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The effectiveness of a negative interest rate policy[☆]

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ABSTRACT

In a dynamic stochastic general equilibrium model that is calibrated for the euro area, a negative interest rate policy (NIRP) can have contractionary effects on the economy when interest rates on household deposits reach the zero lower bound, and such deposits are the only source of bank funding and household savings. However, by introducing additional assets to households' portfolios and alternative sources of bank funding, such as bank bonds, the NIRP becomes expansionary. Because both features characterize the euro area well, they are essential to study the effectiveness of NIRP policies.

1. Introduction

In response to disinflationary pressures following the global financial crisis, a number of central banks have implemented a negative interest rate policy (NIRP). For example, the European Central Bank (ECB) cut its deposit facility rate into negative territory for the first time in June 2014, thereby charging banks for their excess liquidity holdings at the central bank.[1] The NIRP of the ECB was successful in pushing market rates (such as money market rates and government bond yields) to negative levels in an environment where the interest rate on bank deposits held by households was largely subject to a zero lower bound (see Eisenschmidt and Smets, 2019).

The effectiveness of a NIRP in stimulating the economy has come under scrutiny. In particular, Brunnermeier and Koby (2019) and Eggertsson et al. (forthcoming) - hereafter EJSW - have pointed out that a NIRP may compress bank interest rate

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[1] Prior to its removal from negative territory in June 2022, the deposit facility rate of the ECB was -0.5%. In September 2019, the ECB also established a tiering system whereby a portion of excess reserves was remunerated at the Main Refinancing Rate, which was then 0%.

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margins when banks are unable to pass on the reduction in the reserve rate to depositors, e.g. due to a zero lower bound. Accordingly, a NIRP may lead to a decline in bank profitability, which could result in undesired contractionary effects on credit supply or an increase in bank lending rates.[2]

In Brunnermeier and Koby (2019), a NIRP has a contractionary impact on the economy when the banking sector is faced with binding liquidity and capital constraints. The reduction in bank profits under such constraints negatively affects the net worth of banks, which leads to a decline in the volume of loans. When the capital constraint is not binding, a decrease in policy rates does lead to an increase in the supply of credit as the policy rate passes through to loan rates. Nevertheless, the reduction of profits may still lead to a reduction in bank net worth and the eventual imposition of a binding capital constraint, which restricts lending. According to EJSW, policy rate cuts can stimulate lending through two channels. The first channel works by lowering deposit rates, which reduces banks' marginal funding costs. However, when deposit rates hit their lower bound, this channel is eliminated. The second channel is through the effect on banks' profitability and net worth, but this bank capital channel is negative when the pass-through of the interest rate cut to reserves and liquid assets is greater than the pass-through to the cost of funding.

Other studies have examined the effectiveness of a NIRP through different channels and have reported more favorable results. Ulate (2021) finds that a NIRP is between 60 and 90 percent as effective as monetary policy in positive territory. The effectiveness of a NIRP in his model depends on two opposing channels that impact the lending rate's response. On the one hand, banks have a certain degree of monopoly power, which implies that the interest rate on loans (deposits) is set as a mark-up (mark-down) on the policy rate. This profit margin in the loan market enables the transmission of reductions in the policy rate to lending rates. On the other hand, the reduction in bank profitability due to a decrease in the deposit spread, coupled with a deterioration in bank equity and an increase in leverage, counteracts this effect. As banks' willingness to lend is dependent on their equity, they become less inclined to provide credit when leverage is high, resulting in a positive impact on the lending rate. The effectiveness of a NIRP, therefore, relies on the relative importance of these two channels.[3]

De Groot and Haas (2020) and Sims and Wu (2021) have demonstrated that a NIRP can be a useful tool in stimulating the economy by helping the central bank to credibly commit to maintain a low policy rate for an extended period. In De Groot and Haas (2020), a NIRP has such a signalling effect if the policy rule exhibits persistence and depends on the lagged reserve rate. Sims and Wu (2021) suggest that a NIRP is a particularly credible form of forward guidance, where the central bank takes action instead of merely announcing future interventions.

This paper investigates the effectiveness of a NIRP by abstracting from imperfect competition and signalling channels. Similarly to Ulate (2021), we allow bank lending to be influenced by the value of the bank, but we do not study the implications of monopoly power.[4] To close the signalling channel, the policy rate is assumed to be a function of the lagged notional Taylor rule rate rather than the lagged effective reserve rate. Instead, we revisit the findings of Brunnermeier and Koby (2019) and EJSW by allowing for alternative sources of bank funding and alternative investment possibilities for households. These extensions can be motivated by the fact that two implicit assumptions in their models are important for the contractionary effects.[5] The first is that households rely solely on bank deposits for savings, making a NIRP ineffective in affecting their consumption and saving decisions. This assumption implies that there is no intertemporal substitution channel of monetary policy when there are reductions in policy rates below zero and interest rates on household deposits have reached the zero lower bound. The second assumption is that household deposits are the marginal funding source for the financial sector. As a consequence, negative interest rates on bank reserves function as a tax that adversely affects bank profitability, ultimately leading to a rise in lending rates and a decline in aggregate demand.

These two assumptions are at odds with key euro area (EA) characteristics. First, while euro area households primarily hold deposits as their financial assets (44% of household financial assets), they also rely on other saving vehicles such as bonds (5%), shares (7%), mutual funds (9%), pension funds (24%) and others assets (11%), which may be affected by a NIRP.[6] EA data show that the degree of substitutability between deposits and these other assets is limited, and their shares in households' portfolios have remained relatively unchanged after the introduction of negative rates. Second, household deposits are not the sole source of bank funding in the EA, as wholesale funding constituted approximately 17% of European bank liabilities in 2014.

To account for these characteristics, we introduce two types of financial intermediaries in the model: banks and investment funds. The modelling of banks builds on Gertler and Karadi (2011) - hereafter GK - and Gertler et al. (2012). We follow Cúrdia and Woodford (2016) and EJSW in modelling investment funds. The financial sector has two main features. The first is that households save through bank deposits and investment fund shares. The optimal allocation between these two assets is determined by portfolio adjustment costs, which reflect a preference for holding different types of assets to save

[2] See also Cavallino and Sandri, 2019; De Groot and Haas, 2020; Kumhof and Wang, 2018; Sims and Wu, 2021; Ulate, 2021; Gerke et al., 2021 for the analysis of a NIRP.

[3] In a related paper, Gerke et al. (2021) evaluate the efficacy of a NIRP by utilizing a medium-scale DSGE model that incorporates both contrasting channels. They estimate the model for the euro area and find a net positive impact on economic activity.

[4] In contrast to Ulate (2021), we incorporate this feature through the agency problem described in Gertler and Karadi (2011). Another difference is that banks are assumed to hold reserves at the central bank because of a reserve requirement, as in De Groot and Haas (2020) and Sims and Wu (2021).

[5] In EJSW, a third relevant assumption is that firms can only borrow from banks and do not have alternative funding sources. This assumption has not been relaxed in this paper.

[6] See ECB (2016) for a detailed description of households financial assets composition.

(Andrés et al., 2004). We assume that only the household deposit rate is bounded by zero, which is consistent with the data. When market rates turn negative as a result of the NIRP, the return on investment fund shares responds accordingly, restoring the intertemporal substitution channel of monetary policy. Following Gertler et al. (2012), the second feature of the financial sector is that banks fund their activities through household deposits and bank bonds, which are a type of market funding. As in Meeks et al. (2017) and Mazelis (2016), investment funds can invest in bank bonds. This feature creates a bank bond financing channel of monetary policy, which is operative even when the interest rate on deposits is bounded at zero.

The model is calibrated to capture EA bank balance sheet and interest rate spread data, and simulated using Occbin (Guerrieri and Iacoviello, 2015). We analyze the effects of a negative consumption preference shock that results in a zero interest rate constraint on household deposits, and compare two scenarios: a standard Zero Lower Bound (ZLB) situation, where all interest rates are bounded by zero, and a case where the policy rate becomes negative and the return on household deposits remains constrained.

In the baseline model with both banks and investment funds, a NIRP has positive effects on output and inflation. As investment funds have an incentive to rebalance their portfolio from government bonds to bank bonds, the market funding cost of banks falls and the negative effect on bank profitability is mitigated. The stronger this market funding supply effect, the lower the bank bond rate, the higher the gain in terms of bank profitability, and the stronger the transmission mechanism. This contrasts with a version of the model in which there are no investment funds and households only save through bank deposits. In this case, a NIRP has a contractionary effect on output as highlighted in EJSW.

To illustrate the relative importance of the bank bond financing channel vis-a-vis the intertemporal substitution channel, we also simulate a model in which households hold (negatively yielding) government bonds as well as bank deposits. This restores the intertemporal substitution channel, offsetting the aforementioned contractionary effect, but less so than in the full model with a bank bond financing channel.

We examine the sensitivity of our results to variations in the key parameters of the model. As expected, the positive effects of a NIRP on output are greater when the excess liquidity ratio of the bank sector is lower, when the marginal cost of adjusting the portfolio of households is higher, when the marginal cost of monitoring bank bonds by investment funds is lower, and when investment funds have higher government bond holdings. Overall, our analysis shows that the NIRP is effective in stimulating the economy when these alternative channels of transmission are large enough to offset the negative impact of the ZLB on household deposit rates on bank profitability.

Finally, this paper provides new empirical evidence on the effectiveness of a NIRP in the EA that is consistent with the transmission mechanism explored in the theoretical model. In particular, we show that negative interest rate innovations in the NIRP era had favorable effects on bank lending rates and the volume of bank lending. Moreover, such innovations reduced the spread between bank bond yields and household deposit rates, while they stimulated the issuance of bank debt securities relative to household deposit funding. We document a similar response and substitution, albeit smaller in magnitude, for household deposits towards (cheaper) deposits of non-financial corporations.

The rest of the paper is structured as follows. Section 2 presents some facts which motivate our modelling choices and provides some new empirical evidence. Section 3 and 4 describe the main features of the model and its calibration, respectively. Results of the numerical simulations are reported and discussed in Section 5, while Section 6 concludes.

2. Some stylized facts and new empirical evidence

The NIRP transmission channels introduced in this paper are supported by several stylized facts for the EA. Specifically, panel A in Fig. 1 suggests that there indeed exists a ZLB on deposit rates for households. This also applies to some extent to deposit rates for firms. These rates became negative, but only from December 2020 onwards. However, the figure also shows that there has been a reduction in bank lending rates after the introduction of the NIRP in June 2014. Thus, EA data do not seem to confirm the increase in the cost of borrowing for households and firms suggested by EJSW. Moreover, Panel B of Fig. 1 shows that there has also been an increase in the volume of bank lending.

To formally assess whether there has been a causal link between NIRP and bank lending in the NIRP era, we use instrumental variables local projections (LP-IV) to estimate the dynamic effects of changes in the 1-month OIS rate on a number of bank variables for the period 2014M6-2021M12. The local projections have the following general representation:

$$Y_{i,t+h} = \alpha_{i,h} + \beta_{i,h} OIS_t + \rho_{i,h}(L) Y_{i,t} + \delta_{i,h}(L) X_{i,t} + \epsilon_{i,t+h}$$

where $Y_{i,t+h}$ is the bank variable i at horizon h. $\alpha_{i,h}$ is a vector that includes a constant, a linear and a quadratic time trend. OIS_t is the 1-month OIS rate. $X_{i,t}$ is a vector of (lagged) control variables; that is, the OIS rate, the Eurostoxx50, the 5-year inflation swap rate and the 1-month Euribor. Furthermore, L is set to four.

We use the Policy Target Factor shocks of Altavilla et al. (2019) as the instrument for OIS interest rate innovations. The factor captures high-frequency surprises in the ECB's press release window around the immediate setting of policy rates. To disentangle conventional policy surprises from central bank information signaling, we use the Poor Man's Sign Restrictions approach of Jarociński and Karadi (2020). Specifically, shocks are considered as a proxy for monetary policy surprises when stock prices shifted in the opposite direction of the Target Factor during the press release window (the proxy is zero otherwise). By contrast, these shocks are classified as information surprises when both variables shifted in the same direction. The shocks are converted to a monthly time series, and appear to be strong instrumental variables for innovations

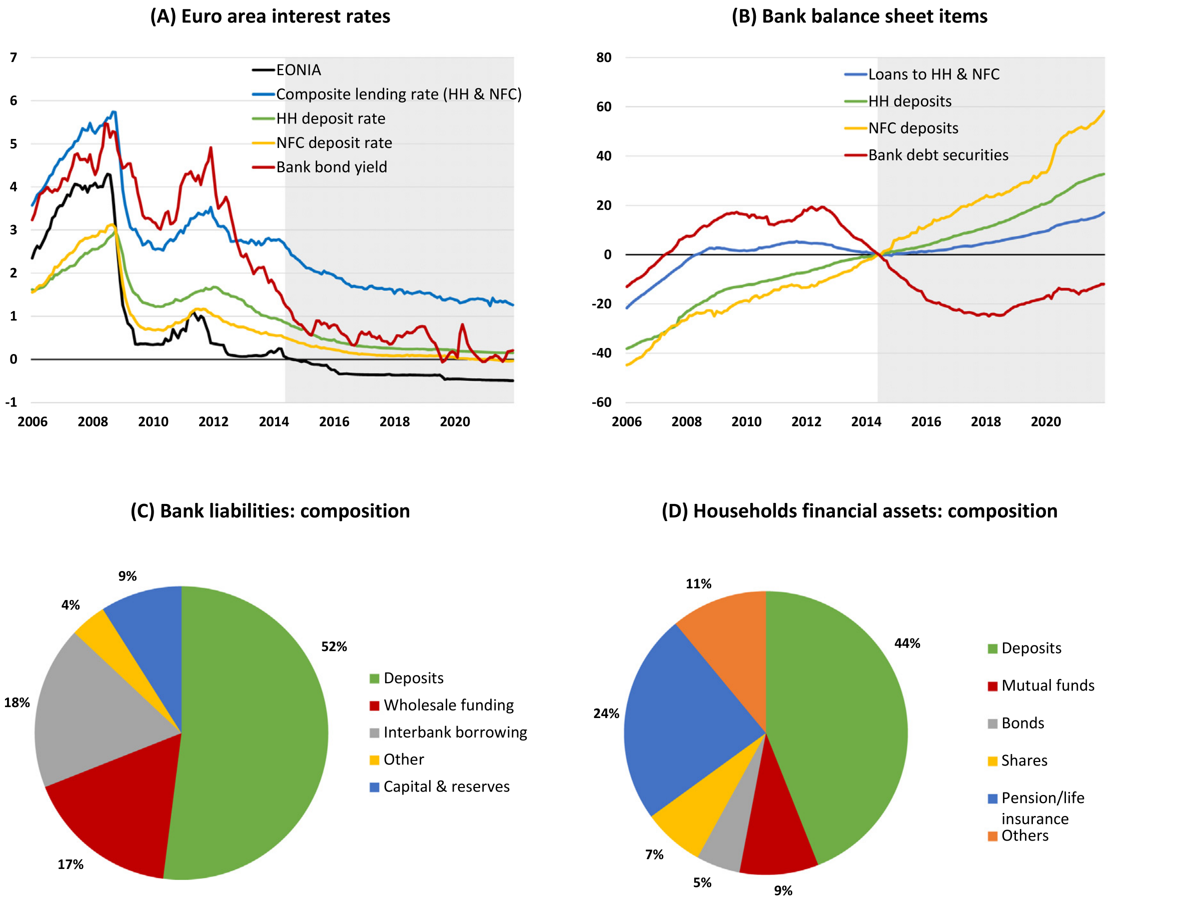

Fig. 1. Some stylized facts for the euro area.

in the 1-month OIS rate in the NIRP era; that is, the F-stats are always above 30. Finally, note that the projections for each horizon h control for the impact of monetary policy and information surprises that occurred between $t+1$ and $t+h$.

As can be observed in Fig. 2, interest rate innovations in the NIRP era have indeed been passed through to bank lending rates and have stimulated bank credit to households and firms. This finding is consistent with several existing studies. For example, Altavilla et al. (2018) and Lopez et al. (2020) find that banks pass on interest rate cuts to lending rates when policy rates move into negative territory. Bräuning and Wu (2017) document a positive effect of interest rate decreases on lending that is even stronger than the impact before rates became negative. Mendicino et al. (2021) show that the effects of the NIRP on borrowing conditions is not significantly different from interest rate cuts in positive territory. Finally, Eisenschmidt and Smets (2019) review the available evidence for the EA and conclude that there is very little sign of adverse effects.[7]

The second fact that is important to stress is that other sources of bank funding than deposits represent a substantial share of bank liabilities in the EA. This is illustrated in panel C of Fig. 1, which shows the composition of the liabilities of the banking sector at the start of the NIRP in 2014. Deposits are the largest share, and account for more than 50% of bank liabilities. However, wholesale funding represents 17% of bank liabilities, which makes it also a significant source of bank funding. Hence, the equilibrium on the market for these assets cannot be ignored as it could affect banks' decisions.

The presence of alternative sources of financing that are relevant for banks should be considered in tandem with a third relevant stylized fact. Specifically, as can be observed in panel A of Fig. 1, there has been a sizeable decrease of bank bond yields after the introduction of the NIRP. Accordingly, for banks relying on other liabilities than deposits, the NIRP should have reduced the costs of wholesale funding. In addition, lower costs encourage banks to increase these alternative sources of funding. Put differently, the decline in bank bond yields induced by the NIRP could have stimulated bank lending.

The local projections support the hypothesis that interest rate decreases in the NIRP era have led to a reduction in the spread between bank bond and household deposit rates, as shown in Fig. 2. Even though the magnitude is smaller, the same applies to the spread between deposit rates for firms versus households. Most importantly, despite the downward trend in

[7] It has to be noticed that there are also papers which find different results, for example, Goodhart and Kabiri (2019). Overall, most studies find favorable effects on bank lending volumes and risk, while a minority report unfavorable or neutral effects. There are, however, mixed views on the mechanisms that explain the pass-through to lending. Notice also that a majority of empirical papers finds that negative interest rates are detrimental for bank profitability and equity prices. See Balloch et al. (2022) for a comprehensive overview and a detailed discussion of the empirical literature.

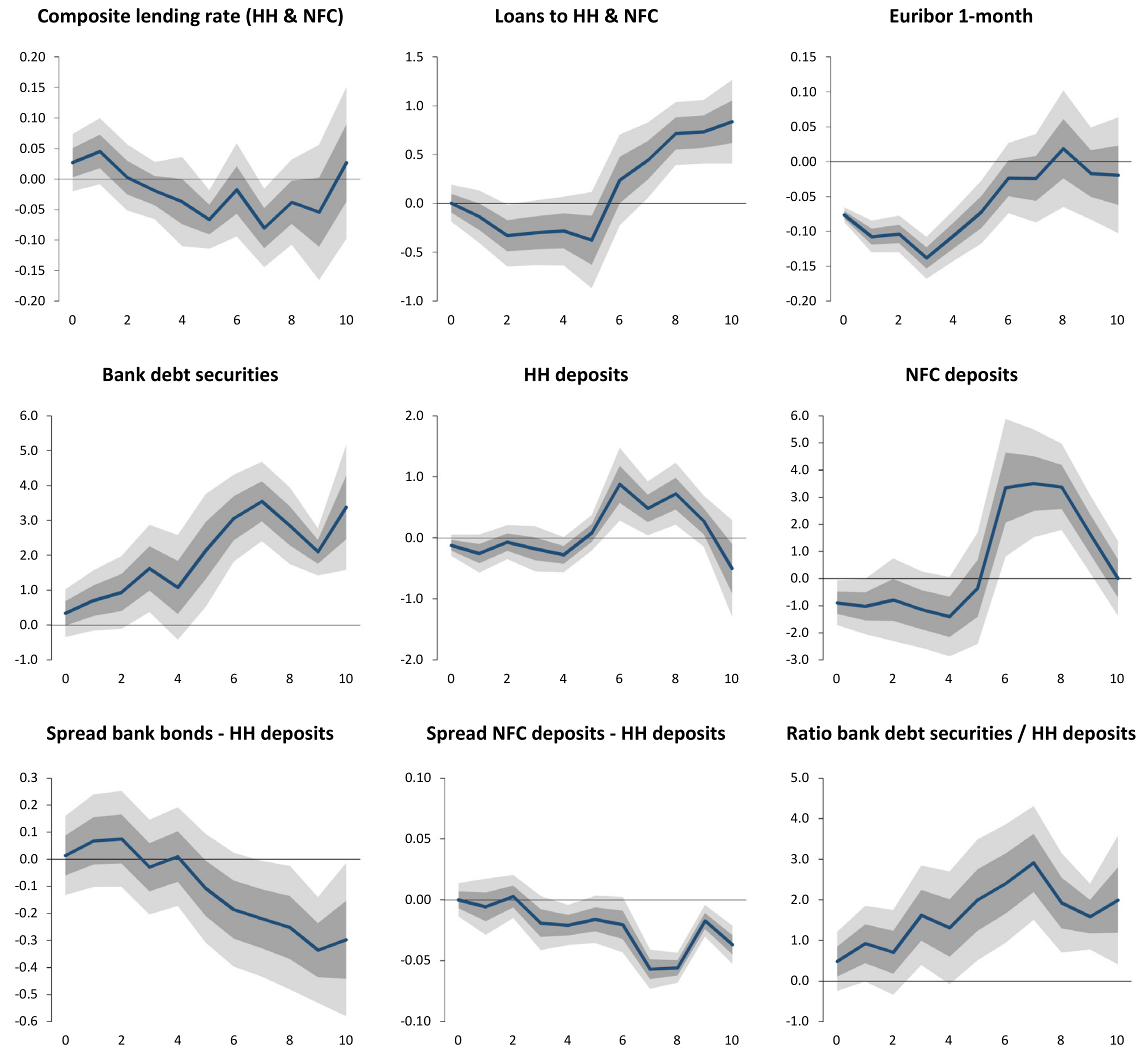

Fig. 2. Dynamic effects of interest rate decreases in the NIRP era.

the volume of debt securities issued by banks (MFIs) in the first years of the NIRP, as illustrated in panel B of Fig. 1, the local projections in Fig. 2 show a significant positive impact of interest rate cuts on the issuance of bank debt securities. Interestingly, the rise in bank debt securities is greater than the increase in household deposits, which suggests that banks substitute household deposits by bonds as a consequence of the NIRP. Notice also the strong rise of firm deposits, which also become relatively cheaper following an expansionary monetary policy shock.

Since the sample period is relatively short, this new evidence should be approached with more than the usual degree of caution. Nevertheless, we consider the results as supporting the view that, overall, a wholesale funding channel could offset the unfavorable effects of EJSW and play an important role in the transmission of the NIRP. The evidence is also consistent with Bottero et al. (2019), who find that the NIRP has shifted down the yield curve for bank bonds. Mendicino et al. (2021) show that banks that rely more on wholesale funding have reduced their loan rate more than those that rely mainly on deposits. Finally, Altavilla et al. (2022) find that banks which are able to pass on negative rates to corporate depositors, increase their credit volumes more than other banks.

The transmission mechanisms proposed in this paper are supported by a final stylized fact that is related to the composition of household assets. Panel D in Fig. 1 summarizes the distribution of financial assets held by households, as reported in ECB (2016). Although deposits constitute the bulk of assets held by households, other forms of savings that are typically affected by a NIRP also represent a significant proportion of households' portfolios, such as pension and life insurances, mutual funds, securities and bonds. A comparison between two subsequent waves of the ECB's household finance and consumption survey shows that the share of deposits in total financial assets remained almost constant throughout this period (ECB, 2016 and 2020). The absence of strong substitutability between deposits and other types of saving, suggests that there exists a preferred habitat in households preference for their portfolio composition. This feature is important given the heterogeneous effects of a NIRP on various financial assets. If the returns on financial assets other than deposits respond to the NIRP, the intertemporal substitution channel of monetary policy can be restored.

3. The model

This section describes the model that will be used for the numerical exercise reported in Section 5. Specifically, we introduce a financial sector in a fully micro-founded DSGE model in the spirit of Smets and Wouters (2003, 2007). The model also features non-linearities stemming from the existence of occasionally binding constraints on the nominal return of deposits.

The economy is inhabited by households, firms, banks, investment funds and the central bank. The modelling of households, firms and the public sector closely follows GK. However, we differ from GK concerning household's savings options, which includes both bank deposits and investment fund shares. Regarding the supply side, our model aligns with other studies in this field. There are three types of firms: capital, intermediate and final good producers. The model is completed with the inclusion of a central bank that sets the short-term interest rate as a function of inflation.

The main novelty is the financial sector, which is assumed to be populated by banks and investment funds. These two agents are connected through an asset, bank bonds, which is issued by banks as an alternative funding source to deposits. Banks are assumed to be leveraged and we follow Gertler et al. (2012) in modelling their decision problem. On the other hand, the investment fund decision problem is similar to the one described in Cúrdia and Woodford (2016) and EJSW. Banks invest a fixed share of their deposits in reserves issued by the central bank (Sims and Wu, 2021 and De Groot and Haas, 2020) and are the only intermediary which can originate loans to capital producers. Investment funds hold bank bonds and government bonds and are funded through shares held by households.

Two characteristics are crucial for the functioning of the transmission mechanisms explored in this paper. The first key feature is the ability for households to invest in fund shares, in addition to holding deposits, which can restore the intertemporal substitution channel of monetary policy at the ZLB. Without this feature, households would be limited to only holding deposits, which are constrained by the lower bound.

The second important characteristic is the availability of bank bonds as a source of bank funding, which reduces the negative effect of the NIRP on bank profitability described in EJSW. The negative return on central bank reserves can hurt banks' profitability, but banks can mitigate this by substituting deposits with bank bonds. This substitution is facilitated by a rebalancing effect on the investment funds' balance sheets. In particular, the share of government bonds held by investment funds decreases because of the fall in government bond yields, whereas their bank bond holdings increase.

3.1. Households

The household block of the model is similar to other papers in this literature. The economy is populated by a continuum of identical households of mass one. Within a household there are f "bankers" and $1-f$ "workers". The former manage a financial intermediary and transfer dividends to the household they belong to, while the latter supply labor and earn a wage that is returned to the family. In every period, bankers leave the market and become workers with probability $1-\sigma$. Households gain utility from consumption, C_t, and dislike labor, L_t, which is remunerated at the real wage, W_t. Households, are assumed to be subject to a consumption preference shock, ζ_t, while the existence of habit formation, h, introduces persistence in the consumption choice. Moreover, households save through bank deposits, D_t, and investment fund shares, Sh_t^{IF}. Reflecting a preferred habitat as in Andrés et al. (2004), we assume that it is costly to depart from a fixed steady-state shares-to-deposit ratio (denoted by $x=\frac{Sh_t^{IF}}{D}$).[8] It is worth stressing that households cannot directly invest in government bonds. To do so, they have to invest in investment funds, which allocate resources between bank and government bonds. Finally, χ represents the weight of labor in the utility function, while the term Π_t is the net distribution from profits of firms and financial intermediaries, which we assume to be owned by households.

Every period, households maximise their lifetime discounted utility function:

$$\max_{C_t,L_t,D_t,Sh_t^{IF}} \mathbb{E}_t \sum_{\tau=t}^{\infty} \beta^{\tau-t}\left(\log\left(C_\tau - hC_{\tau-1}\right)\zeta_t - \frac{\chi}{1+\varphi}L_\tau^{1+\varphi} - \frac{a}{2}\left(\frac{D_t}{Sh_t^{IF}}x-1\right)^2\right) \tag{1}$$

subject to the sequence of budget constraints:

$$C_t + D_t + Sh_t^{IF} = W_tL_t + R_t^D D_{t-1} + \Pi_t + R_t^{IF} Sh_{t-1}^{IF} \tag{2}$$

[8] An alternative approach would be to assume that deposits provide liquidity services in the utility function. In this case, there would also be a well-defined steady-state household portfolio composition depending on the curvature of the utility of liquidity services. There would be a spread between the deposit rate and the reserve/government bond rate, possibly reducing the distance of the steady-state deposit rate from zero. High substitution with zero-interest-bearing cash would still lead to a zero lower bound on the deposit rate.

The set of first order conditions is given by:

$$\begin{aligned} &\textit{FOCs Households} \\ &[Consumption]: \Xi_t = \frac{\zeta_t}{C_t - hC_{t-1}} - \frac{\beta h \mathbb{E}_t \zeta_{t+1}}{\mathbb{E}_t C_{t+1} - hC_t} \\ &\left[Labour\, supply\right]: \frac{\chi L_t^{\varphi}}{\Xi_t} = W_t \\ &\left[Euler\ deposits\right]: \Xi_t = \beta \mathbb{E}_t \Xi_{t+1} R_{t+1}^D - a\left(\frac{D_t}{Sh_t^{IF}} x - 1\right)\frac{x}{Sh_t^{IF}} \\ &\left[Euler\ shares\right]: \Xi_t = \beta \mathbb{E}_t \Xi_{t+1} R_{t+1}^{IF} + a\left(\frac{D_t}{Sh_t^{IF}} x - 1\right)\frac{D_t}{Sh_t^{IF}}\frac{x}{Sh_t^{IF}} \end{aligned} \tag{3}$$

where Ξ_t represents the Lagrange multiplier associated with the budget constraint and β is the discount factor. The labor supply equation is standard. It links the marginal rate of substitution between consuming and working to the (real) wage. Furthermore, since households invest in two different assets, their consumption-saving decision is defined according to two Euler equations. These are slightly modified with respect to the standard textbook New Keynesian model because of the portfolio reallocation costs discussed above. As shown by Andrés et al. (2004), these equations implicitly pin down the relationship between the interest rate on bank deposits, R_t^D, and investment fund shares, R_t^{IF}.[9]

The introduction of investment fund shares allows to partially restore the intertemporal substitution channel of monetary policy in a model with a ZLB on the interest rate on deposits. Since the deposit rate is bounded by zero, while the return on investment fund shares can be negative, an intertemporal substitution effect arises when the policy rate becomes negative. Moreover, the assumption of portfolio adjustment costs implies that it is optimal for households to hold some shares even when they have a negative return. It is possible to quantify this intertemporal substitution effect by looking at Eq. (4), which is the linearized version of the consumption equation.[10]

$$\widehat{c_t} = \mathbb{E}_t \widehat{c_{t+1}} - \left\{ \widehat{R_t^{IF}} + \frac{a}{\Xi Sh^{IF}} \left[\widehat{D_t} - \widehat{Sh_t^{IF}} \right] \right\} \tag{4}$$

As shown in (4), the return on shares enters into the relation with a negative sign. Therefore, a drop in this return translates into a rise of consumption. The introduction of this feature is the first reason why the NIRP could be effective in stimulating the economy during a recession.

3.2. Financial intermediaries

The presence of market funding in the financial block of the model is the second feature of our model that could explain why negative interest rates are not contractionary. This block consists of banks and investment funds.

3.2.1. Banks

The economy is populated by a continuum of banks, which are managed by household members (i.e., bankers). The structure of the balance sheet of the bank is as follows:

Asset	Liabilities
Loans	Deposits
Reserves	Bank Bonds
	Net Worth

Banks extend loans (S_t) to capital producers at the rate $\mathbb{E}_t R_{t+1}^K$ and hold reserves at the central bank (DF_t), which are remunerated at R_t^R. Banks are funded through deposits (D_t) and bank bonds $\left(BB_t^B\right)$, which pay each period R_t^D and $\mathbb{E}_t R_{t+1}^{BB}$ to households and investment funds, respectively. The returns on deposits and reserves are pre-determined, but those on loans and bank bonds are not. Firms pay to banks the ex-post return on capital. Similarly, banks remunerate investment funds for their bank bond holdings at the interest rate resulting from the equilibrium in the bank bond market.

The timing of the decision problem of banks is as follows. At the end of period t banks repay their funders (i.e., households and investment funds) and determine the amount of bank bonds to be issued in the next period. The clearance of the bank bond market requires the following condition: $\mathbb{E}_t BB_{t+1}^B = BB_t^{IF}$.

A net worth constraint is introduced through an agency problem, as proposed by GK and Gertler et al. (2012). After obtaining funds, bankers could divert part of these funds, denoted by Θ, to their households. Since this behavior is known by all households, it implies a limit on the amount of funds they are willing to lend. Moreover, although bank bonds are

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[9] From the FOCs on deposits and shares it is possible to obtain the return on deposits as $\mathbb{E}_t R_{t+1}^D = \frac{1}{\beta \mathbb{E}_t \Xi_{t+1}} \left\{ \Xi_t + a\left(\frac{D_t}{Sh_t^{IF}} x - 1\right)\frac{x}{Sh_t^{IF}} \right\}$, while the return on shares is given by $\mathbb{E}_t R_{t+1}^{IF} = \frac{1}{\beta \mathbb{E}_t \Xi_{t+1}} \left\{ \Xi_t - a\left(\frac{D_t}{Sh_t^{IF}} x - 1\right)\frac{D_t}{Sh_t^{IF}}\frac{x}{Sh_t^{IF}} \right\}$

[10] For simplicity, it is assumed there are no habits.

more expensive than deposits from the bank's perspective, holding some of these assets is optimal, as it relaxes the incentive compatibility constraint just described. The rationale behind this assumption is that investment funds, which invest in these assets, have better information about banks' operations than households. As a consequence, the quantity of assets that a banker could divert is assumed to be a decreasing function of the fraction of loans funded through bank bonds, which is given by $F_t = \frac{BB_t^B}{Q_t S_t}$. This assumption is also consistent with the idea that market funding could be considered as a disciplining tool for banks (see Diamond and Rajan, 2001; Bliss and Flannery, 2002).[11] The constraint is then that the franchise value of the bank has to be greater or equal to the value of (possibly) diverted assets:[12]

$$V_t^B \geq \Theta\left(F_t; \theta, \gamma_1\right) Q_t S_t \tag{5}$$

Note that it is assumed that banks cannot divert central bank reserves.

Moreover, banks face an additional constraint as they have to invest a fixed share of deposits in central bank reserves, such that $DF_t = mD_t$.[13]

The balance sheet of the bank at the end of period t is given by:

$$Q_t S_t + DF_t = N_t^B + BB_t^B + D_t \tag{6}$$

where Q_t is the price of capital and N_t^B represents net worth, which is given by:

$$\mathbb{E}_t N_{t+1}^B = \mathbb{E}_t R_{t+1}^K Q_t S_t + R_t^R DF_t - R_t^D D_t - \mathbb{E}_t R_{t+1}^{BB} BB_t^B \tag{7}$$

Returns on reserves and deposits are linked to each other through the following condition:

$$i_t^D = \max\left(0, i_t^R\right) \tag{8}$$

where i_t^D and i_t^R represent nominal deposit and reserve rates, respectively. Due to a zero lower bound on the deposit rate, banks cannot pass on negative rates on the reserve rate to depositors.

The franchise value of the bank is given by:

$$V_t^B = \sum_{j=0} (1-\sigma)\sigma^j \beta^j \mathbb{E}_t \Lambda_{t,t+1+j} N_{t+1+j}^B \tag{9}$$

where σ represents the survival probability of bankers and N_t^B is net worth, which can be rewritten as:

$$\mathbb{E}_t N_{t+1}^B = \left(\mathbb{E}_t R_{t+1}^K - \frac{\left(R_t^D - mR_t^R\right)}{1-m}\right) Q_t S_t - \left(\mathbb{E}_t R_{t+1}^{BB} - \frac{\left(R_t^D - mR_t^R\right)}{1-m}\right) BB_t^B + \frac{\left(R_t^D - mR_t^R\right)}{1-m} N_t^B \tag{10}$$

Eq. (10) shows that the parameter m, which pins down the share of deposits to be invested in central bank reserves, plays a key role in affecting the interest rate margins and the net worth of the bank. When the reserve rate is positive, the interest rates on reserves and deposits are the same and the funding term simplifies to R_t^D. In contrast, a negative reserve rate generates a spread with the zero deposit rate and implies a negative impact on net worth. This effect can be sizeable in a situation characterized by high excess liquidity.

Substituting (10) into (9) and using $F_t = \frac{BB_t}{Q_t S_t}$, it is possible to define the value of the bank as:

$$V_t^B = \nu_t^S Q_t S_t - \nu_t^{BB} F_t (Q_t S_t) + \eta_t N_t^B \tag{11}$$

with:

$$\nu_t^S = (1-\sigma)\beta \mathbb{E}_t \Lambda_{t,t+1} \left(\mathbb{E}_t R_{t+1}^K - \frac{\left(R_t^D - mR_t^R\right)}{1-m}\right) + \sigma\beta \mathbb{E}_t \nu_{t+1}^S x_{t,t+1}^S$$

$$\nu_t^{BB} = (1-\sigma)\beta \mathbb{E}_t \Lambda_{t,t+1} \left(\mathbb{E}_t R_{t+1}^{BB} - \frac{\left(R_t^D - mR_t^R\right)}{1-m}\right) + \sigma\beta \mathbb{E}_t \nu_{t+1}^{BB} x_{t,t+1}^{bb}$$

$$\eta_t = (1-\sigma)\beta \mathbb{E}_t \Lambda_{t,t+1} \frac{\left(R_t^D - mR_t^R\right)}{1-m} + \sigma\beta \mathbb{E}_t \Lambda_{t,t+1} z_{t,t+1} \eta_{t+1}$$

where $x_{t,t+1}^S \equiv \frac{Q_{t+j} S_{t+j}}{Q_t S_t}$ represents the growth rate of loans extended to firms between t and $t+j$, $x_{t,t+j}^{bb} \equiv \frac{BB_{t+j}^B}{BB_t^B}$ is the growth rate of bank bonds funded by investment funds and $z_{t,t+j} \equiv \frac{N_{t+j}^B}{N_t^B}$ is defined as the growth rate of the net worth.

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[11] This assumption contrasts with the finding in EJSW that market financing does not necessarily become cheaper following a NIRP. In EJSW this is because of the assumption that banks insure against refinancing risk by investing in negative yielding liquid assets, and the refinancing risk associated with market financing is larger than with insured deposit-financing, making market financing more costly. The evidence reported in Section 2 suggests that in the euro area banks did rebalance funding towards relatively cheaper bank bond financing.

[12] Notice that in Eq. (5) we assume $\Theta\left(F_t; \theta, \gamma_1\right) = e^{-\theta(1+\gamma_1 F_t)}$

[13] We abstract from cash in this model. If banks could hold cash, this could put a lower bound on the assets they are willing to invest in corresponding to the marginal cost of holding cash. We assume this marginal cost to be higher than the NIRP scenarios analysed in this paper.

Maximising (11) subject to the constraint (5) yields the following balance sheet relation:

$$Q_t S_t = \phi_t N_t^B \tag{12}$$

where $\phi_t = \frac{\eta_t}{\Theta(F_t)-\left(\nu_t^S-\nu_t^{BB}F_t\right)}$ represents the endogenous leverage.

3.2.2. Investment funds

We assume that investment funds are able to lend out all acquired funds and are not subject to an incentive compatibility constraint like the one in (5). However, following EJSW, we assume that investment fund profits influence their intermediation cost.

Investment funds invest in bank bonds, BB_t^{IF}, and government bonds, B_t, and are funded through shares held by households, Sh_t^{IF}. The structure of their balance sheet is as follows:

Asset	Liabilities
Bank Bonds	Shares
Gov-Bonds	

Similarly to EJSW, we assume that at the end of each period investment funds remunerate their shareholders with whatever profits (or losses) registered in that period. Their profits are defined by:

$$z_t^{IF} = \frac{\mathbb{E}_t R_{t+1}^{BB} - R_t^{IF}}{R_t^{IF}} BB_t^{IF} + \frac{R_t^g - R_t^{IF}}{R_t^{IF}} B_t - \Gamma\left(BB_t^{IF}, B_t, z_t^{IF}\right) \tag{13}$$

Note that the relevant spread for determining the supply of bank bonds is the one between the expected return on bank bonds and on investment fund shares.

Investment funds maximise profits (13) taking interest rates as given. The first-order conditions are given by:

$$FOCs\ Investment\ Funds \tag{14}$$

$$\left[BB_t^{IF}\right] : \frac{\mathbb{E}_t[R_{t+1}^{BB}] - R_t^{IF}}{R_t^{IF}} = \Gamma_b\left(BB_t^{IF}, B_t, z_t^{IF}\right)$$

$$[B_t] : \frac{R_t^g - R_t^{IF}}{R_t^{IF}} = \Gamma_g\left(BB_t^{IF}, B_t, z_t^{IF}\right)$$

where the cost function is given by:

$$\Gamma(\bullet) = \left(BB_t^{IF}\right)^{\varrho^{IF}} \left(z_t^{IF}\right)^{-\iota} + \frac{1}{2}\left(B_t - \bar{B}\right)^2 \tag{15}$$

ϱ^{IF} represents the inverse of a (fixed) cost for investing in bank bonds and the parameter ι introduces a feedback between the level of profits and the cost of investing in bank bonds.

Three features of Eq. (15) are worth highlighting. First, investment funds hold government bonds to reduce their operational costs, implying that they will never hold $B_t > \bar{B}$. On the other side, the existence of a satiation point $\bar{B}$ implies that there is a limit to the investment funds' ability to cut costs by holding government bonds. In particular, $\Gamma_g = 0$ when $B_t = \bar{B}$. Second, as long as $\varrho^{IF} > 1$, the intermediation cost function is increasing and convex in the amount of funds allocated to bank bonds (i.e., $\Gamma_b > 0$ and $\Gamma_{bb} \geq 0$). This assumption reflects the fact that investing in bank bonds requires costly monitoring. Finally, the marginal cost of investing in bank bonds is assumed to be a decreasing function of profits, i.e., $\Gamma_{bz^{IF}} \leq 0$.[14] As discussed in EJSW, this feature captures in reduced form a link between profits and the operational costs of the investment funds.[15]

3.3. Firms

Since the supply side block of the model does not substantially depart from GK, the description is kept very brief. Specifically, there are three different types of firms. First, intermediate goods producers invest resources obtained through bank loans in capital, which, together with labour, is used in the subsequent period to produce an intermediate good. Second, retailers produce a final good using the intermediate output obtained from intermediate firms as input and are subject to nominal rigidities as in (Christiano et al., 2005). Third, capital producers acquire leftover capital from intermediate producers at the end of the period. After having repaired the worn-out capital, both newly produced and refurbished capital are sold for production to be carried out in the next period.

[14] To ease the notation, we use the short hand notation Γ_g for the derivative with respect to B_t as well as $\Gamma_{b,bb}$ as short notations for first and second derivative with respect to BB_t^{IF}. Finally, we define $\Gamma_{bz^{IF}} = \frac{\partial^2 \Gamma}{\partial BB^{IF} \partial z^{IF}}$

[15] In GK this is introduced through the incentive compatibility constraint, which links banks net worth to the amount of external funds that can be obtained from households.

Table 1
Calibration of model's parameters.

Parameter	Value	Definition	Target
Standard parameters			
h	0.815	Habit	GK
φ	0.276	Inverse Frisch elasticity Labor Supply	GK
η_i	1.728	Elasticity Investment adjustment cost	GK
ϵ	4.167	Elasticity of substitution between goods	GK
γ	0.779	Price stickiness	GK
γ_P	0.241	Price indexation	GK
ρ_i	0.8	Interest rate smoothing	GK
κ_π	1.5	Inflation coefficient	GK
χ	2.651	Labor utility weight	$L = 0.33$
β	0.995	Discount rate	$R = 2\%$
ρ^ζ	0.9	Persistence consumption preference shock	
Specific to our model			
θ	0.3913	Asset diversion	$\frac{R^K}{R^D}; \frac{R^{BB}}{R^D}; \phi$
γ_1	0.228	Asset diversion	
ω	0.0007	Start-up funds new bankers	
σ	0.9507	Survival Probability	
ϱ^{IF}	52	IF Marginal Cost investing in Bank Bonds	$\frac{Bank\ Bonds}{TBL}$
ι	0.8	Feedback IF profits - cost of investing in BB	
α	0.3	Capital Share	$\frac{Sh^{IF}}{THA}; \frac{B}{Sh^{IF}}$
δ	0.03	Depreciation rate	
$\bar{B}$	0.625	IF Satiation point Government Bond	
a	0.95	Households Portfolio Structure	
m	0.04	Share of Deposits invested in Reserves	$\frac{Reserves}{TBA}$

Note: Parameters that are specific to the model are grouped based on the different steady state ratios implied by their calibration.

3.4. Aggregate demand and policy

We define aggregate output as the sum of household consumption, investment and a fixed amount of government consumption, $\bar{G}$.[16] The aggregate resource constraint is therefore given by:

$$Y_t = C_t + I_t + f\left(\frac{I_{nt} + I_{ss}}{I_{nt-1} + I_{ss}}\right)(I_{nt} + I_{ss}) + \bar{G} \tag{16}$$

The model is closed by assuming that the central bank follows a reaction function with interest rate smoothing as in (17).[17]

$$\widehat{i^{st}_t} = i^{st} + \rho^i \widehat{i^{st}_{t-1}} + \left(1 - \rho^i\right)\kappa_\pi \widehat{\pi}_t + \epsilon^m \tag{17}$$

Furthermore, we assume that the central bank uses the nominal reserve rate as its policy instrument by imposing $i^R_t = i^{st}_t$. In the model, all nominal and real returns are linked through the Fisher relation:

$$i_t = \mathbb{E}_t R_{t+1} \pi_{t+1} \tag{18}$$

Finally, it is important to stress that the central bank is able to (partially) control the interest rate on deposits through the reserve rate. As specified in Eq. (8),[18] as long as the policy rate is positive, these two returns are equal. However, the nominal deposit rate is bounded by zero, so the central bank loses the possibility to control this rate when introducing a NIRP. For simplicity we do not micro-found the existence of this lower bound.[19] As shown in Section 2, the interest rate on household deposits has generally remained positive in the EA. Moreover, in some countries the deposit rate cannot fall below a certain limit by law.[20]

[16] Adopting a fixed public consumption is consistent with GK. Setting this parameter to a value higher or equal to zero would not affect the dynamics of the model. We therefore assume $\bar{G} = 0$ in order to simplify the analysis. Since the government is not explicitly modelled, sovereign bonds are defined as assets which earn the (risk-free) return on central bank reserves (i.e., the policy rate).

[17] Notice that (17) is expressed in linearised form and ϵ^m is assumed to be a white noise disturbance.

[18] We report here this relation for simplicity: $R^D_t = \max\left(1, R^R_t\right)$

[19] As suggested by EJSW, it would be possible to micro-found the existence of the lower bound by introducing money in the model and assuming a fixed storage cost for holding cash. In this case, as soon as the return on deposits would fall below this fixed cost, agents would simply withdraw all their cash.

[20] For example, in Belgium banks are by law forced to pay at least 0.11% on savings.

Table 2
Steady State targets.

Variable	Definition	Steady-state	Data
Commercial banks			
$\frac{Dep}{TBL}$	Deposits	68.18%	66.6%
$\frac{BB}{TBL}$	Bank bonds	18.85%	21.8%
$\frac{N}{TBL}$	Net worth	12.97%	11.5%
$\frac{DF}{TBL}$	Reserves	2.80%	1.28%
Households			
$\frac{Dep}{THA}$	Deposits	66.34%	44.0%
$\frac{Sh}{THA}$	Shares	33.6%	33.5%
Spreads			
$R^K - R$	Loans	$0.0241/4$	2.41%
$R^{BB} - R$	Bank bonds	$0.0111/4$	1.11%

TBL= total bank liabilities; THA = total household assets.
Note: Data on bank liabilities have been re-scaled excluding the inter-bank borrowing and other assets. Among bank assets we have considered only loans (excluding MFI), reserves and securities. Spread figures relate to the average ones in 2014.
Source: ECB data (spreads, banks assets and liabilities in 2014) and ECB (2016).[21,22]

4. Calibration

This section presents the calibration of the model used for the simulation exercises reported in Section 5.

As our model is an extension of GK, we follow their calibration for parameters that are not specific to our analysis. As shown in Table 1, these parameters concern the consumption habit, h, the labour supply elasticity, φ, the elasticity of the investment adjustment cost, η_i, the interest rate smoothing coefficient, ρ_i, the Taylor Rule inflation coefficient, κ_π, the elasticity of substitution between goods, ϵ, as well as the price stickiness and the degree of price indexation, γ and γ_P respectively. Moreover, we set steady state labor to match the average amount of hours worked, and calibrate the labour utility weight, χ, accordingly. The value of the discount rate, β, implies a 2% annual real interest rate in steady state.

The other parameters that are related to the financial structure are calibrated to match key ratios in EA household and bank balance sheets and associated interest rate spreads, as listed in Table 2. First, in order to easily solve for the steady state of the model, the spread between the bank loan and deposit rate in 2014 (2.41%), as well as the spread between the interest rate on bank bonds and the deposit rate (1.11%), and bank leverage (7.5, or a net worth to total bank liabilities ratio of 13%), together with the calibration of bankers' survival probability σ, are used to pin down ω, the start-up funds of new bankers, and the two parameters characterizing the incentive compatibility constraint, θ and γ_1. Targeting a leverage ratio that is different from the one in GK implies a somewhat different combination of σ and θ, although both parameters are reasonable and relatively close to those used in GK.

Second, the ratio of bank bonds to total bank liabilities of 18.9% (Table 2), together with the spread between the bank bond and deposit rate, determines the calibration of the two parameters of the bank bond investment cost function for investment funds (ϱ^{IF} and ι).

Third, the capital share, α the depreciation rate δ and the investment fund satiation point for holding government bonds, $\bar{B}$, mostly determine the steady-state shares of deposits and bank and government bonds in the asset portfolio of households. Note that it is assumed that investment funds are satiated in government bond holdings at the steady state, such that $B = \bar{B}$. This implies that investment shares and government bonds have the same return in steady state. The calibration of $\bar{B}$ also defines the share of government bonds in the investment fund, which is roughly 50%. This underestimates the amount of government bonds held by investment funds.[23]

Fourth, we choose a relatively high value of 0.95 for the parameter a, which determines the household cost of deviating from its steady state portfolio structure. This high value is meant to capture the fact that the composition of the asset portfolio of households has been very stable over time. The share of deposits in total household assets varied only from

[21] The equilibrium level of net worth as a share of total bank liabilities is consistent with a leverage of 7.5.

[22] Data for the ratio between shares and THA relates to the sum of "pension/life insurance" (24%) and "mutual funds" (9%). Other components of households, portfolio are bonds (5%), shares (7%) and other assets (11%)

[23] It is important to stress that the higher this parameter, the more effective the NIRP in stimulating the economy. Section 5.3, discusses the sensitivity of our results to different calibrations of $\bar{B}$.

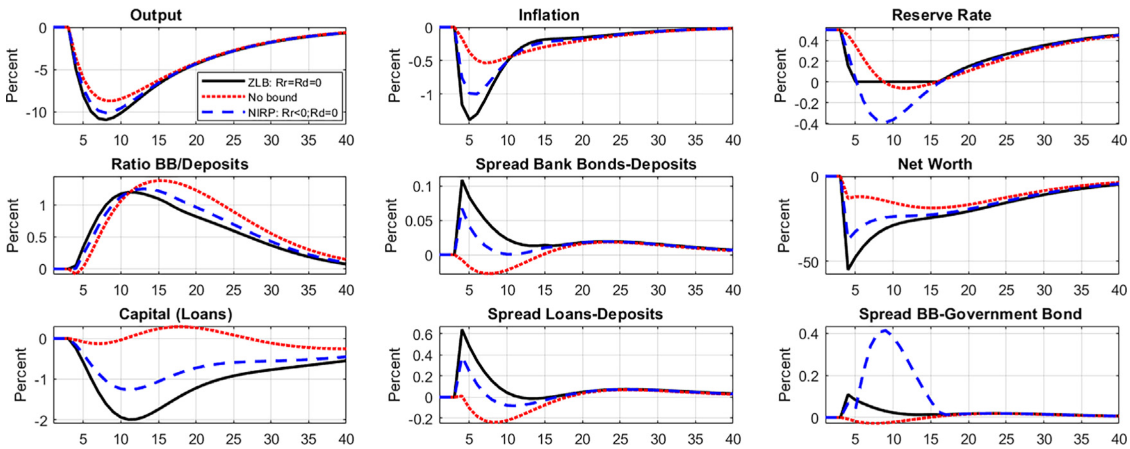

Fig. 3. IRFs complete model.
Note: panel showing responses to a recessionary shock in the case of a ZLB and a NIRP scenario.

44.2% to 43.7% between 2014 and 2017, whereas the share of investment funds varied between 33.5% and 33.9% over the same period (see ECB, 2016 and 2020). In the sensitivity analysis, we show how the results change when adjustment costs are lower (see Section 5.3).

Finally, the share of deposits to be invested in central bank reserves, m, is set at 4%. This is four times the regulatory minimum reserve requirement and more than double the reserve ratio in 2014 (see Table 2). The expansion of the central bank balance sheet after the introduction of the large-scale asset purchase programs in early 2015 resulted in a notable increase in the proportion of reserves in the balance sheets of banks. Since this parameter defines the exposure of banks to the NIRP in our model, we investigate the sensitivity of our results to different calibrations of this parameter in Section 5.3.[24]

5. Numerical simulations

To induce a recession that causes a lower bound on interest rates, we introduce a negative consumption preference shock with a persistence parameter of 0.9.[25] In Section 5.1, the effectiveness of a NIRP is analyzed by comparing the response of the economy under three policy scenarios. We then compare the effects on output, bank profitability, loan supply, and inflation between the baseline model and two alternative versions to evaluate the relative importance of the intertemporal substitution channel and the bank bond financing channel in Section 5.2. Finally, the sensitivity of our findings to different calibrations of critical model parameters is discussed in Section 5.3.

5.1. The baseline model

Fig. 3 shows the response of the economy in our calibrated model under three different policy scenarios. In the first scenario, both the policy and the deposit rate can be negative (red dotted line, ‘*No Bound*’). The second represents a standard ZLB scenario, where both the policy rate and the deposit rate are bounded by zero (black solid line, ’*ZLB*’). The third scenario is most closely related to the NIRP era that we have observed after 2014 (blue dashed line, ’NIRP’). In this scenario, the policy rate can be negative, while the deposit rate is bounded by zero. These scenarios allow us to investigate the effectiveness of a NIRP.

When comparing the response of output in the NIRP scenario to the ZLB case, which is shown in the upper left panel of Fig. 3, it appears that the NIRP is effective in partially mitigating the negative output effects of the recessionary shock. Specifically, the response of output in the NIRP case remains consistently higher than in the ZLB case during the binding constraint periods. The policy rate reaches a minimum of -0.4% after about six quarters in this scenario. Fig. 3 also reveals that inflation responds less negatively to the shock under the NIRP policy. While the NIRP does not fully restore the path of the economy that would prevail when there is no ZLB on the deposit rate (red line), it significantly reduces the associated output and deflation costs by about 35%.

[24] Note that the value of holding reserves or other liquid, negative-interest-rate-yielding assets, has not been modelled. Banks often hold such assets as they provide benefits (for instance in terms of liquidity and collateral pledgeability) that are not accounted for in our model.
[25] Qualitatively similar results can be achieved using a capital efficiency shock as in GK or a risk premium shock as in De Groot and Haas (2020) to generate the recession.

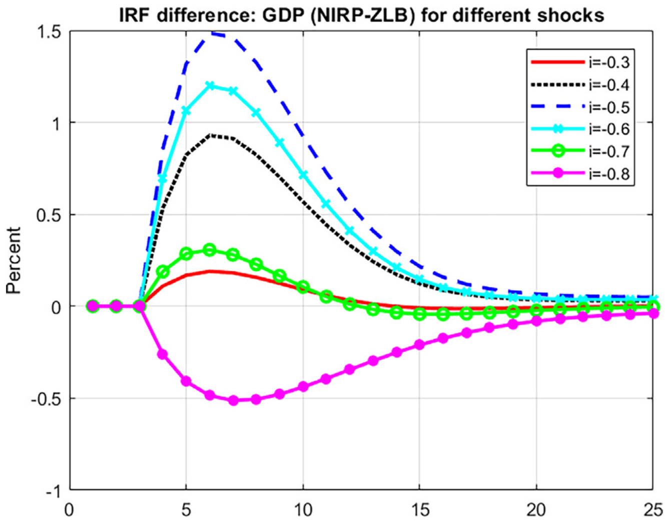

Fig. 4. Comparison across different shocks.
Note: The figure shows the difference between responses in the NIRP and in the ZLB scenario for six recessionary shocks having diverse intensities.

It is worth noting that this effectiveness of the NIRP comes on top of the other mechanisms highlighted in the introduction, such as those presented in Ulate (2021). In addition, the capacity to alleviate the costs is contingent upon the size of the shock and the extent to which policy rates must be lowered in negative territory. Fig. 4 shows that there is a reversal rate at -0.8% in the calibrated model. This implies that when the magnitude of the shock requires such a substantial negative response, the resulting decrease in bank profitability and erosion of bank net worth becomes so large that the implementation of a NIRP becomes counterproductive.

To gain insight into the mechanisms that explain the effectiveness of a NIRP in stimulating the economy, it is helpful to examine the liability side of banks. The second row in Fig. 3 shows the impulse responses of the ratio of bank bonds to deposits, the bank bond-deposit interest rate spread, and bank net worth. In the NIRP scenario, the ratio of bank bonds to deposits is higher than in the ZLB scenario. Moreover, the spread between the returns on these two assets is lower in the NIRP scenario, indicating that bank bond funding becomes relatively cheaper. However, the response of this spread is positive, as bank bonds remain more costly than deposits also outside the steady state. This difference does not vanish when the deposit return reaches its lower bound.

Two key factors need to be considered to understand why banks issue more bank bonds during a NIRP period. First, market funding sources are cheaper under NIRP compared to the ZLB, which is reflected by a weaker response of the bank bond-deposit spread in the NIRP scenario. This feature of the model aligns with the empirical evidence of Bottero et al. (2019), who show that the NIRP has the ability to flatten the yield curve. It implies that bank bonds are more appealing. Second, the incentive compatibility constraint faced by banks should also be analyzed. As market funding is a tool for monitoring bank risks, we have assumed that the share of divertible assets, $\Theta\left(F_t; \theta, \gamma_1\right)$, is a decreasing function in the amount of loans funded by bank bonds. Therefore, banks are willing to bear higher funding costs as long as it affects their incentive compatibility constraint. When net worth decreases, banks issue more bank bonds to relax the constraint. In Eq. (5), $\Theta\left(F_t; \theta, \gamma_1\right)$ represents the ratio between the franchise value of the bank and the value of loans granted.

The third row of Fig. 3 shows the response of loans (which is equal to the capital stock), as well as the spread between loan and deposit rates, and the spread between bank bond and government bond returns. The figure demonstrates that the more subdued decline in bank net worth in the NIRP scenario results in a more moderate rise in the cost of borrowing compared to the ZLB case. This moderate increase in the cost of borrowing is associated with a less substantial decrease in lending.

Finally, how do investment funds respond to the shock? As discussed in Section 3, investment funds hold government bonds and fund banks by investing in bank bonds. Fig. 3 shows that the response of the spread between bank bonds and government bonds is higher in the NIRP scenario compared to the ZLB scenario. This difference renders the NIRP more appealing to investment funds, which is an incentive to adjust their portfolio towards bank bonds.

Overall, two key elements explain the additional transmission channel of the NIRP through the financial sector and its enhanced effectiveness in our model. On one hand, market-based funding becomes more attractive for banks after the policy implementation. Such assets become cheaper and it allows banks to relax their incentive compatibility constraint and increase their leverage when net worth decreases. This, in turn, reduces the cost of borrowing for firms. On the other hand, investment funds find investing in bank bonds more lucrative as the introduction of negative rates lowers the yield of risk-free assets. Consequently, rebalancing investment portfolios towards bank bonds is a strategy to maintain their profitability.

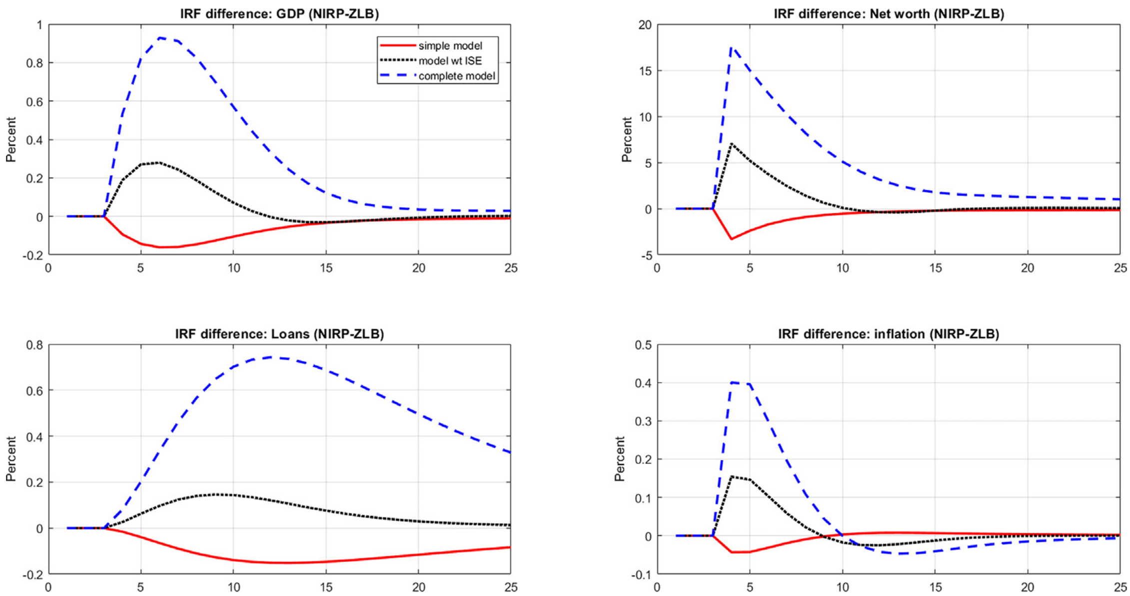

Fig. 5. Comparison across models.
Note: Panels show the difference between responses in the NIRP and in the ZLB scenario for three versions of the model.

5.2. The intertemporal substitution and bank bond financing channel

To investigate the relative importance of the bank bond financing channel and the intertemporal substitution channel, we compare the effectiveness of the NIRP in mitigating negative output effects in three versions of the model. The first version (broken blue line) is the baseline version of Section 5.1 that includes both channels. The second version (solid black line) assumes that investment funds solely invest in government bonds, thereby eliminating the bank bond financing channel. The return on government bonds is equal to the policy rate. Similar to the baseline model, households prefer holding both assets. As in Andrés et al. (2004), we assume that it is costly for households to deviate from their preferred ratio between deposits and government bonds. Hence, it is optimal to hold a combination of both assets, even if the return on one of them is negative. As a result, the intertemporal substitution channel will be operative, in contrast to EJSW. Finally, the third version of the model (solid red line) assumes that households only save in deposits. When the deposit rate remains at zero, households will not experience any change in the interest rate, even if the policy rate falls further. This model also eliminates the intertemporal substitution channel.[26]

Fig. 5 presents the results from our model comparison exercise for output and net worth. A number of conclusions can be drawn. First, the absence of both channels leads to a contractionary effect on output and bank net worth when the NIRP is implemented. Similarly to EJSW, banks cannot transmit the policy rate reduction to depositors due to the lower bound, resulting in unresponsive household consumption and savings. Furthermore, if central bank reserves generate negative returns, and banks cannot impose negative interest rates on depositors, their profitability declines, thus negatively affecting net worth. As a result, banks raise the interest rate on loans, leading to an adverse impact on output. Second, this contractionary effect of the NIRP disappears when allowing for an intertemporal substitution effect (black line). In this scenario, households temporarily face a lower return on their portfolio due to negative interest rates on government bonds, prompting them to increase consumption and thus output, offsetting part of the negative effects of the recessionary shock. Finally, the favorable effects on output are bolstered to almost 1pp when we also allow for a bank bond financing channel, as in the calibrated baseline model. As discussed above, banks can partially reduce their funding costs, increase profitability and ease their leverage constraint by issuing bank bonds. In the calibrated model, the bank bond financing channel accounts for approximately two-thirds of the effectiveness of the NIRP in alleviating the output cost of the recession.

5.3. Sensitivity analysis

This section analyzes the sensitivity of results to different calibrations of some of the important model parameters. In particular, we discuss the consequences of assuming different values for the reserve share, m, and the parameter that defines households' portfolio adjustment cost, a. We also analyze the general equilibrium implications of investment funds facing

[26] The models are compared by simulating a shock that corresponds to a policy rate response of -0.4%. The calibration is the same for all parameters that are common for the three models, except the survival probability, σ. Since its calibration affects the one of θ (i.e., one of the parameters that enters the incentive compatibility constrained described in (5)), we have adjusted σ in order to obtain the same θ in all models.

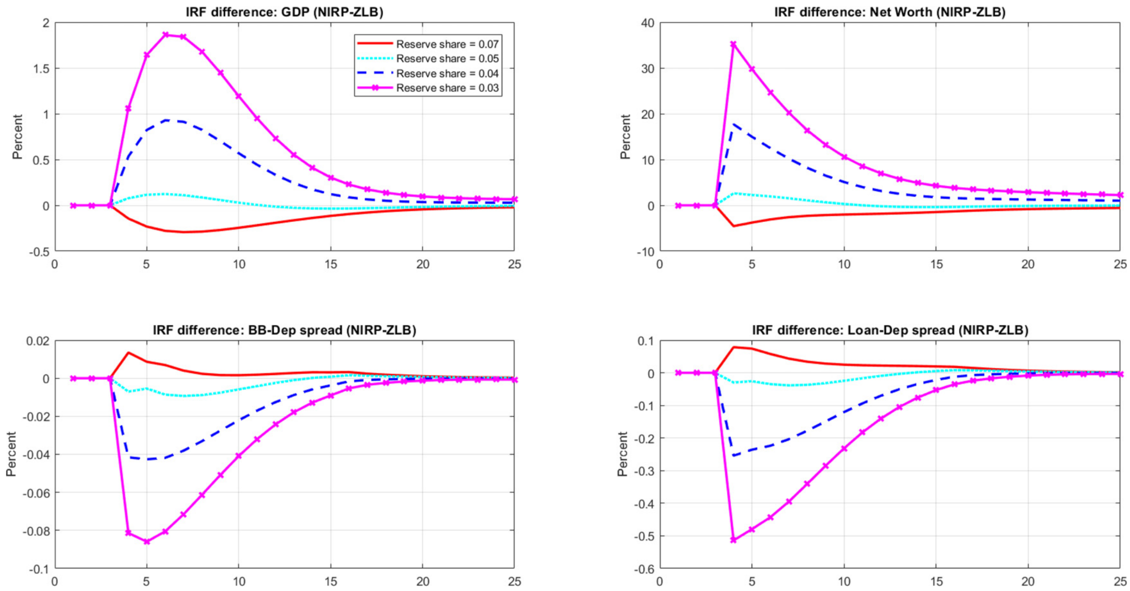

Fig. 6. Sensitivity to reserve share, *m*.
Note: Panels show the difference between responses in the NIRP and in the ZLB scenario for different calibrations of the reserve share, *m*.

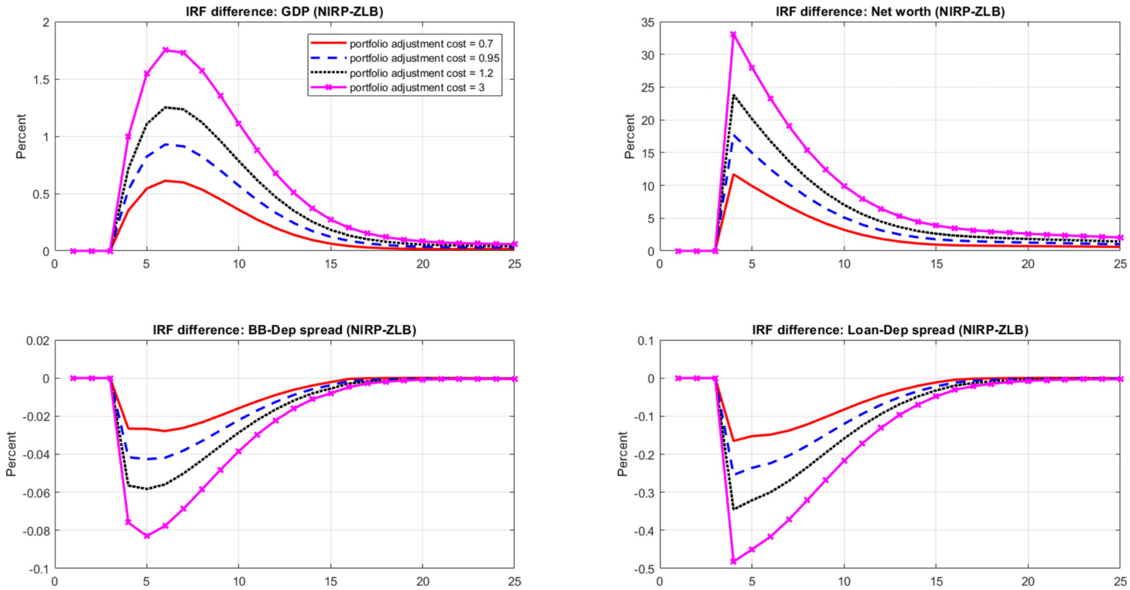

Fig. 7. Sensitivity to household portfolio adjustment cost, *a*.
Note: Panels show the difference between responses in the NIRP and in the ZLB scenario for different calibrations of the household portfolio adjustment cost, *a*.

different monitoring costs for investing in bank bonds, ϱ^{IF}, and different satiation points for their government bond holdings, $\bar{B}$. Fig. 6 to 9 show the difference between the responses under the NIRP and the ZLB scenarios of four key variables: output, net worth, bank bond-deposit and loan-deposit spreads.

Fig. 6 shows that, the higher the reserve share, the stronger the negative impact of the policy on bank profitability and the weaker the effectiveness of the NIRP. More specifically, the difference between the output responses turns negative when m reaches 7% of deposits. The net worth of banks exhibits a similar response. In contrast, the difference in the IRFs of the bank bond-deposit spread and the loan-deposit spread are increasing in the reserve share.

Fig. 7 reveals that, the smaller the portfolio adjustment cost for households, the more limited the effects of a NIRP on bank net worth and output and the weaker the bank bond financing channel. Since the return on investment fund shares can reach negative values, households move their savings towards deposits when the cost for deviating from the equilibrium portfolio is negligible. In such a scenario, the investment funds have limited resources to invest in bank bonds, which implies

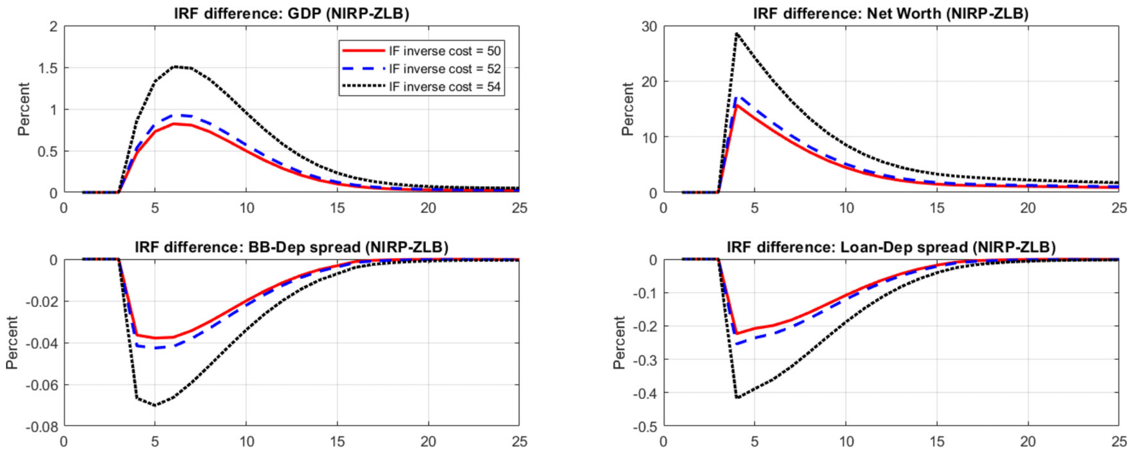

Fig. 8. Sensitivity to investment fund cost for investing in bank bonds, ϱ^{IF}.
Note: Panels show the difference between responses in the NIRP and in the ZLB scenario for different bank monitoring costs faced by the investment funds, ϱ^{IF}.

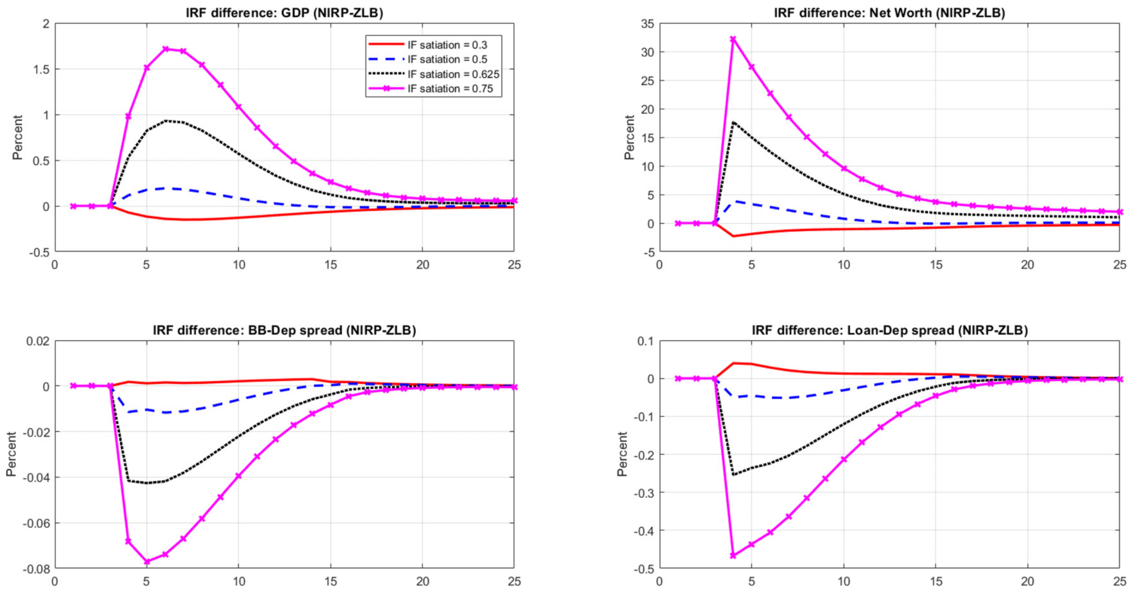

Fig. 9. Sensitivity to invetsment fund satiation of risk-free asset holdings, $\bar{B}$.
Note: Panels show the difference between responses in the NIRP and in the ZLB scenario for different calibrations of the risk-free as a share of total assets held by investment funds in equilibrium, $\bar{B}$.

a smaller reduction in bank funding costs and a weaker loosening of the banks' incentive compatibility constraint. As a consequence, differences in output and net worth responses are increasing in a, while both spreads are decreasing in this parameter.

Fig. 8 depicts the sensitivity to the inverse of the investment fund cost of investing in bank bonds. As can be observed in the figure, the higher the value of ϱ^{IF} (i.e., the smaller the monitoring cost), the higher the incentive for investment funds to rebalance their portfolio towards bank bonds and the stronger the effectiveness of the NIRP in stimulating the economy.

Finally, Fig. 9 documents the importance of portfolio rebalancing by the investment fund for the effectiveness of a NIRP. The panels show the sensitivity to different satiation points for government bond holdings, $\bar{B}$. The higher this parameter, the stronger the incentive for investment funds to rebalance their assets towards bank bonds and the more effective the NIRP. In contrast, when investment funds hold too few negative yielding assets, the NIRP generates a contractionary effect.[27] In

[27] The red solid lines in Fig. 9 correspond to the case in which risk-free assets account to around 30% of the investment fund's balance sheet in equilibrium.

this case, their demand for bank bonds is weak, bank funding costs are only marginally affected and the negative effect of the NIRP on bank profitability dominates.

6. Conclusions

Investigating the effectiveness of the NIRP in the euro area is the main objective of this paper. We provide empirical evidence that in spite of a zero-lower-bound on household deposit rates, the ECB's NIRP reduced bank lending rates and stimulated the volume of bank lending. This is partly due to the operation of a bank bond financing channel. As documented in Section 2, a reduction in the ECB deposit rate reduced the spread between bank bond yields and household deposit rates and stimulated the issuance of bank debt securities relative to household deposit funding.

We then develop a New Keynesian model with a financial sector that allows for both market and deposit funding. When calibrating such a model to the euro area, the bank bond financing channel may overturn the negative impact of a NIRP on bank profitability, lending and economic activity as highlighted in EJSW. Because households hold investment funds in addition to bank deposits, this model also restores the intertemporal substitution channel, which is missing at the ZLB when bank deposits are the only vehicle for saving. The strength of the intertemporal substitution and bank bond financing channels depends on key features of the model economy such as the portfolio adjustment costs faced by households and the bank monitoring costs faced by investment funds. The transmission channels of a NIRP highlighted in this paper are complementary to the signalling channel proposed by De Groot and Haas (2020) and the imperfect competition channel highlighted by Ulate (2021).

In future work various extensions could be explored. First, this paper assesses the effectiveness of the NIRP in a closed economy model abstracting from the impact of a NIRP on the exchange rate. The exchange rate channel may be another important channel determining the effectiveness of a NIRP. Second, we do not explicitly model the reasons for a ZLB on household deposit rates and abstract, for example, from the possibility of banks charging fees on households instead of setting negative deposit rates. Third, we do not take into account interactions with other policy measures. For example, introducing large scale asset purchases would enable to analyze the interactions and possible synergies between these two unconventional policies.[28]

Data availability

Data will be made available on request.

Supplementary material

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jmoneco.2023.07.002.

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[28] This topic has been addressed in Sims and Wu (2021).

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