4 Results

In this section, we present and discuss the results of our empirical analysis described above. We begin with the average treatment effects from the conventional *static* difference-in-differences model, where the sample period is divided into two time periods, namely "before treatment" and "after treatment". Then, we quantify the treatment effects over time using the dynamic model described in section 4.2. Finally, we present the results of additional tests as well as robustness checks.

4.4.1 Average Treatment Effects

We start by presenting our main results for the baseline *static* specification. These concern the differential response to the NIRP impulse by banks with different liquidity levels and/or different reliance on deposit funding. Table 1 reports the regression results using the time

[46] The NPLs Ratio is not included in the baseline specification due to reporting issues. To recall, this variable is drawn from the SLB dataset, where data is gathered following different criteria and serving a different purpose. As we will see in section 4.4.4.4, however, results remain qualitatively similar when this additional control is included in the regressions.

[47] Again, this can also be verified by the different deposit ratios between high- and low-liquidity banks.

window from 2013m10 to 2016m12. For each dependent variable, we first present the results for the regression without controls in columns 1-4, and with full controls in columns 5-8.

We find a positive and statistically significant effect of NIRP on the NFCs Loans Ratio via interbank liquidity (columns 2 and 6), suggesting that banks with higher interbank liquidity prior to NIRP increase the share of NFC Loans after the policy by more than other banks. The estimated impact is economically sizeable: A one standard deviation higher interbank liquidity ratio is associated with a relative increase in the share of NFC Loans by 3.42pp after 30 months by more exposed banks (0.29×0.118=0.03422).

Table 1 - Long Time Window Estimation

	(1) Log (NFCs Loans)	(2) NFCs Loans Ratio	(3) Log (Loans to Indiv.)	(4) Indiv. Loans Ratio	(5) Log (NFCs Loans)	(6) NFCs Loans Ratio	(7) Log (Loans to Indiv.)	(8) Indiv. Loans Ratio
NIRP=1 × Interbank Liquidity	0.187 (0.338)	**0.119*** (0.042)**	-0.011 (0.456)	-0.008 (0.034)	0.179 (0.294)	**0.118*** (0.039)**	-0.042 (0.399)	-0.013 (0.034)
NIRP=1 × Deposit Ratio	0.383 (0.245)	-0.037 (0.040)	0.154 (0.176)	0.009 (0.026)	0.325 (0.286)	-0.039 (0.043)	0.175 (0.200)	0.015 (0.028)
NIRP=1 × Bank Size					-0.063 (0.042)	-0.001 (0.003)	-0.054** (0.024)	-0.004 (0.003)
NIRP=1 × Capital Ratio					-0.148 (0.916)	0.006 (0.121)	-0.545 (0.620)	-0.158 (0.103)
NIRP=1 × Securities Ratio					-0.053 (0.519)	-0.002 (0.037)	-0.345 (0.239)	0.025 (0.033)
Bank FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1725	1796	1661	1796	1725	1796	1661	1796
Adjusted R-squared	0.969	0.948	0.993	0.967	0.970	0.948	0.993	0.967

Note: The table shows the results for the static difference-in-differences model (4.1). The time window employed runs from October 2013 to December 2016. The dependent variables include Log(credit outstanding to NFCs) in columns (1) and (5), Log(credit outstanding to Individuals) in columns (3) and (7), the share of NFCs credit to total assets in columns (2) and (6), and the share of Individuals credit to total assets in columns (4) and (8). Regression results without controls are presented in columns 1-4. Regression results with full controls are presented in columns 5-8. NIRP is a time dummy variable taking the value of 1 for every month from June 2014 onwards, and 0 otherwise. This dummy is interacted with all other regressors, whether these are included as treatment variables or simply as controls. The treatment variables are Interbank Liquidity, calculated as interbank loans minus interbank deposits divided by total assets, and the Deposit Ratio, defined as the share of short-term deposits over total assets. Controls include: 1) Bank Size, measured as the logarithm of banks' total assets; 2) Capital Ratio, measured as the sum of capital and reserves divided by total assets; 3) Securities Ratio, measured as the share of debt and equity securities over total assets. All the independent variables are computed as of end-March 2014. Standard errors are clustered at the bank level and presented in parentheses. The difference in the number of observations used in the different specifications is driven by periods in which credit was not reported. *** p<0.01, ** p<0.05, * p<0.10.

The same effect can be found when the sample period is narrowed to ±6 months around the introduction of negative rates. As argued before, although we recognize that banks may

take some time to fully react to the NIRP impulse, the large time window used in Table 1 may capture confounding effects from events unrelated to the introduction of the policy. Therefore, we re-estimate the baseline regression using a short time window, from 2013m12 to 2014m12. Results are shown in Table 2, and are, overall, qualitatively similar.[48] In this case, a one SD higher interbank liquidity ratio is associated with a 1.16pp relative increase in the ratio of NFCs loans after 6 months by more exposed banks (0.29×0.04=0.0116).

Table 2 - Short Time Window Estimation

	(1) Log (NFCs Loans)	(2) NFCs Loans Ratio	(3) Log (Loans to Indiv.)	(4) Indiv. Loans Ratio	(5) Log (NFCs Loans)	(6) NFCs Loans Ratio	(7) Log (Loans to Indiv.)	(8) Indiv. Loans Ratio
NIRP=1 × Interbank Liquidity	0.013 (0.100)	**0.037** (0.016)**	-0.016 (0.195)	-0.002 (0.013)	0.019 (0.103)	**0.040** (0.015)**	-0.025 (0.178)	-0.004 (0.013)
NIRP=1 × Deposit Ratio	**0.224** (0.095)**	-0.012 (0.019)	0.094 (0.079)	-0.002 (0.011)	**0.185** (0.101)*	-0.020 (0.018)	0.127 (0.091)	0.002 (0.012)
Controls	No	No	No	No	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	605	631	579	631	605	631	579	631
Adjusted R-squared	0.995	0.986	0.998	0.995	0.995	0.987	0.998	0.995

Note: The table shows the results for the static difference-in-differences model (4.1). The time window employed runs from December 2013 to December 2014 (±6 months around June 2014). The dependent variables include Log(credit outstanding to NFCs) in columns (1) and (5), Log(credit outstanding to Individuals) in columns (3) and (7), the share of NFCs credit to total assets in columns (2) and (6), and the share of Individuals credit to total assets in columns (4) and (8). Regression results without controls are presented in columns 1-4. Regression results with full controls are presented in columns 5-8. NIRP is a time dummy variable taking the value of 1 for every month from June 2014 onwards, and 0 otherwise. This dummy is interacted with all other regressors, whether these are included as treatment variables or simply as controls. The treatment variables are Interbank Liquidity, calculated as interbank loans minus interbank deposits divided by total assets, and the Deposit Ratio, defined as the share of short-term deposits over total assets. Controls include: 1) Bank Size, measured as the logarithm of banks' total assets; 2) Capital Ratio, measured as the sum of capital and reserves divided by total assets; 3) Securities Ratio, measured as the share of debt and equity securities over total assets. All the independent variables are computed as of end-March 2014. Standard errors are clustered at the bank level and presented in parentheses. The difference in the number of observations used in the different specifications is driven by periods in which credit was not reported. *** p<0.01, ** p<0.05, * p<0.10.

Noticeably, however, the results indicate that the impact of interbank liquidity after the DFR cut is confined to the *NFCs Loans Ratio*, as the coefficients for the *Log(NFCs Loans)*, as well as for Loans to Individuals (either in the logarithm form or as a share of total assets) are non-significant across specifications. Moreover, we do not find significant evidence of changes in lending associated with banks' reliance on deposit funding, which suggests that the

[48] Hereafter, for the sake of brevity and conciseness, we omit the estimates for the control variables.

mechanisms driven by the ZLB on retail deposits may not have been active in the Portuguese setting at the time of the implementation of NIRP. Although the coefficient on *Log(NFCs Loans)* is marginally significant in the short time window (Table 2, columns 1 and 5), we are able to confidently rule out this effect when analyzing the results for the *dynamic* specification, a matter to which we now turn.

4.4.2 Treatment Effects Over Time

As we intend to compare the lending behavior of banks with different characteristics (liquidity/deposit funding) before and after the implementation of NIRP by the ECB, the validity of our study is contingent upon two major assumptions.

First, the ECB's decision to introduce NIRP in June 2014 must have been, at least to some extent, a surprise; otherwise, banks could have incorporated expectations of NIRP in their lending behavior in the months prior to the treatment period (Tan, 2019). This assumption is essential for our empirical approach because our results may underestimate the true effect of the DFR cut into negative territory if it had been anticipated (Schelling & Towbin, 2022).

Even though NIRP was carried out within the existing operational framework of the ECB, substantial "behind-the-scenes" work was necessary to make sure that financial institutions were prepared for a negative rate environment. This involved in-depth reviews of IT systems, legal documentation, accounting rules, as well as other minor adjustments (Bech & Malkhozov, 2016). Hence, ECB policymakers cautiously signaled the possibility of NIRP ahead of time, both to financial institutions and other market participants. Nonetheless, the unprecedented nature of this policy move suggests that there was still considerable uncertainty around its actual introduction and immediate implications, which may imply that its concrete timing was hard to forecast. Figure A6 and Figure A7 show that market rates dropped around the timing of the DRF cut, and not before, indicating that there were no anticipation effects in interest rate setting.[49] Be that as it may, the relevance of this assumption for our study calls for a more explicit verification.

Second, our identifying assumption is that the control group offers a legitimate counterfactual for the lending behavior of the treated group had NIRP not been

[49] Other empirical studies have addressed this issue and found no reason for concerns regarding identification (see *e.g.*, Grandi & Guille, 2021; Heider et al., 2019). Overall, although NIRP might have been somewhat expected, the evidence suggests that anticipation did not result in substantial changes in banks' lending behavior prior to the definite start of the policy.

implemented. This is related to the assumption of parallel trends, which underlies any DiD setting and must be verified in detail. To be specific, this assumption implies that in the absence of NIRP, the lending behavior of banks with different levels of liquidity/deposit funding would move in parallel, *i.e.*, their differences would remain constant over time.

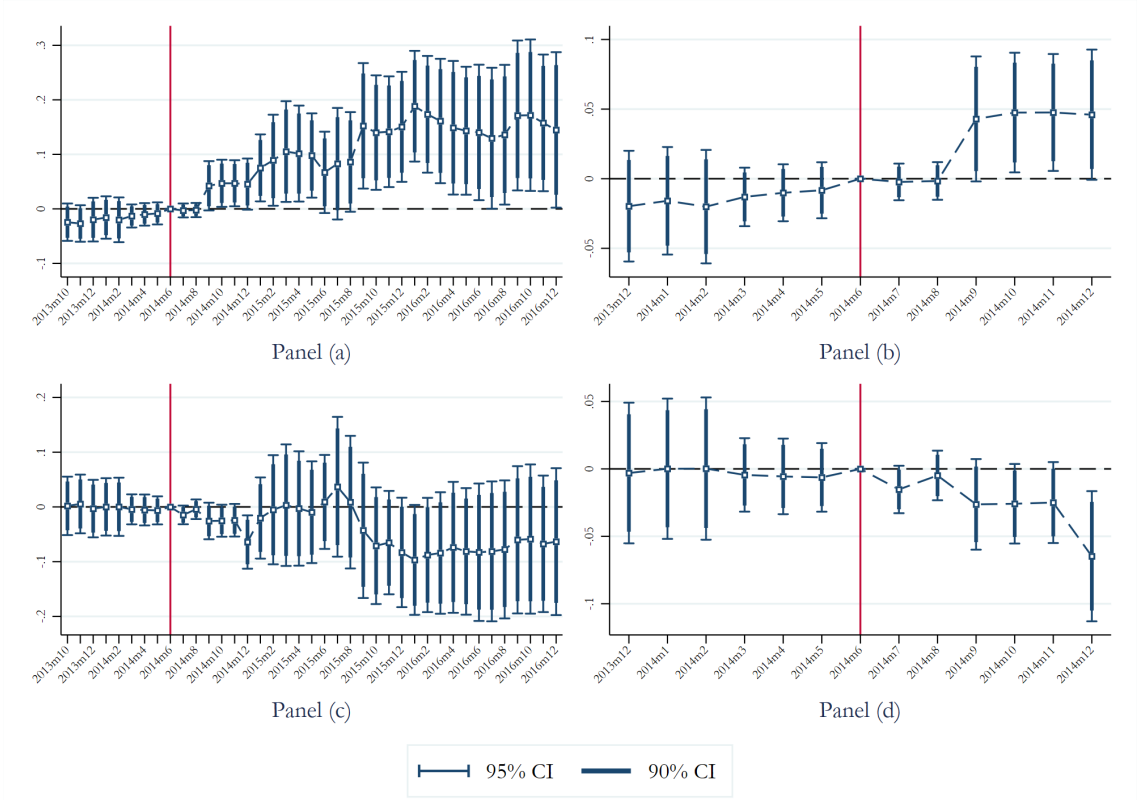
To explicitly address these concerns, while supporting our identification strategy, we extend the previous *static* model to the *dynamic* specification, which uses separate indicator variables for each month relative to the date of the implementation of NIRP, hence allowing us to assess the evolution of the treatment effects over time. Indeed, the DFR cut below zero may take some time to become effective, and there might even be a build-up or a reversal of the initial impact as time progresses.

To this end, we focus mostly on the bank outcomes where we find statistical significance based on the *static* model presented in Table 1 and Table 2, and others deemed relevant.[50] Figure 1 presents the $\beta_{1,t}$ coefficients on $Interbank\ Liquidity_i \times Period_t$ (upper panels) and the $\beta_{2,t}$ coefficients on $Deposit\ Ratio_i \times Period_t$ (lower panels) for the *NFCs Loans Ratio*, both in the long time window (left panels) and in the short time window (right panels).

Supporting the parallel trends assumption, as well as the absence of anticipation effects, we do not find evidence that the share of NFC loans of high- and low-liquidity banks followed a different trend prior to the introduction of NIRP (upper panels). Indeed, the coefficient on the interaction term only becomes statistically significant after the DFR cut. In particular, panels (a) and (b) show that the interaction coefficient became significant in September 2014, *i.e.,* 3 months after the implementation of NIRP. This is consistent with the observation that the pass-through from the negative DFR to interbank rates was not instantaneous. In fact, the EONIA entered negative territory in end-August 2014, and shortly after, so did the EURIBOR (see Figure A6 and Figure A7). Moreover, such timing coincides with the second DFR cut, to -0.20%, which took market participants by surprise (Heider et al., 2019) and reiterated the stance of the ECB by diving the key interest rate deeper below zero. Focusing on Panel (a), we find that the impact is persistent, indicating that the policy became more effective over time, as the estimated coefficients remained on a roughly upward trend for most of the period under consideration.

[50] The results for all other specifications (not shown in the present section) can be found in the Annex (Figure A9 and Figure A10).

Figure 1 - Dynamic Treatment Effects: The Ratio of Loans to NFCs



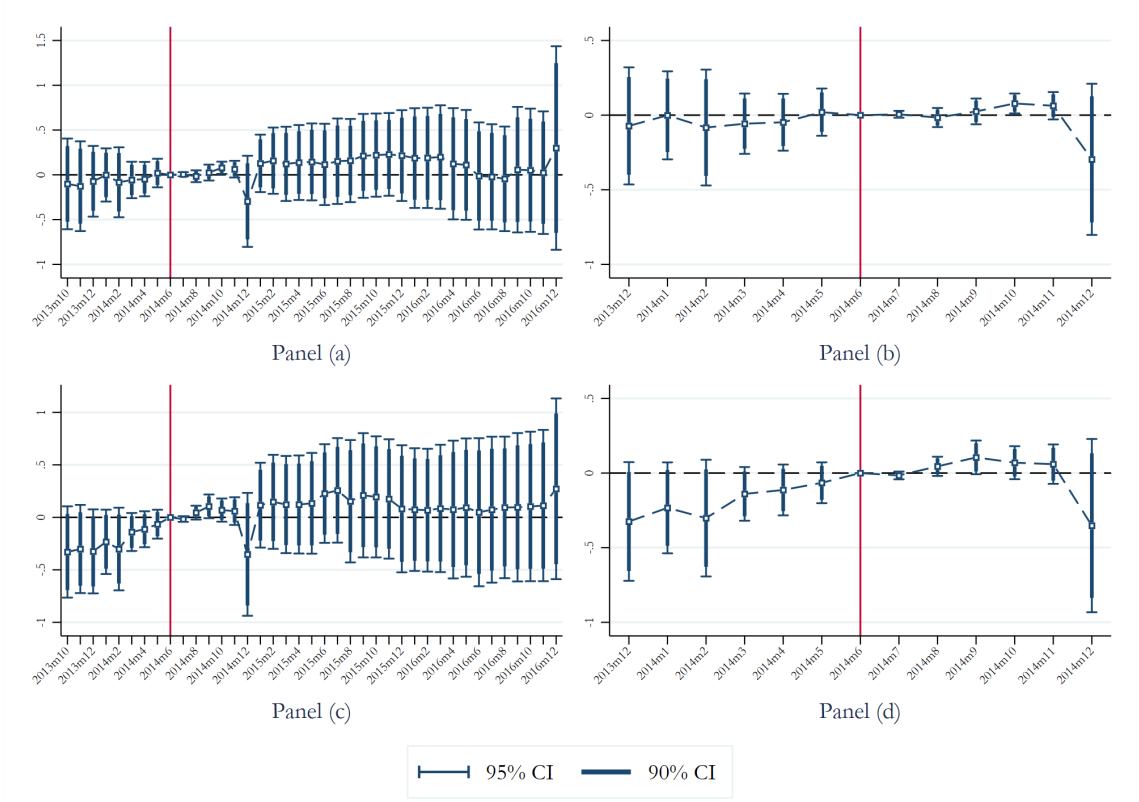
Note: This figure shows the β coefficients on $Interbank\ Liquidity_i \times Period_t$ (upper panels) and $Deposit\ Ratio_i \times Period_t$ (lower panels) for the NFCs Loans Ratio (of regression 4.1), both in the long time window (left panels) and in the short time window (right panels). The labels on the x-axis indicate the month, and the vertical red line represents the start of the treatment period - June 2014 - which is the implicit reference date for all indicator coefficients. Connected dots represent point estimates, while the capped spikes represent the 90% and 95% confidence intervals. Standard errors are clustered at the bank-level.

Despite not showing statistical significance in the *static* model (Table 1 and Table 2), it is worth discussing the results regarding the interaction term $Deposit\ Ratio_i \times Period_t$ for the *NFCs Loans Ratio* (lower panel). Indeed, Panel (d) reveals a noticeably declining trajectory for the estimated coefficients shortly after the enactment of NIRP. Upon closer inspection, Panel (c) tells a rather ambiguous story. As time progresses, it is possible to observe a reversal of the initial impact found in the short time window, which then reappears but without statistical significance. We interpret the latter decline in the estimated coefficients as most likely being unrelated to the NIRP impulse since the effect only emerges more than one year after the shock and remains non-significant throughout the period.[51]

[51] In section 4.4.4.4, when the treatment variables are included separately in the regressions, the validity of our interpretation is reiterated, as the estimated coefficient remains insignificant and close to 0.

Figure 2 presents the results for the *Log(NFCs Loans)*. The $\beta_{1,t}$ coefficients on $Interbank\ Liquidity_i \times Period_t$ are shown in the upper panels and the $\beta_{2,t}$ coefficients on $Deposit\ Ratio_i \times Period_t$ are shown in the lower panels. Estimates using the long time window are in the left panels and those in the short time window are in the right panels. Consistent with the results from the *static* specification (columns 1 and 5), we find no evidence of an effect associated with interbank liquidity, as the $\beta_{1,t}$ estimates remain insignificant and close to zero throughout both time windows employed (upper panels).

Figure 2 - Dynamic Treatment Effects: Log(Loans to NFCs)



Note: This figure shows the β coefficients on $Interbank\ Liquidity_i \times Period_t$ (upper panels) and $Deposit\ Ratio_i \times Period_t$ (lower panels) for the Log(NFCs Loans) (of regression 4.1), both in the long time window (left panels) and in the short time window (right panels). The labels on the x-axis indicate the month, and the vertical red line represents the start of the treatment period - June 2014 - which is the implicit reference date for all indicator coefficients. Connected dots represent point estimates, while the capped spikes represent the 90% and 95% confidence intervals. Standard errors are clustered at the bank-level.

On the contrary, regarding the $\beta_{2,t}$ coefficient on $Deposit\ Ratio_i \times Period_t$ for the *Log(NFCs Loans)*, Figure 2 shows that the positive effect found in columns 1 and 5 (Table 2) is driven by differences in pre-treatment trends between high- and low-deposits banks (lower

panels). This violation of the parallel trends assumption leads us to rule out the effect related to the deposit channel found in the *static* model.

4.4.3 Main Findings

All in all, the evidence found grants support to the hypothesis of a portfolio rebalancing effect after the implementation of NIRP. Following the DFR cut into negative territory, banks with larger *ex-ante* interbank liquidity increase their share of loans to NFCs by more than other banks. Consistent with previous studies (*e.g.*, Bottero et al. (2021), Basten and Mariathasan (2018), and Demiralp et al. (2021)), this result validates the conjecture that negative rates influence bank lending via liquidity management, as banks shift their balance sheets' composition from lower-yielding, liquid assets toward higher-yielding loans. However, the adjustments uncovered in banks' balance sheet structure do not seem to translate into an increase in the overall supply of credit, as we do not find evidence of changes in the volumes of credit granted by differently exposed banks after NIRP.

Furthermore, the non-significant results for the deposit ratio suggest that the mechanisms driven by the ZLB on banks' retail deposits were not active in Portugal at the time of the implementation of NIRP. A potential explanation for this result is related to the heterogeneity in market conditions across EA member countries. As shown in Figure A8, deposit rates in peripheral countries such as Spain and *Portugal* were far away from zero in mid-2014, and thus had scope to decline without reaching the ZLB. On the contrary, deposit rates in core countries, *e.g.*, Germany, were much lower at the time, and therefore did not follow the DFR cuts below zero from June 2014 onwards (Eisenshmidt & Smets, 2019).[52] An interesting subject matter regards the justification for this discrepancy in deposit rates within the Euro Area. The preferred explanation among economists rests on the divergence in sovereign bond yields across member countries, as these are known to be highly correlated with deposit rates. The idea is that sovereign bonds are money-like in several respects, the most important one being that they offer non-pecuniary liquidity services to the non-financial sector, which makes them close substitutes to bank deposits (Krishnamurthy & Vissing-Jorgensen, 2015; Li et al., 2021). Therefore, different deposit rates in the Euro Area

[52] This is consistent with findings by Bittner et al. (2022), who demonstrate the relevance of diversity in the initial economic and financial environment for the impact of NIRP by comparing the response of German banks to that of Portuguese banks, although the focus of their paper is on banks' risk-taking behavior.

in mid-2014 may be justified by the different sovereign bond yields across member countries due to the fall-out from the 2011-2012 European sovereign debt crisis.

4.4.4 Additional Tests

In this section, we perform some additional tests and examine the robustness of the results presented in the previous section. We first conduct a simple test to confirm that the composition of the different groups of banks does not change significantly after NIRP. We also expand our analysis on banks' behavior by assessing changes in fees and commissions, as well as in interest rates charged on loans to customers. Then, we present placebo tests exploring alternative policy rate cuts, both in positive and negative territory, and finally, we introduce some modifications to the baseline specification.

4.4.4.1 Addressing Compositional Changes

To improve the econometric validity of our identification, we ought to ensure that the different groups of banks do not exhibit compositional changes over time. In other words, high-liquidity/high-deposits banks must remain in that category under NIRP and cannot significantly change their position during the enactment of the policy. One may argue that, while banks are able to adjust their exposure to NIRP through their liquidity/funding position at the margin, they will probably be unable to do so at a significant scale because it ultimately represents their business model choice, and they would incur significant fixed costs to switch it. [53] To empirically verify this assumption, we first use $Interbank\ Liquidity_{i,t}$ as the outcome variable in the auxiliary regression (4.2) and assess whether being in the category of banks with high interbank liquidity prior to NIRP is a determining factor for banks' interbank liquidity during the enactment of the policy. We then repeat this exercise for the deposit ratio, even though we did not find significant evidence of its impact on banks' behavior in the previous section. The time window employed in this regression covers the post-treatment period, *i.e.,* from 2014m6 to 2016m12.

$$\begin{aligned} Interbank\ Liquidity_{i,t} \\ &= \beta_1 \times Interbank\ Liquidity_i + \beta_2 \times Deposit\ Ratio_{i,t-12} \\ &+ \beta_3 \times Capital\ Ratio_{i,t-12} + \beta_4 \times Bank\ Size_{i,t-12} \\ &+ \beta_5 \times Securities\ Ratio_{i,t-12} + \lambda_t + \varepsilon_{i,t} \end{aligned} \tag{4.2}$$

[53] Several studies have shown that banks are not prone to changes in their business models over short periods of time (see *e.g.*, Lucas et al., 2019; Urbschat, 2018).

As before, $Interbank\ Liquidity_i$ is computed in end-March 2014. All the other regressors are included with a 12 month-lag to control for the same time-varying characteristics as in the baseline regression.

Table 3 reports the results. Noticeably, the coefficient on $Interbank\ Liquidity_i$ (column 1) is very significant and not far from 1, indicating a close association between banks' interbank position in end-March 2014 and subsequent positions. The same holds for the deposit ratio, as shown in column 2. These results endorse the assumption that while banks are able to change their exposure to NIRP to some extent, such adjustments are of second order when compared to the fundamental determinants of banks' business models.

Table 3 -Compositional Changes

	(1) $Interbank\ Liquidity_{i,t}$	(2) $Deposits\ Ratio_{i,t}$
$Interbank\ Liquidity_i$	**0.840*** (0.010)**	
$Deposit\ Ratio_i$		**0.943*** (0.009)**
Controls	Yes	Yes
Month FE	Yes	Yes
Observations	1404	1404
Adjusted R-squared	0.875	0.914

Note: The table shows the results for regression (4.2). The time window employed runs from 2014m6 until 2016m12, *i.e.*, the post-treatment period. The dependent variable is Interbank Liquidity in column (1), calculated as interbank loans minus interbank deposits divided by total assets, and the Deposit Ratio in column (2), defined as the share of short-term deposits over total assets. The independent variables are also Interbank Liquidity (column 1) and the Deposit Ratio (column 2), computed as of end-March 2014 – as in the baseline regression. Bank controls have a 12 month-lag and include: 1) Bank Size, measured as the logarithm of banks' total assets; 2) Capital Ratio, measured as the sum of capital and reserves divided by total assets; 3) Securities Ratio, measured as the share of debt and equity securities over total assets. The Deposit Ratio is also included as a control in column (1) while Interbank Liquidity is included as a control in column (2). Standard errors are clustered at the bank-level and presented in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

4.4.4.2 Fees & Commissions and Interest Rates

Thus far, our analysis of banks' response to negative rates shows that more exposed banks (via interbank liquidity) shift their balance sheet composition toward corporate loans after NIRP. However, the scope of banks' reaction to the NIRP impulse extends to other dimensions beyond the direct adjustments related to credit granting. For instance, evidence found by Lopez et al. (2020) suggests that banks can counteract losses in net interest income associated with NIRP by achieving significant gains in non-interest income such as fees and

commissions.[54] In addition, NIRP may trigger adjustments in interest rate setting behavior by differently exposed banks. As we aim to provide a comprehensive depiction of changes in bank behavior, we further analyze the impact of NIRP on fees and commissions, as well as on interest rates charged on loans to customers.

To this end, we combine information on income statement and interest rates variables from the SLB dataset and re-estimate alternative versions of regression 4.1. The outcome variable is now the net income from fees and commissions (total amounts and share of total assets) or the interest rate on outstanding loans either to NFCs or households. Since the information from the SLB is available on a quarterly basis, we arrange the monthly data from the MFIs Database on the independent variables to make it consistent with a quarterly specification.

The results, shown in Table 4, suggest that there are no differences in fees and commissions charged nor in interest rate setting behavior between differently exposed banks (neither via liquidity nor deposit reliance) after the DFR cut below zero. These findings reinforce the hypothesis that banks attempt to offset the "tax on liquidity" associated with NIRP by searching for higher-yielding, less-liquid assets such as corporate loans, instead of simply passing on the burden to customers through higher compensation for services performed or higher interest rates on credit granted.

Table 4 - Fees & Commissions and Interest Rates

	(1) Fees & Commissions	(2) Fees & Commissions (Ratio)	(3) Interest Rates NFCs	(4) Interest Rates Individuals
NIRP=1 × Interbank Liquidity	-3.673	0.001	0.500	0.043
	(7.007)	(0.003)	(0.379)	(0.446)
NIRP=1 × Deposit Ratio	1.323	-0.001	-0.155	0.246
	(6.439)	(0.002)	(0.513)	(0.511)
Controls	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes
Observations	598	598	568	530
Adjusted R-squared	0.773	0.762	0.825	0.869

Note: The table shows the results for regression (4.1). The time window employed runs from October 2013 to December 2016. The dependent variables are drawn from the SLB dataset and include net income from fees and commissions (total amounts in column (1) and as a share of total assets in column (2)) or the interest rate on outstanding loans either to NFCs or households (columns (3) and (4), respectively). Since the information from the SLB is available on a quarterly basis, the monthly data from the MFIs dataset is arranged to make it

[54]Also, Bottero et al. (2021) find that Italian banks with higher deposit ratios increase fees for banking services after NIRP, thereby counteracting the income loss from a contraction in intermediation margins. Basten and Mariathasan (2018) find similar results for Swiss banks holding more excess reserves.

consistent with a quarterly specification. NIRP is a time dummy variable taking the value of 1 for every quarter from June 2014 onwards, and 0 otherwise. This dummy is interacted with all other regressors, whether these are included as treatment variables or simply as controls. The treatment variables are Interbank Liquidity, calculated as interbank loans minus interbank deposits divided by total assets, and the Deposit Ratio, defined as the share of short-term deposits over total assets. Controls include: 1) Bank Size, measured as the logarithm of banks' total assets; 2) Capital Ratio, measured as the sum of capital and reserves divided by total assets; 3) Securities Ratio, measured as the share of debt and equity securities over total assets. All the independent variables are computed as of end-March 2014. Standard errors are clustered at the bank level and presented in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

4.4.4.3 Different Cut-Off Points: Other Policy Rate Cuts

Up until this point, we have focused on the first DFR cut into negative territory carried out by the ECB in June 2014, as it marked the implementation of NIRP in the Euro Area. However, two important questions arise: First, is the estimated rebalancing effect toward corporate credit *specific* to the negative DFR? Second, is the impact found a "one-off" effect? Or is it also seen in later DFR cuts as well?

To answer these questions, we conduct supplementary tests to our baseline model by re-centering the period of analysis on different policy rate cuts, both in positive and negative territory. For these additional tests, we estimate only the short time window model, *i.e.*, ±6 months around the event under consideration. The reasoning behind this choice is twofold. On the one hand, and as before, using a large time window would menace any result found due to confounding events around each policy measure. The verification of such events would be far out of focus and is, therefore, unjustified. On the other hand, the long period analysis would result in overlapping time windows, since most of these cuts took place in very close periods, which would further complicate the analysis.[55]

Regarding the first question, it might be the case that NIRP has nothing special to it. In other words, our results may simply be attributable to the rate cut itself, regardless of entering negative territory. To address this hypothesis, we perform placebo tests with the following rationale: if the adjustment toward NFCs loans associated with interbank liquidity is unique to the transition into negative ground, we should not find a similar effect around previous rate cuts above zero (Heider et al., 2019). We formally test this argument by centering our baseline model on the last two policy rate cuts *above* zero: In December 2011, the ECB lowered the DFR from 0.5% to 0.25%, and in July 2012, a further cut was made to 0%. If

[55] Also, the unavailability of data prevents us from performing the long window analysis for the September 2019 cut.

the negative DFR is special, one would expect the coefficient on $Interbank\ Liquidity_i \times Rate\ Cut_t$ to be statistically insignificant in these placebo regressions.

To address the second question, we check whether the rebalancing effect found is exclusive to the *inauguration* of NIRP or if it prevails after deeper cuts below zero. Once again, we re-center the baseline model, this time on the last two cuts *below* zero: In March 2016, the DFR was lowered to −0.40%, and in September 2019, the last cut was made to −0.50%.[56] [57]

The results of these additional tests are reported in Table 5. As expected, we do not find evidence of a rebalancing effect after previous rate cuts (columns 1-2), which consolidates the hypothesis that NIRP is different from conventional policy rate cuts above zero.

Table 5 - Different Cut-off Points

	(1) *Dec11* NFCs Loans Ratio	(2) *July12* NFCs Loans Ratio	(3) *Mar16* NFCs Loans Ratio	(4) *Sep19* NFCs Loans Ratio
Rate Cut=1 × Interbank Liquidity	-0.003	0.021	-0.024	0.057*
	(0.026)	(0.027)	(0.014)	(0.032)
Rate Cut=1 × Deposit Ratio	0.025	0.025	-0.013	0.038
	(0.032)	(0.023)	(0.013)	(0.023)
Controls	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes
Observations	650	659	604	533
Adjusted R-squared	0.969	0.980	0.987	0.955

Note: The table shows the results of regression (4.1) with different cut-off points. The dependent variable is the ratio of loans to NFCs over total assets (NFCs Loans Ratio). The time window employed covers ±6 months around: 1) December 2011, the DFR cut from 0.5% to 0.25% (column 1); 2) July 2012, the last DFR cut in positive territory, from 0.25% to 0% (column 2); 3) March 2016, the DFR cut from −0.30% to −0.40% (column 3); and 4) September 2019, the last DFR cut, from −0.40% to −0.50% (column 4). Rate Cut is a time dummy variable taking the value of 1 for every month from the respective cut onwards, and 0 otherwise. This dummy is interacted with all other regressors, whether these are included as treatment variables or simply as controls. The treatment variables are Interbank Liquidity, calculated as interbank loans minus interbank deposits divided by total assets, and the Deposit Ratio, defined as the share of short-term deposits over total assets. Controls include: 1) Bank Size, measured as the logarithm of banks' total assets; 2) Capital Ratio, measured as the sum of capital and reserves divided by total assets; 3) Securities Ratio, measured as the share of debt and equity securities over total assets. All the independent variables are computed as of 1) end-September 2011 (column 1); 2) end-March 2012 (column 2); 3) end-December 2015 (column 3); and 4) end-June 2019 (column 4). Standard errors are clustered at the bank level and presented in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

[56] To recall, our long time window spans until December 2016, thereby covering the rate cuts to −0.20% in September 2014 and to −0.30% in December 2015.

[57] The September 2019 cut comes with one caveat: At the time, the ECB announced the implementation of a two-tier system for remunerating banks' excess reserve holdings, which exempts part of the excess liquidity held with the central bank from the negative DFR. The volume of reserves in excess of minimum reserve requirements that is exempt from the DFR – often referred to as the "allowance" – is calculated as a multiple of each credit institution's minimum reserve requirements.

Regarding the last two DFR cuts in March 2016 and September 2019, the coefficients on the interaction terms (columns 3 and 4) yield by and large insignificant estimates. Our preferred explanation for these results is that the shift toward corporate credit uncovered in the baseline model may have been a one-time effect due to the novelty of breaking through the ZLB. Even though we found a rather persistent impact 30 months after the first DFR cut, it might be the case that the initial rate cuts withheld a "surprise element" - as economic agents were oblivious to the location of the ELB – which eventually faded over time.

4.4.4.4 Alternative Specifications

To verify the robustness of our main results, we introduce some modifications to the baseline regression. We begin by running an alternative specification where the treatment variables – interbank liquidity and the deposit ratio – are included one at a time to account for possible correlation between them. As Table 6 shows, our results are robust to this change: the estimated coefficients on interbank liquidity are quantitatively similar to the ones in the baseline model, while the coefficients on the deposit ratio remain statistically insignificant.

Table 6 - Treatment Variables Included Separately

	(1) Log (NFCs Loans)	(2) NFCs Loans Ratio	(3) Log (Loans to Indiv.)	(4) Indiv. Loans Ratio	(5) Log (NFCs Loans)	(6) NFCs Loans Ratio	(7) Log (Loans to Indiv.)	(8) Indiv. Loans Ratio
NIRP=1 × Interbank Liquidity	0.305	**0.102****	0.027	-0.007				
	(0.342)	**(0.038)**	(0.382)	(0.032)				
NIRP=1 × Deposit Ratio					0.422	0.029	0.153	0.007
					(0.349)	(0.052)	(0.227)	(0.028)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1725	1796	1661	1796	1725	1796	1661	1796
Adjusted R-squared	0.970	0.947	0.993	0.967	0.970	0.944	0.993	0.967

Note: The table shows the results for the static difference-in-differences model (4.1). The time window employed runs from October 2013 to December 2016. The dependent variables include Log(credit outstanding to NFCs) in columns (1) and (5), Log(credit outstanding to Individuals) in columns (3) and (7), the share of NFCs credit to total assets in columns (2) and (6), and the share of Individuals credit to total assets in columns (4) and (8). NIRP is a time dummy variable taking the value of 1 for every month from June 2014 onwards, and 0 otherwise. This dummy is interacted with all other regressors, whether these are included as treatment variables or simply as controls. The single treatment variable is Interbank Liquidity in columns 1-4, calculated as interbank loans minus interbank deposits divided by total assets, and the Deposit Ratio in columns 5-8, defined as the share of short-term deposits over total assets. Controls include: 1) Bank Size, measured as the logarithm of banks' total assets; 2) Capital Ratio, measured as the sum of capital and reserves divided by total assets; 3) Securities Ratio, measured as the share of debt and equity securities over total assets. All the independent variables are computed as of end-March 2014. Standard errors are clustered at the bank level and presented in parentheses. The difference in the number of observations used in the different specifications is driven by periods in which credit was not reported. *** p<0.01, ** p<0.05, * p<0.10.

In Table 7 (columns 1-4), we add the NPLs Ratio as a further control to the baseline. The reason to control for this additional characteristic is twofold. First, in recent studies, the NPLs ratio is often used as an indicator of banks' health and efficiency, which may play a part in their reaction to NIRP. Second, since this variable is moderately correlated with banks' interbank liquidity (see Table A12), not including it could pose a threat to our identification strategy. Reassuringly, our main results are left unaffected, and it should be noted that the estimated impact on the *NFCs Loans Ratio* via interbank liquidity is even larger than in the baseline model (column 2). Moreover, in columns 5-8, we run the baseline specification while computing all the independent variables as their average in the year before NIRP, rather than in end-March 2014. Once again, our results remain qualitatively similar.

Table 7 – NPLs Ratio & Averaged Independent Variables

	(1) Log (NFCs Loans)	(2) NFCs Loans Ratio	(3) Log (Loans to Indiv.)	(4) Indiv. Loans Ratio	(5) Log (NFCs Loans)	(6) NFCs Loans Ratio	(7) Log (Loans to Indiv.)	(8) Indiv. Loans Ratio
NIRP=1 × Interbank Liquidity	0.063 (0.321)	**0.132*** (0.039)**	-0.347 (0.329)	-0.020 (0.044)	0.255 (0.345)	**0.125*** (0.043)**	-0.051 (0.394)	-0.014 (0.032)
NIRP=1 × Deposit Ratio	0.305 (0.290)	-0.037 (0.044)	0.095 (0.190)	0.014 (0.027)	0.215 (0.248)	-0.053 (0.040)	0.162 (0.199)	0.018 (0.029)
NIRP=1 × NPLs Ratio	-0.945 (0.792)	0.113 (0.104)	-2.502*** (0.798)	-0.055 (0.120)				
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1725	1796	1661	1796	1725	1796	1661	1796
Adjusted R-squared	0.970	0.948	0.994	0.967	0.970	0.948	0.993	0.968

Note: The table shows the results of modifications to the baseline specification. The time window employed runs from October 2013 to December 2016. The dependent variables include Log(credit outstanding to NFCs) in columns (1) and (5), Log(credit outstanding to Individuals) in columns (3) and (7), the share of NFCs credit to total assets in columns (2) and (6), and the share of Individuals credit to total assets in columns (4) and (8). NIRP is a time dummy variable taking the value of 1 for every month from June 2014 onwards, and 0 otherwise. This dummy is interacted with all other regressors, whether these are included as treatment variables or simply as controls. The treatment variables are Interbank Liquidity, calculated as interbank loans minus interbank deposits divided by total assets, and the Deposit Ratio, defined as the share of short-term deposits over total assets. Controls include: 1) Bank Size, measured as the logarithm of banks' total assets; 2) Capital Ratio, measured as the sum of capital and reserves divided by total assets; 3) Securities Ratio, measured as the share of debt and equity securities over total assets. In columns 1-4, the NPLs Ratio is included as an additional control, computed as the share of domestic overdue credit over total assets, and all the independent variables are measured as of end-March 2014. In columns 5-8, all the independent variables from the baseline regression are computed as their average in the year before NIRP. Standard errors are clustered at the bank level and presented in parentheses. The difference in the number of observations used in the different specifications is driven by periods in which credit was not reported. *** p<0.01, ** p<0.05, * p<0.10.

5. Concluding Remarks

The theoretical and empirical literature on the role played by bank lending in the transmission of monetary policy is largely inconclusive when it comes to banks' response to policy rate cuts below zero. Some studies claim that negative interest rates discourage banks from lending (Brunnermeier & Koby, 2018; Eggertsson et al., 2019; Heider et al., 2019), as squeezed intermediation margins and low net worth hinder their capacity to extend loans. Meanwhile, other recent empirical contributions uncover diametrically opposing effects, showing that banks most affected by NIRP rebalance their portfolios in favor of credit origination, thereby increasing lending by more than other banks (Bottero et al., 2021; Demiralp et al., 2021; Schelling & Towbin, 2022). The ambiguous evidence is among the justifications for some policymakers' reluctance to adopt this policy instrument.

We contribute to the nascent research on this topic by exploiting comprehensive datasets on Portuguese banks' balance sheets and income statements held by Banco de Portugal. Using a quasi-experimental analysis – the difference-in-differences method – we explore cross-sectional variation in two bank-specific characteristics that may determine banks' reaction to negative interest rates, namely interbank liquidity and reliance on deposit funding. At a fundamental level, we compare the lending behavior of high-liquidity/high-deposits banks to that of low-liquidity/low-deposits banks, before and after the implementation of NIRP by the ECB on June 11, 2014.

We do not find evidence of significant differences in the volumes of credit granted to non-financial corporations or individuals by differently exposed banks (neither via liquidity nor deposit reliance). However, our results indicate that, after the enactment of NIRP, banks with higher *ex-ante* liquidity increase the share of corporate loans in their balance sheets by more than other banks. The average treatment effect is considerable, as a one SD higher liquidity ratio is associated with a 3.42pp increase in the ratio of NFCs loans after 30 months by more exposed banks. The impact becomes statistically significant just 3 months after the impulse, coinciding precisely with the EONIA's first entrance into negative territory. In addition, we test for changes in fees and commissions charged, as well as in interest rate setting behavior between differently exposed banks, although we do not find statistically significant results.

Taken together, the evidence found grants support to the hypothesis of a portfolio rebalancing effect after the implementation of NIRP, hence validating the conjecture that

negative rates influence banks' behavior via liquidity management: liquid banks are encouraged to shift the composition of their balance sheets toward higher yielding, illiquid assets, such as loans. The fact that this adjustment does not seem to translate into significant differences in the *volumes* of credit granted may be related to the turmoil in the Portuguese banking sector after the unexpected collapse of a major bank – Banco Espírito Santo (BES) – around the time of the introduction of NIRP. To be specific, this resolution was achieved through a bail-in, which also impacted other resident banks that had to contribute with *ad hoc* funding to the Portuguese Resolution Fund. As this sort of event often affects credit decisions across the banking system (Beck et al., 2021), it may contaminate the analysis centered exclusively on credit volumes, thus motivating our focus on changes in banks' balance sheet structure.

Moreover, the non-significant results for the deposit ratio indicate that the mechanisms driven by the ZLB on banks' retail deposits were not active in Portugal at the time of the introduction of NIRP. Our preferred explanation for this finding, in the spirit of Eisenshmidt and Smets (2019), is that deposit rates in Portugal were relatively high in June 2014, and thus had scope to decline without reaching the zero lower bound.

The evidence presented should be interpreted with two caveats in mind, both related to the unavailability of bank-firm level data in the present study. The first one derives from a common identification challenge in the empirical banking literature – disentangling the supply of credit from the demand for credit (explained in section 2.2). To recall, the amount of credit available to the real economy cannot be assumed to depend solely on banks' willingness to grant credit, since the demand for credit is also ultimately driven by the same economic and monetary environment. Most recent studies overcome this challenge by conducting within-firm analyses to fully absorb firm-specific shifts in credit demand, which requires bank-firm/loan-level data.[58] Although we cannot address this issue with the most *avant-garde* econometric techniques, we take solace in the argument that for demand effects to be driving our results, the demand for credit faced by banks would have to change systematically with their exposure to NIRP (via liquidity/deposit funding), which does not seem like a plausible hypothesis.

[58] Following the contribution of Khwaja and Mian (2008), some papers focus exclusively on firms that borrow from multiple banks. Others follow Degryse et al. (2019) and use industry-location-size-time (ILST) fixed effects to control for credit demand. Their rationale is that firms operating in the same industry, located in the same area, and with similar size may be assumed to exhibit the same demand for credit.

Second, the rebalancing effect toward corporate credit may also be viewed through the lens of the risk-taking channel of monetary policy.[59] In case this channel is at work, banks would shift lending toward riskier borrowers in a *search-for-yield* attempt, which hints at a potential cause for financial fragility. Indeed, whenever banks grant loans disproportionately to unsound, low-quality borrowers, that frequently culminates in NPLs and other financial imbalances, ultimately undermining financial stability. Prominent as this hypothesis may be, we cannot explicitly test it, once again due to the unavailability of bank-firm level data. Overcoming this limitation may provide an interesting avenue for future research.

Another unresolved question worth analyzing relates to the interaction between NIRP and other unconventional monetary policies, especially Quantitative Easing. To the extent that both policies flatten the yield curve and lead to a decline in the return of liquid assets, they could be seen as alternatives to one another. But if NIRP and QE somehow interact distinctively with different components of banks' portfolios, they may instead be seen as complementary. However, unraveling the impact of each policy is a challenging task on both empirical and theoretical grounds. From an empirical perspective, it is difficult to identify changes in the data that are unequivocally associated with each policy measure due to the contemporaneity of their implementation. As stated before, the ECB launched its rendition of QE very soon after the enactment of NIRP.

But perhaps more prominent are the theoretical challenges ahead. There is an absolute need to incorporate the importance of bank liquidity in theoretical models of the banking system. Indeed, holding and exchanging liquid assets within interbank markets is a crucial part of the banking activity, as it provides banks with an effective way to handle liquidity risk. Yet, most macroeconomic models of the banking system seem to neglect banks' liquidity management concerns altogether, thus creating an important gap in the existing literature (some novel exceptions are Bianchi and Bigio (2022) and De Fiore et al. (2022)).

[59] See *e.g.*, Adrian and Shin (2010), Dell'Ariccia et al. (2017), Jiménez et al. (2014), Maddaloni and Peydró (2011).

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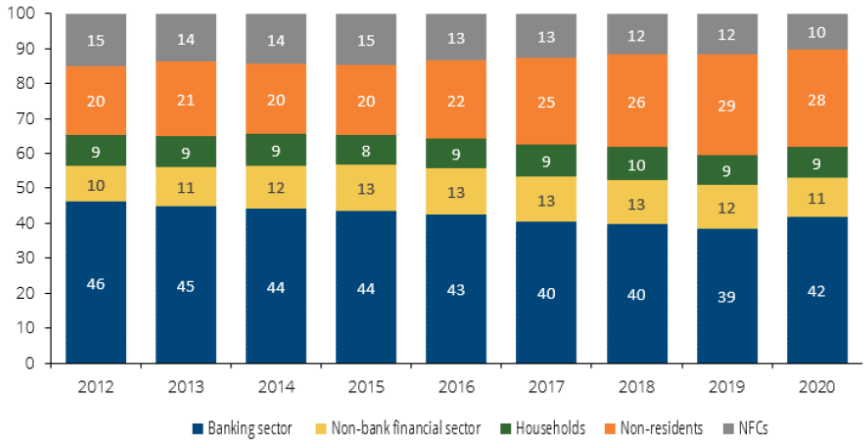
7. Annex

7.1 Figures

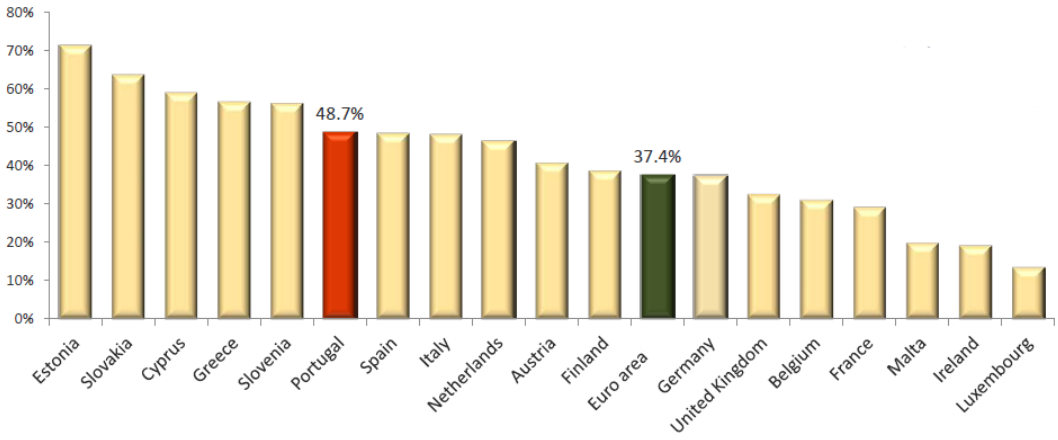
Figure A3 - Financing Structure of Portuguese Firms, by Financing Sector (%)



Note: This figure indicates the share of each financing sector in the total non-consolidated financial debt of NFCs, obtained from data from the National Financial Accounts. Financial debt includes loans and debt securities issued.

Source: Banco de Portugal

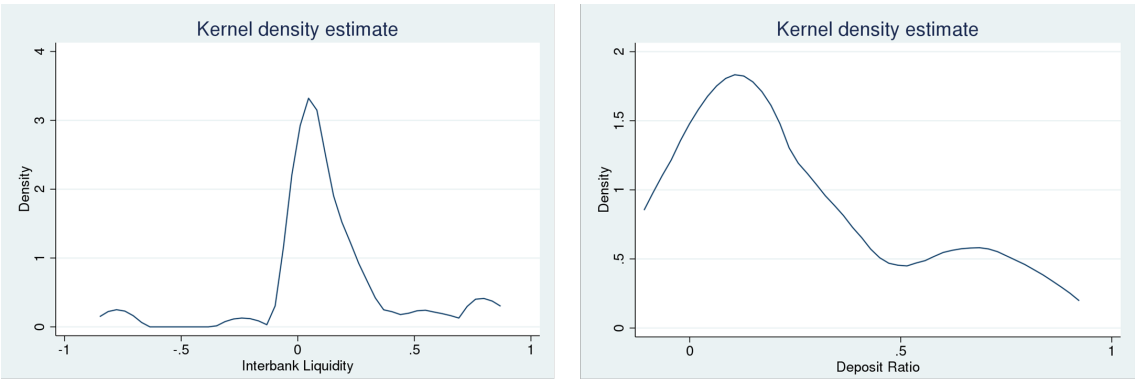
Figure A4 - Loans to the Non-Monetary Sector as a % of Total Assets



Note: This figure indicates the share of loans to customers in the non-monetary sector (gross outstanding volumes at the end-September 2014), as a percentage of total assets.

Source: ECB

Figure A5 - Distribution of the Treatment Variables

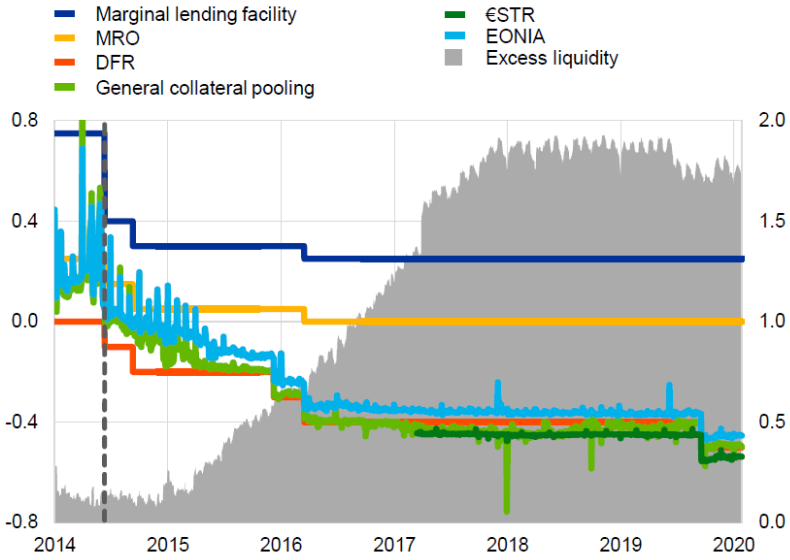


Panel (a) Panel (b)

Note: This figure shows the kernel density distribution of banks' Interbank Liquidity (panel a) and Deposit Ratio (panel b) as of end-March 2014.

Source: Own Elaboration

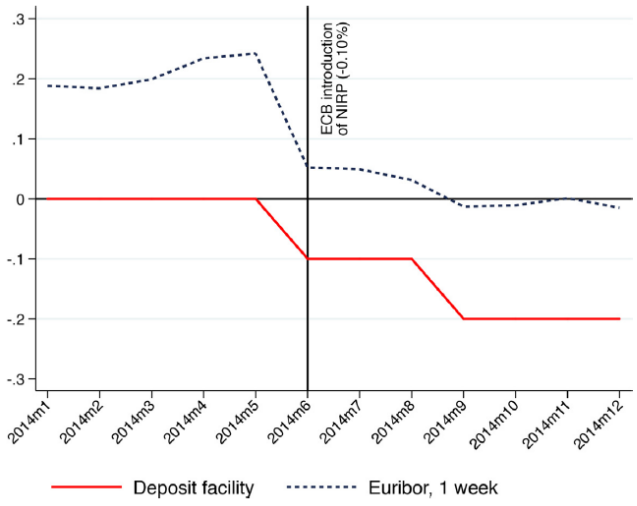
Figure A6 - Short-term Money Market Rates in the Euro Area



Note: This figure shows the evolution of short-term money market rates and excess liquidity in the Euro Area. Left-hand scale: percentages; Right-hand scale: EUR trillions.

Source: ECB

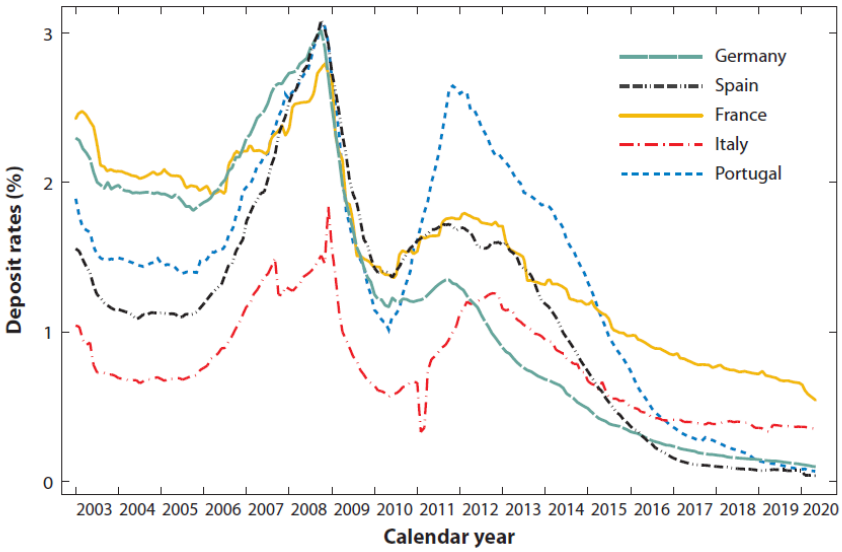
Figure A7 - Policy and Interbank Rates



Note: This figure shows the DF rate and the EURIBOR one-week interest rate, at monthly frequency, taking the end-month values. The vertical line represents June 2014, when NIRP was first implemented.

Source: Bottero et al. (2021)

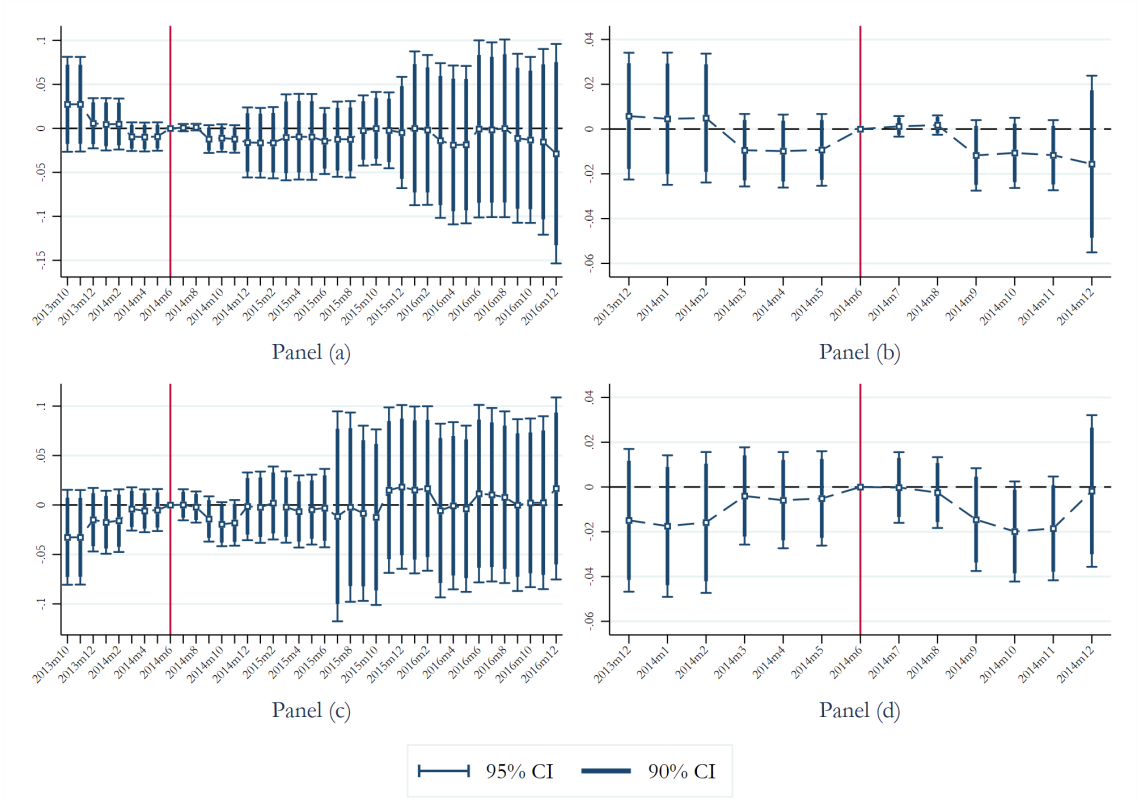
Figure A8 - Deposit Rates in the Euro Area



Note: This figure illustrates the rates on bank deposits by country, weighted by type of deposits, for Germany, Spain, France, Italy and Portugal between 2003 and 2020. For each country, weighted rates are calculated based on the rates and volumes of overnight deposits, agreed-maturity deposits (all maturities), and deposits redeemable at notice, and include deposits held by NFCs and households.

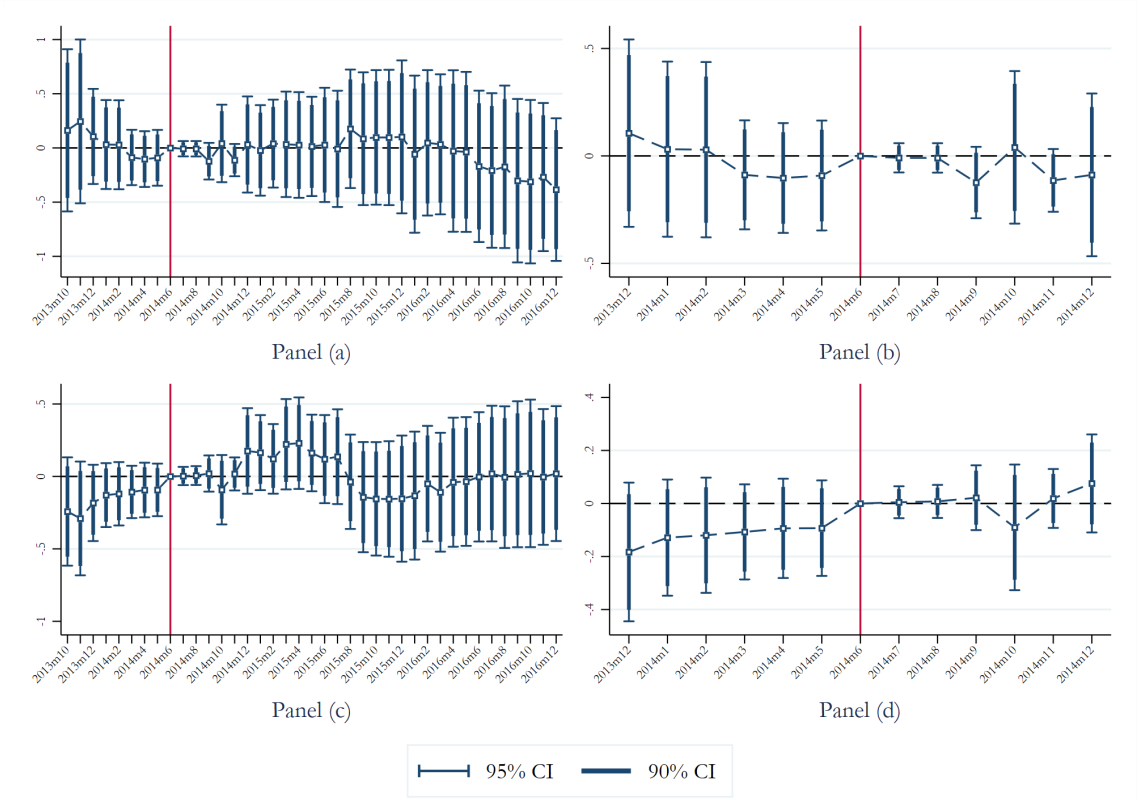
Source: Heider et al. (2021)

Figure A9 - Dynamic Treatment Effects: The Ratio of Loans to Individuals



Note: This figure shows the β coefficients on $Interbank\ Liquidity_i \times Period_t$ (upper panels) and $Deposit\ Ratio_i \times Period_t$ (lower panels) for the Individuals Loans Ratio (of regression 4.1), both in the long time window (left panels) and in the short time window (right panels). The labels on the x-axis indicate the month, and the vertical red line represents the start of the treatment period - June 2014 - which is the implicit reference date for all indicator coefficients. Connected dots represent point estimates, while the capped spikes represent the 90% and 95% confidence intervals. Standard errors are clustered at the bank-level.

Figure A10 - Dynamic Treatment Effects: Log(Loans to Individuals)



Note: This figure shows the β coefficients on $Interbank\ Liquidity_i \times Period_t$ (upper panels) and $Deposit\ Ratio_i \times Period_t$ (lower panels) for the Log(Loans to Individuals) (of regression 4.1), both in the long time window (left panels) and in the short time window (right panels). The labels on the x-axis indicate the month, and the vertical red line represents the start of the treatment period - June 2014 - which is the implicit reference date for all indicator coefficients. Connected dots represent point estimates, while the capped spikes represent the 90% and 95% confidence intervals. Standard errors are clustered at the bank-level.

7.2 Tables

Table A8 - Summary Statistics on Banks' Outcomes

	Mean	25th Percentile	Median	75th Percentile	Std. Dev.	Obs.
Loans to NFCs	1899,47	44,92	119,00	1220,93	4220,58	1796
Loans to Individuals	2641,06	12,00	71,18	1215,16	6127,09	1796
Log (Loans NFCs)	5,36	3,91	4,81	7,27	2,29	1725
Log (Loans Individuals)	5,09	2,60	4,36	7,59	2,81	1661
Loans to NFCs Ratio	0,26	0,10	0,20	0,35	0,21	1796
Loans to Individuals Ratio	0,23	0,06	0,19	0,33	0,21	1796
Interest rates on Total Loans	4,03	2,36	3,71	4,82	2,58	1746
Interest rates on Loans to NFCs	4,16	2,90	3,99	5,17	1,80	1704
Interest rates on Loans to Households	3,91	1,59	2,89	5,46	3,10	1590
Fees & Commissions Income (Net)	38,48	0,18	1,71	14,50	105,33	1796

Note: The data cover the period from the long time window employed in this study, between October 2013 and December 2016. Loans to NFCs includes total credit granted to Non-Financial Corporations. Loans to Individuals includes total credit granted to Individuals. Both variables are first presented in the natural logarithm form, and then as a share of total assets. The interest rates variables are drawn from the SBL dataset and include interest rates on total outstanding loan amounts, as well as on loans to NFCs and loans to Households. Fees and Commissions represent net income from services and commissions, also drawn from the SLB dataset.

Table A9 - Summary Statistics on Banks' Characteristics

	Mean	25th Percentile	Median	75th Percentile	Std. Dev.	Obs.
Interbank Liquidity	0,14	0,03	0,07	0,20	0,29	1796
Deposit Ratio	0,26	0,01	0,19	0,42	0,26	1796
Bank Size	7,03	5,30	6,73	8,63	2,13	1796
Capital Ratio	0,13	0,08	0,11	0,19	0,09	1796
Securities Ratio	0,21	0,00	0,15	0,37	0,21	1796
NPLs Ratio	0,05	0,00	0,03	0,04	0,07	1796

Note: Interbank Liquidity measures banks' (net) position in the interbank market, calculated as interbank loans minus interbank deposits, divided by total assets. This variable includes interbank notes and coins, as well as interbank credit with maturity up to 1 year minus interbank demand deposits, deposits redeemable at notice, and interbank debt securities issued with a maturity up to 1 year. The Deposit Ratio includes demand deposits, deposits redeemable at notice, and other deposits with maturity up to 1 year from Individuals or Non-Financial Corporations, as a share of total assets. Bank Size is measured as the logarithm of banks' total assets. The Capital Ratio is measured as the sum of capital and reserves divided by total assets. The Securities Ratio is the share of debt and equity securities, scaled by total assets. The NPLs Ratio is measured as the ratio of domestic overdue credit over total assets. All the variables are computed as of end-March 2014.

Table A10 - Bank Characteristics: High-Liquidity vs. Low-Liquidity Banks

	Mean		Obs.		Test of Differences	
	High-Liquidity	Low-Liquidity	High-Liquidity	Low-Liquidity	t-statistic	P-Value
Interbank Liquidity	0,30	-0,05	25	24	-5,20	0,00
Deposit Ratio	0,38	0,11	25	24	-4,23	0,00
Bank Size	6,72	7,22	25	24	0,81	0,42
Capital Ratio	0,14	0,12	25	24	-0,55	0,59
Securities Ratio	0,26	0,15	25	24	-1,76	0,08
NPLs Ratio	0,02	0,08	25	24	2,71	0,01

Note: The table compares the characteristics of banks with Interbank Liquidity above the median with those below the median. Interbank Liquidity measures banks' (net) position in the interbank market, calculated as interbank loans minus interbank deposits, divided by total assets. The Deposit Ratio indicates each bank's share of short-term deposits over total assets. Bank Size is measured as the logarithm of banks' total assets. The Capital Ratio is measured as the sum of capital and reserves divided by total assets. The Securities Ratio is the share of debt and equity securities, scaled by total assets. The NPLs Ratio is measured as the ratio of domestic overdue credit over total assets. All the variables are computed as of end-March 2014.

Table A11 - Bank Characteristics: High-Deposits vs. Low-Deposits Banks

	Mean		Obs.		Test of Differences	
	High-Deposits	Low-Deposits	High-Deposits	Low-Deposits	t-statistic	P-Value
Interbank Liquidity	0,23	0,03	25	24	-2,46	0,02
Deposit Ratio	0,45	0,05	25	24	-8,34	0,00
Bank Size	7,34	6,57	25	24	-1,25	0,22
Capital Ratio	0,14	0,12	25	24	-0,98	0,33
Securities Ratio	0,28	0,13	25	24	-2,78	0,01
NPLs Ratio	0,02	0,07	25	24	2,40	0,02

Note: The table compares the characteristics of banks with the Deposit Ratio above the median with those below the median. Interbank Liquidity measures banks' (net) position in the interbank market, calculated as interbank loans minus interbank deposits, divided by total assets. The Deposit Ratio indicates each bank's share of short-term deposits over total assets. Bank Size is measured as the logarithm of banks' total assets. The Capital Ratio is measured as the sum of capital and reserves divided by total assets. The Securities Ratio is the share of debt and equity securities, scaled by total assets. The NPLs Ratio is measured as the ratio of domestic overdue credit over total assets. All the variables are computed as of end-March 2014.

Table A12 - Correlation Matrix for Bank Characteristics

	Interbank Liquidity	Deposit Ratio	Bank Size	Capital Ratio	Securities Ratio	NPLs Ratio
Interbank Liquidity	1					
Deposit Ratio	0.44***	1				
Bank Size	-0.17***	-0.13***	1			
Capital Ratio	0.037	0.06**	-0.25***	1		
Securities Ratio	-0.09***	0.18***	0.34***	0.018	1	
NPLs Ratio	-0.43***	-0.28***	-0.13***	0.14***	-0.24***	1

Note: The table reports the Pearson Correlation Matrix for the independent variables employed in the regressions.

Table A13 - Literature Review Summary Table

Nº	*Authors*	*Sample*	*Data*	*Methodology*	*Treatment Variables(s)*	*Main Findings*
1	Demiralp et al. (2021)	214 **Euro Area** banks (2010q1-2017q3)	Bank-level	DiD	Excess Liquidity Holdings & Reliance on Deposit Funding (Deposit Ratio)	Higher excess liquidity (central bank reserves above reserve requirements) is associated with increased lending to households and firms during NIRP. The impact found is stronger for the sub-sample of banks most reliant on deposit funding.
2	Basten and Mariathasan (2018)	50 **Swiss** banks (2013m7-2016m6)	Bank-level	DiD	Excess Reserves (above the SNB exemption threshold)	During NIRP, more exposed banks reduce holdings of safe reserves and rebalance their balance sheets toward mortgages, uncollateralized loans, and other financial assets. In this setting, variation in the cost of holding excess reserves is caused by the Swiss tiering mechanism (implemented together with the negative DFR).
3	Arsenau (2020)	30 largest **U.S** bank holding companies (1996q4-2017q4)	Bank-level	Multiple Regression Analysis	(---)	U.S. banks' exposure to NIRP is driven by liquidity management concerns: banks holding more short-term liquid assets anticipate the sharpest declines in net income if the federal funds rate dropped below zero. However, this paper does not address the question of how banks change their lending behavior in response to NIRP.
4	Bottero et al. (2021)	95 **Italian** banks, lending to >167.000 firms (2012m1-2016m12)	Loan-level	DiD	Net Interbank Position & Overall Liquid Assets Ratio	More exposed banks (through larger interbank positions and holdings of liquid assets) increase the supply of credit, especially to financially constrained firms, and cut lending rates, which induces firms to expand investment and the wage bill. Banks' reliance on deposit funding does not play a role in the Italian setting because deposit-reliant banks counteract losses in NIM by charging higher fees for banking services.
5	Heider et al. (2019)	70 **Euro Area** banks (lead arrangers in syndicated loans) (2013m1-2015m12)	Transaction-level	DiD	Reliance on Deposit Funding (Deposit Ratio)	During NIRP, syndicated lending is significantly reduced by high-deposits banks relative to low-deposits banks. Moreover, high-deposits banks engage in riskier lending to

						financially constrained firms, although there is no evidence of reckless lending behavior.
6	Eggertsson et al. (2019)	11 **Swedish** banks (2014m1-2017m12)	Bank-level	DiD	Reliance on Deposit Funding (Deposit Ratio)	Within mortgage markets, deposit reliant banks experienced lower credit growth after NIRP because they do not reduce loan rates in order to protect profitability.
7	Arce et al. (2021)	23 **Spanish** banks lending to ≈900.000 firms (2014-2019)	Loan-level	Probit Regression + DiD	Reliance on Deposit Funding (Deposit Ratio)	Reliance on deposit funding is the primary channel through which NIRP affects banks' behavior, and adversely affected banks reduce their loan supply to firms and increase lending rates, relative to non-affected banks. The estimated impact appears toward the end of the sample period and is stronger for low-capitalized banks.
8	Tan (2019)	189 **Euro Area** banks (2013m1-2015m12)	Bank-level	DiD	Reliance on Deposit Funding (Deposit Ratio)	High-deposits banks expand lending relative to low-deposits banks after NIRP. This result is mostly driven by mortgage lending and is stronger for banks with larger households' deposit ratios and banks with larger overnight deposit ratios. High-deposits banks' intermediation margins are unchanged, suggesting that the increase in credit granted is enough to counterbalance the adverse influence of NIRP on profitability. Nonetheless, the positive impact on bank lending fades as NIRP persists.
9	Schelling and Towbin (2022)	20 **Swiss** banks and ≈1.5 million loan agreements (2006m6-2014m12)	Transaction-level	DiD	Reliance on Deposit Funding (Deposit Ratio)	During NIRP, deposit-dependent banks relax lending terms and conditions relative to other banks, concede larger loan amounts, and are less prone to charge loan commissions. The increase in lending is stronger for firms from riskier sectors and the estimated impact is persistent.
10	Grandi and Guille (2021)	33 **French** banks lending to 3889 firms (2012m1-2017m1)	Bank-firm level	DiD	Reliance on Deposit Funding (Deposit Ratio)	Banks with higher dependence on deposit funding expand corporate lending and increase fees and commission income during NIRP, compared to other banks. The estimated impact is greater for banks with weaker *ex-ante* capitalization and larger shares of households' and liquid deposits (which face direct competition from cash).