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THE EFFECTIVENESS OF A NEGATIVE INTEREST RATE POLICY

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The Effectiveness of a Negative Interest Rate Policy*

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Abstract

We analyze the effectiveness of a Negative Interest Rate Policy (NIRP) in a quantitative Dynamic Stochastic General Equilibrium model for the euro area with a financial sector. Similarly to other studies in the literature, we show that a NIRP can have a contractionary effect on the economy when there is a zero lower bound on the interest rate of household deposits, and such deposits are the only source of bank funding and household savings. However, we show that the contractionary effects vanish and the NIRP becomes expansionary when we allow for additional assets in the savings portfolio of households, and when we introduce alternative sources of bank funding in the model, such as bank bonds. These two features, which characterize the euro area very well, are hence essential to study the effectiveness of a NIRP.

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1 Introduction

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

The effectiveness of a NIRP in stimulating the economy, however, has come under scrutiny. In particular, Brunnermeier and Koby (2019) and Eggertsson et al. (2019) - hereafter EJSW - have pointed out that a NIRP may compress bank interest rate margins as long as banks are unable to pass on the reduction in the reserve rate to depositors, e.g. due to a zero lower bound. As a consequence, a NIRP leads to a decline in banks' profitability, which under some conditions might result in undesired contractionary effects on credit supply or an increase in bank lending rates.[2]

In Brunnermeier and Koby (2019), a NIRP has contractionary effects on the economy when liquidity and capital constraints of the banking sector bind. In such a situation, the reduction in bank profits negatively affects net worth and translates into a decline of the volume of loans. If the capital constraint does not bind, the policy rate passes through to the loan rate and the supply of credit increases. However, the increase in lending and the reduction of profits may still reduce the bank's net worth and eventually imply a binding capital constraint, that reduces bank lending. In EJSW, a NIRP always yields aggregate contractionary effects as it negatively affects the spread between the interest rate on reserves and the interest rate on household deposits, which are bounded by zero. The reduction in bank profitability leads to a tightening of bank lending rates.

In both studies, two implicit model assumptions are key for the contractionary result.[3] First, the only savings vehicle for households are bank deposits, which implies that the introduction of a NIRP does not affect the household consumption and savings decision. In particular, as long as households only save through deposits, and the returns on these deposits are bounded by zero, they do not react to cuts in the policy rate below zero. Second, household deposits are the only funding source of the financial sector. As a result, banks cannot benefit from the reduction in market rates

[1] The ECB's deposit facility rate currently stands at -0.5%. In September 2019, the ECB introduced a tiering system by which a part of excess reserves are remunerated at the Main Refinancing Rate, which currently stands at 0%.

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

[3] A third important implicit assumption is that firms can only borrow from banks and do not have alternative funding sources. We do not relax this assumption in this paper.

that are related to a reduction in the policy rate. Negative rates then act like a tax as they only, negatively, affect a bank's profitability. Accordingly, the NIRP triggers an increase in the lending rate and reduces aggregate demand.

Other theoretical papers analyze different channels and find more positive results.[4] In a recent contribution, Ulate (2021) finds that a NIRP is "between 60 and 90 percent as effective as monetary policy in positive territory". Specifically, its effectiveness depends on two contrasting channels, which affect the behavior of the lending rate. In his model, banks have some monopoly power and the return on loans (deposits) is set as a mark-up (mark-down) on the policy rate. Because of the presence of a profit margin in the loans market, reductions in the policy rate transmit to the lending rate. However, this expansionary effect is hindered by a drop in banks profitability. As long as banks lose deposits when offering a negative return for them, the deposit spread drops, banks equity deteriorates and the leverage increases. Since banks willingness to lend depends on their equity and they are less inclined to provide credit when the leverage is high, this has a positive impact on the lending rate. Overall, the effectiveness of a NIRP depends on the relative importance of these two channels.[5]

In this paper 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. Similarly to Ulate (2021) we allow bank lending to be influenced by the value of the bank,[6] but we do not study the implications of monopoly power.[7] We calibrate our model to euro area (EA) data in order to capture two key characteristics. First, while deposits are the main financial assets held by european households (44% of households financial assets[8]), they also rely on other saving vehicles, such as bonds (5%), shares (7%), mutual funds (9%), pension funds (24%) and others assets (11%), whose returns are likely affected by a NIRP. EA data show that there is not a great substitutability between deposits and these other savings vehicles. Their relative shares in households' portfolio have not changed substantially after the introduction of negative rates. Second, household deposits are not the only source of bank funding in the EA. In 2014, households' deposits amounted to more

[4] De Groot and Haas (2019) and Sims and Wu (2021) show that a NIRP might help the economy as long as the central bank credibly commits to maintain the policy in place for a long period. In this respect, Sims and Wu (2021) suggest that the NIRP could be seen as a particularly credible type of forward guidance, which requires for the central bank to act, instead of simply announcing future interventions.

[5] In a related paper, Gerke et al. (2021) assess the effectiveness of the NIRP through a medium-scale DSGE model featuring both these contrasting channels. On the one hand, the NIRP stimulates the economy by reducing borrowing costs. On the other hand, it squeezes banks' profitability, thereby weakening the supply of loans. They estimate the model based on EA data and highlight an overall positive effect of the NIRP.

[6] We incorporate this feature through the agency problem described in Gertler and Karadi (2011), while in Ulate (2021) banks face costs for deviating from a target level of the loan-equity ratio.

[7] Another difference with respect to Ulate (2021) is that we assume banks to hold reserves at the central bank because of a reserve requirement (see also De Groot and Haas, 2019 and Sims and Wu, 2021). On the contrary, in Ulate (2021), banks face a downward sloping demand for loans. Therefore, it is optimal for them to limit the amount of loans offered by holding funds which are not employed as reserves at the central bank.

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

than 50% of european banks liabilities, while the wholesale funding was roughly 17%.

On the modelling side, we extend the mechanism proposed in EJSW by introducing two types of financial intermediaries: commercial banks (CBs) and investment funds (IFs). The modelling of the CBs builds on Gertler and Kiyotaki (2010), Gertler and Karadi (2011) - hereafter GK - and Gertler et al. (2012). We follow Curdia and Woodford (2016) and EJSW in modelling the IF. In line with the empirical literature, we assume that only the household deposit rate is bounded by zero.

The financial sector is characterized by two main features. First, households consume, supply labor, and save through both CB deposits and IF shares. The optimal allocation between these two assets is obtained by assuming portfolio adjustment costs, which reflect a preference for holding different varieties of assets as a means of saving (Andres et al., 2004). As the return on IF shares can fall when market rates turn negative, this extension restores the intertemporal substitution channel of monetary policy, which could offset the negative effect through the commercial banking sector. Second, following Gertler et al. (2012), we assume that CBs fund their activities through household deposits and alternative market funding, which we label as bank bonds. Moreover, following Meeks et al. (2017) and Mazelis (2016), we allow IFs to invest in those bank bonds, thereby providing alternative market funding. Allowing market funding of banks is a second reason why the transmission channel of negative interest rates on commercial banks may be positive.

We tentatively calibrate the model to EA bank balance sheet and interest rate spread data and simulate it using Occbin (Guerrieri and Iacoviello, 2015). We analyze responses to a negative consumption preference shock that leads to a binding zero interest rate on household deposits. We compare a standard Zero Lower Bound (ZLB) scenario, in which all interest rates are bounded by zero, to a case in which the policy rate goes negative, while the return on household deposits remains bounded. To illustrate the transmission channels of the NIRP, we analyze three different versions of the model. First, we simulate a model which is similar in spirit to EJSW. Bank deposits are the only means by which households save and there are no IFs. In this case, the aggregate contractionary effect discussed in EJSW arises. Second, we allow households to hold (negative yielding) risk-free assets as well as bank deposits. This gives rise to an intertemporal substitution effect in the consumption decision and with our calibration the aforementioned contractionary effect disappears. Third, we study the behavior of the full model characterized by both CBs and IFs. In this case, the positive effects of NIRP are further enhanced relative to the ZLB case and the contractionary effect disappears. As in this case IFs have an incentive to rebalance their portfolio from riskless government bonds to bank bonds, the 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 CB profitability, and the stronger the transmission mechanism.

We analyze the sensitivity of these results to changes in the key parameters of the model. Not surprisingly, the positive output effects of a NIRP are larger the lower the excess liquidity ratio of the CB sector, the higher the marginal cost of adjusting the households' portfolio towards household deposits, the lower the marginal cost of monitoring bank bonds by investment funds and the higher the IFs government bond holdings in equilibrium. Overall, we conclude that the NIRP is effective in stimulating the economy if the alternative channels of transmission are large enough to offset the negative effect of the zero lower bound on household deposit rates on bank's net worth.

This seems to be consistent with the empirical evidence on a positive pass-through of negative interest rates and the positive effects on lending and the economy, which will be discussed in Section 2.

The rest of the paper is structured as follows. Section 2 outlines some facts which motivate our modelling choices and surveys the empirical literature which is related to our paper. Section 3 describes the main features of the model. Next, we describe our calibration in Section 4. Results of our numerical simulations are reported and discussed in Section 5, while Section 6 concludes.

2 Empirical literature and some stylized facts

This paper contributes to the literature exploring the effectiveness of unconventional monetary policies and their transmission to the real economy.[9] The introduction of negative policy rates in a number of advanced economies has stimulated research aimed at shedding light on the effectiveness of such a measure. In addition to the theoretical papers discussed in the introduction, the effectiveness of a NIRP has also been explored from an empirical perspective. As briefly mentioned, these empirical studies generally find that negative policy rates have been passed through to bank lending rates and have stimulated bank credit and the real economy.[10] Eisenschmidt and Smets (2019) review the available evidence for the EA and conclude that there is very little sign of adverse effects. Similarly, Altavilla et al. (2018) and Lopez, Rose and Spiegel (2020) find that banks pass on interest rate cuts to lending rates also when policy rates move into negative territory and that negative rates do not adversely affect bank profitability once its positive macroeconomic effects are taken into account. In the same strand of literature, Ampudia and Van den Heuvel (2018) analyze the reaction of EA bank stock prices to ECB monetary policy announcements. They show that unexpected increases in short term rates reduce bank stock prices. However, this effect is time

[9]The functioning of these policies is a topic which has been extensively analyzed both from an empirical (Kashyap and Stein, 2000; Andrade et al., 2016; Altavilla et al., 2020; Boeck et al., 2017) and a theoretical point of view (GK, Gertler et al. 2012; De Fiore and Tristani, 2019; Coenen et al., 2018; Coenen et al., 2019 among many others) in the last 20 years.

[10]It has to be noticed that the empirical literature on this topic is substantially increasing and there are also papers which suggests different results (see for instance Goodhart and Kabiri, 2019).

varying, as it reverses in the NIRP period. Because of banks reluctance to charge negative rates to depositors, banks profitability drops. This effect is stronger for banks that rely more on deposits funding. However, they also show that accommodative monetary policies do not have negative effects on banks profitability per se. These interventions also reduce long-term rates, which has positive, large and significant effects on banks equity values in the NIRP period. The importance of deposit funding in the transmission of negative rates has been documented also by Heider et al. (2018). They find that banks responded to a NIRP expanding their loan portfolio towards riskier firms. In particular, high-deposit banks increased their risk taking more than low-deposit banks, which instead provided relatively more credit. The search for yield undertaken by high-deposit banks has a positive effect on the real economy as it relaxes firms' credit constraints, thereby avoiding credit rationing. Bottero et al. (2019) analyze the effect of a NIRP using Italian administrative data. Differently than Ampudia and Van den Heuvel (2018) and Heider et al. (2018), they analyze a different transmission mechanism, which highlights the role of liquidity. They show that the policy has been effective in stimulating lending through a portfolio rebalancing effect. In particular, banks with liquid balance sheets rebalance their portfolio from liquid assets to credit, mainly granted to smaller and riskier firms. A similar transmission channel is also discussed in Demiralp et al. (2017). They test whether the (negative) effect on bank profitability due to the zero lower bound on deposit returns is compensated by the portfolio rebalancing effect discussed above. They identify the impact of a NIRP on banks in the cross section by interacting a bank's holding of excess liquidity with its deposit ratio. This strategy allows to take into account both effects. On the one hand, the greater the deposit ratio, the larger the profitability loss. On the other hand, the higher the amount of excess liquidity held, the stronger the incentive to rebalance the portfolio towards higher-yielding assets. Their results show that high-deposit banks which also hold more excess liquidity reacted the most to the policy, increasing their lending. The heterogeneous response of banks depending on their characteristics is also discussed in Mendicino et al. (2021). They show that the overall effect of the NIRP on borrowing conditions is not significantly different from the one of interest rate cuts in positive territory. However, the pass-through is strong for banks having an high (ex-ante) deposit rate, while intermediaries offering a low deposit rate are on average less responsive to the policy. Finally, Altavilla et al. (2019) find that healthy banks are able to pass on negative rates to corporate depositors without experiencing a shortening of funding. In particular, banks which are able to do so increase their credit more than other banks. Moreover a NIRP has positive effects on the economy as firms which get charged for their deposit holding increase their investment in tangible and intangible assets and reduce their cash holding.

After having discussed the results of empirical studies, we now review some facts for the EA that are key to evaluate the transmission channels of a NIRP in this paper. The first fact is that, after the introduction of a NIRP, there has been a pass through, albeit not perfect, to bank loan rates. In Figure 1, we report the deposit facility rate, the interest rate on loans to households and firms as well as the return on deposits held by these agents in the 2003-2019 period in the EA. The part highlighted in grey represents the time period in which the ECB introduced NIRP and lowered its deposit facility rate from 0% to -0.5% most recently. As this figure shows, bank loan rates to households and firms continued to fall after the introduction of the policy. Therefore, EA data do not seem to confirm the increase in the cost of borrowing suggested by EJSW. At the same time, Figure 1 does confirm the existence of a ZLB on the deposit rate.

The second fact which is important to stress is that in the EA other sources of bank funding than deposits represent a substantial share of banks liabilities. Figure 2 shows the composition of the liabilities of the EA banking sector in 2014. The largest share of bank liabilities is represented by household deposits, which account for more than 50% of the total. However, wholesale funding represents 17% of banks' liabilities, which makes it a significant source of bank funding. Therefore, the equilibrium on the market for these assets should not be ignored as it could affect banks' decisions. Moreover, relying on a larger set of financing sources could play an important role in the transmission of the NIRP. In this respect, Heider et al. (2018) underline that the effect of the policy is stronger on banks which rely mainly on deposits, while Tan (2019) finds that banks which are mostly affected by the policy increased their lending even more than other intermediaries.

A third relevant piece of evidence is the effect that a reduction of the deposit facility rate into negative territory has on the yield of bank bonds and other market funding. In Figure 3, we compare returns on bank bonds and deposits in the 2006-2019 timeframe. As the figure shows, although the return on bank bonds is much more volatile than the one on deposits, it dropped substantially after the introduction of the NIRP. This evidence is in line with Bottero et al. (2019), which suggests that the NIRP has shifted down the yield curve for bank bonds. Therefore, for banks relying on other liabilities than deposits, the NIRP reduces costs by lowering the return on the wholesale funding. As shown by Mendicino et al. (2021), these bank have reduced their loan rate more than banks funded mainly by deposits.

Finally, the last fact relates to the composition of household assets. Figure 4 summarises the relative shares of financial assets held by households as reported in ECB (2016). As depicted in the figure, deposits represent the largest share of assets held by households, but it is not the only means of saving. Specifically, pension and life insurance, mutual funds, securities and bonds, whose returns are generally affected by a NIRP, represent a non-negligible share in the composition of households' portfolio. A comparison between the first and the second wave of the household's finance and consumption survey (ECB, 2016) shows that the share of deposits in total financial assets remained almost constant throughout this period. 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 to the extent that there is heterogeneity in the effect that the NIRP has on different types of financial assets. If the returns on other financial assets than deposits do respond to a NIRP, it can restore the intertemporal substitution effect of monetary policy.

3 The model

In this section we describe the model that will be used for the numerical exercise reported in Section 5.

We introduce a financial sector in a fully micro-founded DSGE model in the spirit of Smets and Wouters (2003, 2007). The model features non-linearities stemming from the existence of occasionally binding constraints on the nominal return on deposits. The economy is inhabiteb by households, firms, CBs, IFs and the central bank. The way households, firms, and the public sector are modelled follow closely GK. The only substantial difference concerns households, whom we assume can save through CB deposits and IF shares.

As to the supply side, we do not depart substantially from other papers in this literature, allowing for the existence of three type of firms: capital, intermediate and final good producers, respectively. The model is closed by a central bank which determines the short-term interest rate as a function of inflation.

The main novelty is the financial sector, which is assumed to be populated by CBs and IFs. These two agents are connected through an asset, bank bonds, which is issued by CBs 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 IF decision problem is similar to the one described in Curdia 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, 2019) and are the only intermediary which can originate loans to capital producers. IFs are funded through shares (held by households) and hold risky assets (i.e., bank bonds) and risk-free assets (i.e., government bonds).

Two main characteristics are crucial for the functioning of the transmission mechanism of the NIRP, which we explore in this paper.

First, allowing households to save through IF shares in addition to CB deposits restores the intertemporal substitution effect of monetary policy at the ZLB. Such a feature would not be present if households were allowed to hold only deposits, the return of which is constrained by the lower bound.

Second, the possibility of banks to fund themselves through bank bonds dilutes the negative effect of NIRP on banks profitability presented in EJSW - i.e., the adverse effect that the negative return on central bank reserves poses on bank's profitability. More specifically, after the introduction of the NIRP, CBs substitute deposits by bank bonds. At the same time, there is a rise in the availability of bank bonds due to a portfolio rebalancing effect on the asset side of IF balance sheets. In particular, the share of government bonds held by IFs decreases because of the fall in government bond yields, whereas their bank bond holdings increases.

3.1 Households

The household block of the model does not substantially differ from those depicted in other papers in the same strand of 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 first manage a financial intermediary and transfer dividends back to the household they belong to, while the second supply labor and earn a wage that is returned to the family. In every period, bankers leave the market and become workers with probability $1-\sigma$. These agents 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 CB deposits, D_t^e, and IF shares, Sh_t^{IF} . As shown in figure 4, assuming that households only rely on deposits as a mean of saving is an assumption which does not seem to be confirmed by EA data. Therefore, we allow for a wider composition of households' portfolio in our model. In order to set the choice between these two assets, we assume that it is costly to depart from a given portfolio structure, which comprehends both deposits and shares (Andres et al., 2004). This affects the relative share of these assets held in equilibrium. Notice that $x=\frac{Sh^{IF}}{D^e}$, is defined as the shares-deposits ratio in steady state. It is worth stressing that households cannot directly invest in government bonds. To do so they have to invest in IFs, which then allocate resources amongst 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.

In every period households maximise their lifetime discounted utility function:

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

subject to the sequence of budget constraints:

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

The set of first order conditions is given by:

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

where Ξ_t represents the Lagrange multiplier associated with the budget constraint and β is the discount factor. The labor supply equation is standard and 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 conditions describe the relationship between the marginal utility of consumption between times t and $t+1$. They are slightly modified with respect to the standard textbook New Keynesian model because of the existence of the preference for the portfolio structure discussed above. As shown by Andres et al. (2004), these equations implicitly pin down the relationship between the interest rate on CB deposits and IF shares, respectively.

The introduction of IF shares allows to partially restore the intertemporal substitution effect of monetary policy, which would vanish in a model characterized by the ZLB. IFs introduce a second return, which affects the household's consumption/savings decision. Since the deposit rate is bounded by zero, while the return on IF 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 equation (4), which is the linearized version of the consumption equation.[11]

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

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.

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

3.2 Financial intermediaries

In this section we describe the financial block of the model. The presence of market funding is the second feature of our model that could explain why negative interest rates are not contractionary.

3.2.1 Commercial Banks

The economy is populated by a continuum of CBs, which are managed by household members (i.e., bankers). CBs extend loans (S_t) to capital producers at the rate R^K_{t+1} and hold reserves at the central bank (DF_t), which are remunerated at R^R_t. On the other hand, CBs are funded through deposits (D^e_t) and Bank Bonds $\left(BB^{CB}_t\right)$, which pay each period R^D_t and R^{BB}_{t+1} to households and IFs, respectively. The returns on deposits and reserves are pre-determined, but not those on loans and bank bonds. Firms pay to banks the ex-post return on capital. Similarly, CBs remunerate IFs for their bank bond holdings, by the interest rate resulting from the equilibrium in the financial market.

The timing of the decision problem of CBs is as follows. At the end of period t banks repay their funders (i.e., households and IFs) and determine the amount of bank bonds to be issued in the next period to fund their assets. The clearance of the bank bond market requires the following condition: $BB^{CB}_{t+1} = BB^{IF}_t$. The structure of the balance sheet of the CB is as follows:

Asset	Liabilities
Loans	Deposits
Reserves	Bank Bonds
	Net worth

As shown in Figure 2, deposits represent the larger share of banks liabilities in the EA. However, also other sources of funding, such as wholesale funding, are non-negligible. It is important to take these other types of liabilities into account to evaluate the effectiveness of the NIRP.

A constraint for CBs in obtaining funds is introduced through an agency problem, as proposed by GK and Gertler et al. (2012): after obtaining the funds, bankers could transfer part of CB assets to their households. Since this behavior is known by all households, it implies a limit in the amount of funds they are willing to lend. Bank bonds are more expensive than deposits from CB perspective. However, it is optimal for these intermediaries to hold some of these assets in equilibrium as it relaxes the compatibility constraint just described. The rationale behind this assumption is that IFs, which invest in these assets, have better information about CB 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 $F_t = \frac{BB^{CB}_t}{Q_t S_t}$. Such an assumption is 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). The constraint is then that the franchise value of the bank has to be greater or equal to the value of (possibly) diverted assets:

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

Note that it is assumed that banks cannot divert central bank reserves. Moreover, CBs face an additional constraint as they have to invest a fixed share of deposits in central bank reserves, such that $DF_t = mD_t^e$.

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

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

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

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

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 the nominal deposit and reserve rate, respectively. This condition is introduced to capture the idea that the deposit rate has a lower bound at zero. Therefore, when the central bank reduces the nominal interest rate into negative territory, CBs cannot pass on the reduction in the reserve rate to depositors.

The franchise value of the bank is given by:

$$V_t^{CB} = \sum_{j=0} \left(1 - \sigma\right) \sigma^j \beta^j \Lambda_{t,t+1+j} N_{t+1+j}^{CB} \tag{9}$$

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

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

As equation (10) shows, the parameter m, which pins down the share of deposits to be invested in central bank reserves, plays a key role in affecting the net worth of the CB. In particular, spreads faced by these intermediaries depend both on the return of deposits and reserves.. The weight assigned to reserves in affecting these spreads is the amount of reserves that CBs have to hold. As equation (8) suggests, both interest rates are the same and this term simplifies to R_t^D when the policy rate is positive. In contrast, when the policy rate turns negative, the size of the negative effect that the NIRP poses on CBs net worth, strictly depends on the level of central bank reserves. In particular, this effect will 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:

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

with:

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

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

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

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 $t+j$, $x_{t,t+j}^{bb} \equiv \frac{BB_{t+j}^{CB}}{BB_t^{CB}}$ is the growth rate of bank bonds funded by IFs and $z_{t,t+j} \equiv \frac{N_{t+j}^{CB}}{N_t^{CB}}$ is defined as the growth rate of the net worth. Maximising (11) subject to the constraint (5) yields the following balance sheet relation:

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

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

IFs are funded through shares held by households, Sh_t^{IF}, while they invest in bank bonds, BB_t^{IF}, and in government bonds, B_t^g. 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 the financial intermediary has exactly the amount of assets that is required to repay its shareholders at the beginning of the next period. The profit of this intermediary can be implicitly defined as:

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

Notice that, consistent with the assumption for the market of bank bonds, the relevant spread for IFs to determine their supply of bank bonds, is the one between the expected return on bank bonds and the one they have to pay to households for their shares.

IFs maximise profits (13) taking interest rates as given. The set of optimal conditions is then given by:

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

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

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

while the cost function is assumed to be:

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

where ϱ^{IF} represents the inverse of a (fixed) cost for investing in bank bonds and ι is a parameter that introduces a feedback between IF profits and the cost for investing in bank bonds.
Equation (15) captures the following behavior. First, $\varGamma_g \leq 0$, therefore IFs invest in government bonds to reduce their operational costs. The existence of a satiation point $\bar{B}^g$, implies that it is not possible for IFs to infinitely cut costs through this behavior. In particular, $\varGamma_g = 0$ when $B_t^g = \bar{B}^g$. Second, the intermediation cost function is increasing and convex in the amount of funds allocated to bank bonds (i.e., $\varGamma_b > 0$ and $\varGamma_{bb} \geq 0$). The idea behind this assumption is that investing in these assets requires monitoring costs for IFs. Finally, the marginal cost of investing in bank bonds is assumed to be a decreasing function of profits, i.e., $\varGamma_{bz^{IF}} \leq 0$. As discussed in EJSW, this feature is able to capture in a reduced form fashion the link between profits and operational costs of a financial intermediary. In GK it is introduced through the incentive compatibility constraint, which links banks net worth to the amount of external funds that can be obtained from households.

3.3 Firms

We now describe the supply side block of the model. In defining production and investment, we adopt the standard setup that characterizes many New Keynesian models with capital. Since this part of the model does not substantially depart from GK, the description of this block is very brief. A more detailed overview of firms' decision problems is provided in the Appendix.

There are three different types of firms. First, intermediate goods producers are competitive non-financial firms. At the end of the period these agents invest resources obtained through bank loans in capital, which is used in the subsequent period to produce an intermediate good. Second, there are retailers, which are subject to nominal rigidities as in Christiano et al. (2005). These agents produce a final good using the intermediate output that they obtain from intermediate firms. Third, at the end of the period, capital producers acquire leftover capital from intermediate producers in the open market. 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.

3.4 Aggregate Demand and Policy

We define aggregate output as the sum of household consumption, investment and a fixed amount of government consumption,[12] $\bar{G}$. Therefore, the aggregate resource constraint is 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 a central bank, which stabilizes the economy using the (nominal) reserve rate as its policy instrument. We assume that the central bank pursues a pure inflation targeting strategy and follows a reaction function with interest rate smoothing as the one described in (17).[13]

$$\widehat{i_t^R} = i^R + \rho^i \widehat{i_{t-1}^R} + \left(1 - \rho^i\right)\phi^\pi \widehat{\pi}_t + \epsilon^m \tag{17}$$

In the model, all nominal and real returns are linked through the Fisher relation:

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

Finally, it is important to stress that the central bank is also able to (partially) control the interest rate on deposits by setting the reserve rate. As specified in equation (8),[14] as long as the policy rate is positive, these two returns are equal. However, since we assume that the nominal deposit rate is bounded by zero, the central bank loses the possibility to control the deposit rate when introducing NIRP. We do not micro-found the existence of this lower bound in order to keep the model simple. In the EA banks typically do not charge households for their savings. In some countries the deposit rate cannot fall below a certain limit by law.[15] In principle, 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 such a case, as soon as the return on deposits would fall below this fixed cost, agents would simply withdraw all their cash.[16]

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

[13] Notice that (17) is expressed in linearised form and ϵ^m is assumed to be a white noise disturbance. Moreover, different specification for the central bank reaction function are possible

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

[15] In Belgium there is already a law which forces banks to pay at least 0.11% on savings.

[16] This is what has been proposed by EJSW.

4 Calibration

In this section, we describe the calibration for the numerical exercise reported in Section 5. Table 1 reports the parameter values that we have fixed to solve the steady state of the model. First, we set steady state labor to 0.33 in order to match the average behavior of hours worked. Second, we set the spread between the return on loans and deposits and the one between bank bonds and deposits as the average spreads between returns on these assets in 2014 in the EA. Third, we calibrate the steady state leverage ratio to be equal to 7.5. We chose this value to capture a net worth over total liabilities ratio as close as possible to the one reported in EA data for 2014. Fourth, we assume that IFs are satiated in government bond holdings at the steady state, such that $B^g = \bar{B}^g$. It implies that IF shares and government bonds have the same return in steady state.

Table 2 summarizes the calibration of the model's parameters. Most parameters of the macro block are calibrated as in GK. The main difference relates to the capital share, which we set to 0.3 instead of 0.33. We slightly reduce this parameter in order to obtain a steady state equity-deposit ratio as close as possible to the one reported in the data. Other parameters that are slightly different from GK are the depreciation rate, δ, and the elasticity of investment adjustment costs, η_i, which we have both slightly increased. Moreover, we chose a value of 0.95 for the parameter that defines the household cost for deviating from the steady state portfolio structure, a. We decided to calibrate this parameter in order to replicate a moderate cost. It implies that the ratio between deposits and IF shares does not deviate substantially from its equilibrium level. This is meant to capture the fact that the composition of households portfolio appears to be stable over time in the EA (see ECB, 2016).

Moving to the financial block, there are five new parameters that we have introduced in the model. Our calibration is loosely based on EA data, but it can only be suggestive given the relatively simple financial intermediaries structure in our model. First, we calibrate the IF marginal cost of investing in bank bonds, ϱ^{IF}, and the parameter that introduces a feedback between IF profitability and the cost of investing in bank bonds, ι, in order to obtain a steady state ratio of bank bonds over total CB liabilities to be as close as possible to 17%, as the one observed in the EA in 2014. Second, we set the share of deposits to be invested in central bank reserves, m, at 4%, which is four times the minimum reserve requirement. This characterizes a situation of moderate excess liquidity. This choice implies a steady state ratio between central bank reserves and total CB liabilities that is higher than the one registered in EA data for central bank reserves only. However, it has to be noticed that this parameter defines the exposure of banks to the NIRP in our model. This exposure depends mainly on the size of reserves held at the central bank. However, banks have been likely affected by the NIRP also with respect to a large set of securities that they hold on their balance sheet. This is the reason why we have chosen to capture a steady state ratio between reserves and CB liabilities higher than the one that only takes into account reserves held in the deposit facilities of the ECB. Third, we have slightly reduced the survival probability of bankers, σ, compared to the calibration in GK. We decided to do so since this parameter, together with the leverage, influences parameters entering the incentive compatibility constraint, i.e., θ and γ_1. In order to avoid an implausible calibration of asset divertibility, we chose a lower survival probability than GK. Fourth, we choose a value for $\bar{B}^g$ which implies that IFs are no longer able to reduce their costs by investing in risk-free assets when these are roughly 50% of their balance sheet. This underestimates the amount of IFs' government bond holdings. However, this parameter affects the amount of shares held by households in equilibrium. Setting it to a relatively low value enables to match the ratio between shares and household's total assets observed in the data.[17] Fifth, we report in the lower part of the table the persistence of the exogenous shock that is used in the simulations. Differently from GK, we have used a consumption preference shock to simulate a recession. As the value chosen for ρ^ζ shows, this shock is assumed to be persistent. Moreover, we set its size in order to obtain a drop in the policy rate up to -0.4%, which is the level assumed by the ECB deposit facility rate for the longest period since the NIRP has been introduced.

Finally, we report in Table 3 a comparison between the main financial steady state ratios resulting from our calibration and the data. As the table shows, when we do not take into account interbank borrowing and other assets, our calibration is able to capture relatively well banks liability ratios as described in the data. The same does not hold for the ratio between deposits and total assets held by households. This figure is much lower in the data than in the equilibrium implied by our calibration. The discrepancy is due to the fact that we have assumed households to hold only two types of assets (deposits and IF shares). As the table shows, our calibration implies a value for the ratio between IF shares and total assets that is quite close to the one registered in the data. However, differently from what we have assumed in our stylised model, the remaining part of households assets is not limited to deposits only. It also comprehends bonds, shares and other assets that are not included in the model.

5 Numerical Simulations

We simulate the model with Occbin (Guerrieri and Iacoviello, 2015). We implement a negative consumption preference shock in order to generate a recession. We compare results obtained under three different scenarios and three different versions of the model. First, we analyze the behavior of the model when both the policy and the deposit rate can be negative (red dotted line, *'No Bound'*). Second, we report results of a standard ZLB scenario, where both the policy rate and the deposit

[17] It is important to stress that the higher this parameter, the more effective the NIRP in stimulating the economy. In Section 5.2, we study the sensitivity of our results to different calibration of $\bar{B}^g$.

rate are bounded by zero (black solid line, *'ZLB'*). Third, we analyze a scenario that is consistent with the one we have observed after the introduction of the NIRP (blue dashed line, 'NIRP'). In this scenario, the policy rate can be negative, while the deposit rate is bounded by zero.

In section 5.1, we report results for three different versions of the model. First, we analyze a model that is similar to EJSW. Second, we study the behavior of a model in which households have a portfolio that includes both deposits, as well as assets that could have a negative yield. Third, we present results of the complete model with bank bonds, which we described in Section 3.

In Section 5.2 we study the sensitivity of our results to different calibrations of some key model's parameters. In particular, we discuss the implication of choosing different values for the reserve share, m, as well as for the parameter that defines households' portfolio adjustment cost, a. Finally, we analyze the general equilibrium implications of IFs facing different monitoring costs for investing in bank bonds, ϱ^{IF}, and different satiation points for their government bond holdings, $\bar{B}^g$.

5.1 Three versions of the model

In this section, we compare three versions of the model. In 5.1.1, we present results of a model that is similar to the one described in EJSW. We then gradually introduce the two transmission channels that we explore in 5.1.2 and 5.1.3, respectively.

Two key channels are crucial to explain our results. First, allowing households to hold (negative yielding) government bonds in addition to bank deposits, restores the intertemporal substitution channel of monetary policy. In this case, a contractionary effect no longer arises. Second, the introduction of bank bonds as an alternative source of bank funding, further improves the effectiveness of the NIRP in stimulating the economy.

5.1.1 A model with banks only

The model without both transmission channels is a small extension of GK. CBs are funded by household deposits. They lend to firms and hold a fixed share of their liabilities in central bank reserves. The rest of the model is comparable to the one described in Section 3.[18] This version of the model departs from the one described in EJSW in at least two dimensions. First, in EJSW there is no capital, which clearly affects the aggregate resource constraint. Second, in EJSW the problem faced by the bank is static, while the one adopted here builds on Gertler and Kyiotaki (2010) and GK, among many others. Despite these differences, the main mechanism driving results of EJSW is also present in this simplified version of our model.

[18]Notice that the households block is also different. Since there are no IFs in this simplified version of the model, households can only save by holding CB deposits.

Figure 5 reports the IRFs of output, inflation, the nominal deposit and policy rates under the three scenarios. As can be observed in the figure, the hierarchical sequence amongst the three cases is comparable to the one described in EJSW. Lowering the interest rate on bank reserves below zero in response to a recession has adverse effects. The output drop under NIRP is larger compared to the scenario when both policy and deposit rates are bounded by zero. Similarly to EJSW, banks cannot pass on the reduction in the policy rate to depositors, because of the lower bound. As long as central bank reserves yield negative returns, while depositors do not receive a return that is lower than zero, bank profitability drops. As a result, banks increase the interest rate on loans, which triggers the adverse effect on output.

5.1.2 A model with a wider households' portfolio

In this subsection we augment the basic model by relaxing the assumption that deposits are the only assets of households. We allow for a wider composition of households' portfolios, which now includes government bonds as well as bank deposits. We also assume that the return on these risk-free assets is the same as the policy rate.

The main difference relative to the model described in 5.1.1 lies in the fact that we now introduce a preference for holding both these assets. Following Andres et al. (2004), we assume that it is costly for households to deviate from the equilibrium ratio between deposits and government bonds. As a result, it is optimal for households to hold a combination of both assets, even if the return on one of them is negative.

Comparing figures 5 and 6 shows that the contractionary effect that we obtained in the previous section vanishes when we allow households to hold negative yielding assets in addition to bank deposits. This is the consequence of the fact that households determine their consumption path based on the returns of both assets. The return on deposits is zero for all periods in which the policy rate reaches negative values because of the ZLB. However, the drop in the government bond return affects the household saving/investment decisions, thus restoring the intertemporal substitution effect.

5.1.3 The complete model

We now introduce IFs alongside commercial banks in the financial sector. The model used in this simulation is the one described in Section 3.

As shown in the upper left panel of Figure 7, the response of output in the NIRP case lies above the one in the ZLB case for all time periods in which the constraint is binding. Moreover, the distance between the output responses in the NIRP and the ZLB case (i.e., the "gain" with respect to the ZLB) is higher than the one which characterizes the model described in section 5.1.2.

To evaluate the effectiveness of the two new features that we have added, in Figures 8 and 9 we report the difference between responses in the NIRP and the ZLB scenario's of output and banks' net worth in the three versions of the model.[19] As can be observed in these figures, the difference between the NIRP and the ZLB case switches sign and becomes positive when negative yielding assets are introduced in the households' portfolio, as well as bank deposits. It increases even more when CBs issue bank bonds as an alternative funding source to deposits.

In order to better understand the reasons behind the enhanced NIRP effectiveness in stimulating the economy, it is useful to first look at the liability side of the CBs. Figure 10 reports the IRFs of the bank bond-deposit spread, the ratio between these two sources of funding, the share of CB assets which bankers might divert (i.e., $\Theta(F_t;\theta,\gamma_1)$ in equation (5)) and CB net worth. As shown in the upper left panel of this figure, the ratio between bank bonds and deposits is higher in the NIRP than in the ZLB scenario. Moreover, the spread between the returns on these two assets is lower in the NIRP than in the ZLB, suggesting that this source of funding is cheaper in the first than in the second scenario. However, the response of this spread is positive. It implies that bank bonds remain more costly than deposits also outside the steady state and such a difference does not vanish when the deposit return reaches its lower bound.

A legitimate question is then: why do CBs issue more bank bonds when the NIRP is in place? To understand this feature it is important to take into account two elements. First, the weaker response of the bank bond-deposit spread in the NIRP compared to the ZLB signals that market type funding sources are cheaper in such a scenario than in the ZLB. This feature of the model is in line with the empirical evidence reported by Bottero et al. (2019), which shows that the NIRP has the ability to flatten the yield curve. In our model this has the implication of making bank bonds more appealing.

Second, it is also important to analyze the implications for the incentive compatibility constraint faced by CBs. Based on the argument that market funding is a monitoring tool for bank risks, we have assumed the share of divertible assets, $\Theta(F_t;\theta,\gamma_1)$, to be a decreasing function in the amount of loans funded by bank bonds. Therefore, banks decide to tolerate a higher cost of funding as long as they are able to affect the incentive compatibility constraint they are facing. We report responses of $\Theta(F_t;\theta,\gamma_1)$ in the lower left panel of Figure 10. As shown, assets divertibility drops both in the NIRP and in the ZLB, suggesting that after a fall in net worth banks issue more bank bonds in order to relax their constraint. As shown in (5), $\Theta(F_t;\theta,\gamma_1)$ is defined as the ratio between the franchise value of the bank and the value of loans granted. Both CB net worth (lower right panel of figure 10) and the value of loans (not shown in the figure) drop more in the ZLB than in the NIRP

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

case. As a result, the response of $\Theta(F_t; \theta, \gamma_1)$ is stronger in the ZLB than in the NIRP scenario.

Figure 11 depicts the response of loans (equal to the capital stock) and the spread between the loan rate and the deposit rate. As can be observed, the smaller drop in CB net worth results in a smaller rise in the cost of borrowing in the NIRP case versus the ZLB case (lower panel). The smaller rise in the cost of borrowing is associated with a weaker reduction in lending (upper panel).

Finally, Figure 12 focuses on the reaction of the IFs to the shock. As discussed in Section 3, IFs hold risk-free assets, best interpreted as government bonds, and fund CBs by investing in bank bonds. Figure 13 reports the responses of the two spreads that are relevant in the optimization problem of the IF. As shown in the figure, the response of the spread between bank bonds and shares is higher in the NIRP than in the ZLB case, making these assets particularly attractive for IFs. On the contrary, the spread between government bonds and shares substantially drops when negative rates arise. Most interestingly, its response under the NIRP scenario is substantially lower than the one which characterizes the ZLB. Therefore, IFs have an incentive to rebalance their portfolio towards bank bonds.

Overall we can conclude that two main elements explain the additional transmission channel of the NIRP through the financial sector and its enhanced effectiveness in our model. On the one hand, it is convenient for banks to rely more on market based funding. The introduction of the policy makes these assets cheaper and relying on them allows banks to relax their incentive compatibility constraint and increase their leverage when the net worth falls. This reduces the cost of borrowing for firms. On the other hand, investing in these assets is also profitable from the IF perspective. Since the introduction of negative rates substantially reduces the yield of risk-free assets, rebalancing the investment portfolio towards bank bonds is a strategy which IFs adopt to sustain their profitability.

5.2 Sensitivity analysis

In this section we analyze the sensitivity of results presented in 5.1.3 to a different calibration of some parameters that characterize the model. In particular, in Figures 13 to 22 we analyze the difference between the responses under the NIRP and the ZLB scenarios of some variables (namely, output, net worth, bank bonds-deposits and loans-deposits spreads) for different calibrations of four parameters, which are key for the functioning of the transmission channels analyzed in this paper. These parameters are: the reserve share, m, the (inverse) of the IF cost for investing in bank bonds, ϱ^{IF}, the portfolio adjustment cost, a, and the IFs' satiation point for their government bond holdings, $\bar{B}^g$.

As shown in Figures 13 and 14, the higher the reserve share, the stronger the negative impact of the policy on banks profitability and the weaker the effectiveness of the NIRP. Particularly the difference between the output responses is negative when m reaches 7% of deposits. A similar behavior characterizes CB net worth, while the IRFs difference for both the bank bonds-deposit and the loan-deposit spreads are increasing in the reserve share.

Next, Figures 15 and 16 show that the smaller the portfolio adjustment cost, the more limited the effect on CB net worth and output and the weaker the mechanism. Since the return on IF shares can reach negative values, households would move their savings towards deposits when the cost for deviating from the equilibrium portfolio is negligible. In such a scenario, the IFs would have too limited resources to invest in bank bonds, which would imply a smaller reduction in CB funding costs and a weaker loosening of the incentive compatibility constraint. Therefore output and net worth IRF differences are increasing in a, while both spreads are decreasing in this parameter.

Furthermore, Figures 17 to 20 depict the sensitivity to the inverse of the IF cost of investing in bank bonds. As these figures suggest, the higher the value of ϱ^{IF} (i.e., the smaller the monitoring cost), the higher the incentive for IFs to rebalance their portfolio towards bank bonds and the stronger the effectiveness of the NIRP in stimulating the economy.

Finally, Figures 21 and 22 further document the importance of the IFs' portfolio rebalancing channel. They describe the sensitivity to the IFs' satiation point for government bond holdings, $\bar{B}^g$. As shown by these figures, the higher this parameter, the stronger the incentive for IFs to rebalance their assets towards bank bonds and the more effective the NIRP. On the contrary, when IFs hold too few negative yielding assets,[20] the NIRP generates a contractionary effect. In this case, their demand for bank bonds is weak, banks' funding costs are only marginally affected and the negative effect of the NIRP on banks' profitability dominates.

6 Conclusions

In this paper, we have proposed a New Keynesian model with a financial sector that features two distinct intermediaries (Commercial Banks – CBs – and Investment Funds – IFs), as a tool to analyze the effectiveness of a NIRP. These agents differ from each other in their funding structure and in their investment decision. IFs are funded by shares held by households. They hold bank bonds, an asset issued by CBs, as well as risk-free assets, best thought as government bonds, whose return is given by the policy rate. CBs are funded through retained earnings, household deposits and bank bonds. They lend to firms and hold reserves at the central bank.

The results of our paper highlight the importance of financial markets in transmitting a NIRP. Two channels are important to enhance the effectiveness of this policy. First, allowing households to save through deposits and other assets (i.e., government bonds or IF shares), is able to restore the intertemporal substitution effect of monetary policy, because returns on these other assets are

[20] The green dotted lines in Figures 21-24 correspond to the case in which risk-free assets account to 30% of the IF's balance sheet in equilibrium.

not bounded by zero. Second, allowing banks to rely on deposits as well as market funding (namely, bank bonds) provide to CBs the possibility to rebalance their liabilities towards these assets, which become cheaper after the introduction of a NIRP.

We have simulated the model implementing a consumption preference shock to introduce a recession. We have chosen a calibration which enables the model to be as close as possible to EA bank balance sheet and spread data in equilibrium. In our numerical exercise, we compare responses under three different scenarios (i.e., 'No Bound', 'ZLB' and 'NIRP'). In the unbounded case, both policy and deposit returns can fall below zero. In the ZLB one, both these returns have a lower bound at zero. In the third scenario, the deposit rate has a lower bound, while the policy rate can reach negative values. Moreover, we compare three versions of the model, in order to show the relevance of the two transmission channels we analyze. First, we simulate a model in which households can only save through deposits. These assets are also the only CB liability. Second, we allow households to hold negative yielding-assets in addition to deposits, which remain the only CB source of funding. Finally, we also extend the financial sector, introducing IFs alongside commercial banks, and we allow banks to issue both deposits and bank bonds. In this last version of the model, households can save through CB deposits and IF shares.

Our results show that the introduction of NIRP leads to a contractionary effect when deposits are the only bank liability and the only asset households can save through. Such an effect disappears in the second of the aforementioned models, while the effectiveness of the NIRP is further enhanced when allowing for a larger financial sector. In this last case, CBs rebalance their liabilities increasing the bank bond-deposit ratio more in the NIRP than in the ZLB case. This demand for funds is met by IFs, which have an incentive to increase the supply of funds to be allocated to these assets, at the expense of the one for risk-free assets. This portfolio rebalancing is the main driver of a weaker drop in CB profits compared to the ZLB case. As a consequence, reductions in the supply of loans and in the aggregate demand are less pronounced than those characterising a standard ZLB model.

We study the sensitivity of our results to different calibrations of the reserve share, the households portfolio adjustment costs, the cost faced by IFs for investing in bank bonds and the IFs' satiation point for government bond holdings. Not surprisingly, the higher the reserve share, the weaker the positive effect of the NIRP. Similarly, higher IF monitoring costs disincentivize these intermediaries in investing in bank bonds and weaken the transmission mechanism. Furthermore, if portfolio adjustment costs were negligible, households would move a large share of their savings into CB deposits. In this case, IFs would have too limited resources to be invested in bank bonds and the strength of the mechanism would be weaker. Finally, the higher the satiation point for IFs' government bond holdings, the stronger the incentive to rebalance their portfolio towards bank bonds, the more effective the NIRP in stimulating the economy.

The framework proposed in this paper could be used as a base to explore the effectiveness of this policy under different points of view. First, it is important to stress that we assess the effectiveness of the NIRP in a closed economy model. Therefore, the output response is not influenced by exchange rate adjustments to policy rate fluctuations. Extending the model to the open economy setup, would probably show a strong effect on aggregate demand through this channel. Second, we abstract from the possibility of banks charging fees on households instead of setting negative deposit rates. Introducing this feature in the model would be possible but it is beyond the scope of this paper. Third, we analyze the effectiveness of the NIRP only and do not take into account interactions with other policy measures. Introducing large scale asset purchases would enable to analyze synergies between these two unconventional policies.[21]

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

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Appendix

A Firms decision problem

A.1 Intermediate goods firms

As already briefly introduced, intermediate producers are funded through bank loans and operate in a perfectly competitive environment. In particular there are no adjustment cost and the optimization problem for these agents is static. In order to obtain funds, intermediate firms issue as many state contingent securities, S_t, as much as the quantity of capital which is required to produce goods in the subsequent period. Moreover, these securities are assumed to have the same price as capital, Q_t, such that the following condition hold:

$$K_{t+1} = S_t. \tag{19}$$

In every period, intermediate firms employ an exogenous technology, A_t, capital, K_t, and labor, L_t, in order to produce (intermediate) output. Therefore firms choose capital and labor to maximize their production function given by $Y_{mt} = A_t K_t^{\alpha} L_t^{1-\alpha}$. The First order conditions for these inputs represent the standard demand for labor and capital:

$$FOCs\; Intermediate\, Producers \tag{20}$$

$$[K_t] : \alpha P_t^m \frac{Y_{mt}}{K_t} + (Q_t - \delta) = R_t^k Q_{t-1}$$

$$[L_t] :\ (1-\alpha)\, P_t^m \frac{Y_{mt}}{H_t} = W_t$$

Having assumed that intermediate producers operate in a competitive market, firms have zero profits. Therefore, intermediate producers simply pay to the financial intermediary which provided funds the ex-post return on capital, which is given by:

$$R_{t+1}^k = \frac{\alpha P_{t+1}^m \frac{Y_{t+1}}{K_{t+1}} + (Q_{t+1} - \delta)}{Q_t} \tag{21}$$

A.2 Capital producers

Capital producing firms operate in a perfectly competitive environment and are owned by households, who would receive a lump sum transfer if extra profits arose. As noted above, capital goods manufacturers produce new capital and refurbish the existent worn-out one, which they purchase from intermediate producers. In particular, we assume that capital producers face adjustment costs when producing new capital only. We define the gross capital created in every period as I_t. Moreover we assume that capital depreciates constantly at the rate δ, such that the quantity of capital which will be refurbished is given by δK_t. Therefore, we can define the net capital formation as

$I_{nt} \equiv I_t - \delta K_t$. The optimization problem faced by capital producers is given by:

$$\max_{I_{nt}} E_t \sum_{t=0}^{\infty} \beta^t \Lambda_{t-1,t} \left\{ (Q_t - 1) I_{nt} - f\left(\frac{I_{nt} + I_{ss}}{I_{nt-1} + I_{ss}} \right) (I_{nt} + I_{ss}) \right\} \tag{22}$$

Where I_{SS} represents the steady state level of investment and the function $f\left(\frac{I_{nt}+I_{ss}}{I_{nt-1}+I_{ss}}\right)$ captures adjustment costs on the net investment flow. In particular, this function is assumed to have the following features: $f(1) = f'(1) = 0$ and $f''(1) > 0$.

The first order condition resulting from capital producers' optimization problem (22) allows to obtain the price of new capital, which is given by:

$$Q_t = 1 + f(\cdot) + f'(\cdot) \left(\frac{I_{nt} + I_{ss}}{I_{nt-1} + I_{ss}} \right) - \Lambda_{t,t+1} f'(\cdot) \left(\frac{I_{nt+1} + I_{ss}}{I_{nt} + I_{ss}} \right)^2 \tag{23}$$

A.3 Retailers

Retailers produce the final output Y_t using as only input intermediate goods, which they purchase at price P_t^m. Since it is assumed that in order to produce one unit of final output it is required to use the same amount of intermediate output, P_t^m represents the marginal cost. Moreover, we assume that the economy is populated by r retailers, such that the final output can be defined as the CES composite of a continuum of output by each of these sellers, where the elasticity of substitution is given by ϵ:

$$Y_t = \left[\int_0^1 Y_{rt}^{\frac{\epsilon-1}{\epsilon}} dM \right]^{\frac{\epsilon}{\epsilon-1}} \tag{24}$$

Users of final output minimize costs and their optimization problem defines the output of the retailers as:

$$Y_{rt} = \left(\frac{P_{rt}}{P_t} \right)^{-\epsilon} Y_t \tag{25}$$

where $P_t = \left[\int_0^1 P_{rt}^{1-\epsilon} dr \right]^{\frac{1}{1-\epsilon}}$.

Similarly to Christiano et al. (2005), we assume that in each period retailers face a probability to reset their price equal to $1-\gamma$. On the contrary, producers who will not be able to change their price will index it to the past level of inflation. Therefore the pricing decision problem of retailers is obtained by choosing the optimal price P_t^* when solving:

$$\max \sum_{i=0}^{\infty} \gamma^i \beta^i \Lambda_{t,t+i} \left[\frac{P_{rt}}{P_{t+i}} \prod_{k=1}^{i} (1 + \pi_{t+k-1})^{\gamma_P} - P_{rt+i} \right] Y_{rt+i} \tag{26}$$

where the inflation rate between periods $t-i$ and t is defined as π_t. The solution of this optimization problem yields to the following optimal price definition:

$$\sum_{i=0}^{\infty} \gamma^i \beta^i \Lambda_{t,t+i} \left[\frac{P_t^*}{P_{t+i}} \prod_{k=1}^{i} (1 + \pi_{t+k-1})^{\gamma_P} - \frac{\epsilon}{\epsilon - 1} P_{t+i}^m \right] Y_{rt+i} = 0 \tag{27}$$

where $\mu = \frac{1}{1-1/\epsilon}$. Finally, it is possible to obtain a relation capturing the evolution of price level, which is given by:

$$P_t = \left[(1-\gamma)\left(P_t^*\right)^{1-\epsilon} + \gamma\left(\Pi_{t-1}^{\gamma_P} P_{t-1}\right)^{1-\epsilon}\right]^{\frac{\epsilon}{1-\epsilon}} \tag{28}$$

B List of Tables

Table 1: Steady state targets

Targets	Definition	Calibration
L	Labor	0.33
$R^K - R^D$	Spread Loans-Deposit	0.0241/4
$R^{BB} - R^D$	Spread Bank Bonds-Deposit	0.0111/4
ϕ	Leverage Ratio	7.5

Table 2: Calibration of model's parameters

Parameter	Value	Definition	Source
Households, Firms and Monetary Policy			
β	.995	Discount rate	Our calibration
h	.815	Habit	Gertler Karadi
φ	.276	Inverse Frisch elasticity Labor Supply	Gertler Karadi
α	0.3	Capital Share	Our calibration
δ	.03	Depreciation rate	Our calibration
η_i	2	Elasticity Investment adjustment cost	Our calibration
a	0.95	Households Portfolio Structure	Our calibration
ϵ	4.167	Elasticity of substitution between goods	Gertler Karadi
γ	0.779	Price stickiness	Gertler Karadi
γ_P	0.241	Price indexation	Gertler Karadi
χ	2.6507	Labor utility weight	Steady State
Financial Market			
σ	0.95075	Survival Probability	Our calibration
ϱ^{IF}	38	IF Marginal Cost investing in Bank Bonds	Our calibration
$\bar{B}^g$	0.6	IF Satiation point Government Bond	Our calibration
m	0.04	Share of Deposits invested in Reserves	Our calibration
ι	0.8	Feedback IF profits - cost of investing in BB	Our calibration
		Assets diversion:	
θ	0.3564		Steady State
γ_1	0.2415		Steady State
ω	0.00064	Start-up funds new bankers	Steady State
Other parameters			
ρ_i	0.8	Interest rate smoothing	Gertler Karadi
κ_π	1.5	Inflation coefficient	Gertler Karadi
ρ^ζ	0.9	Persistence consumption preference shock	Our calibration

Table 3: Steady State key ratios and spreads

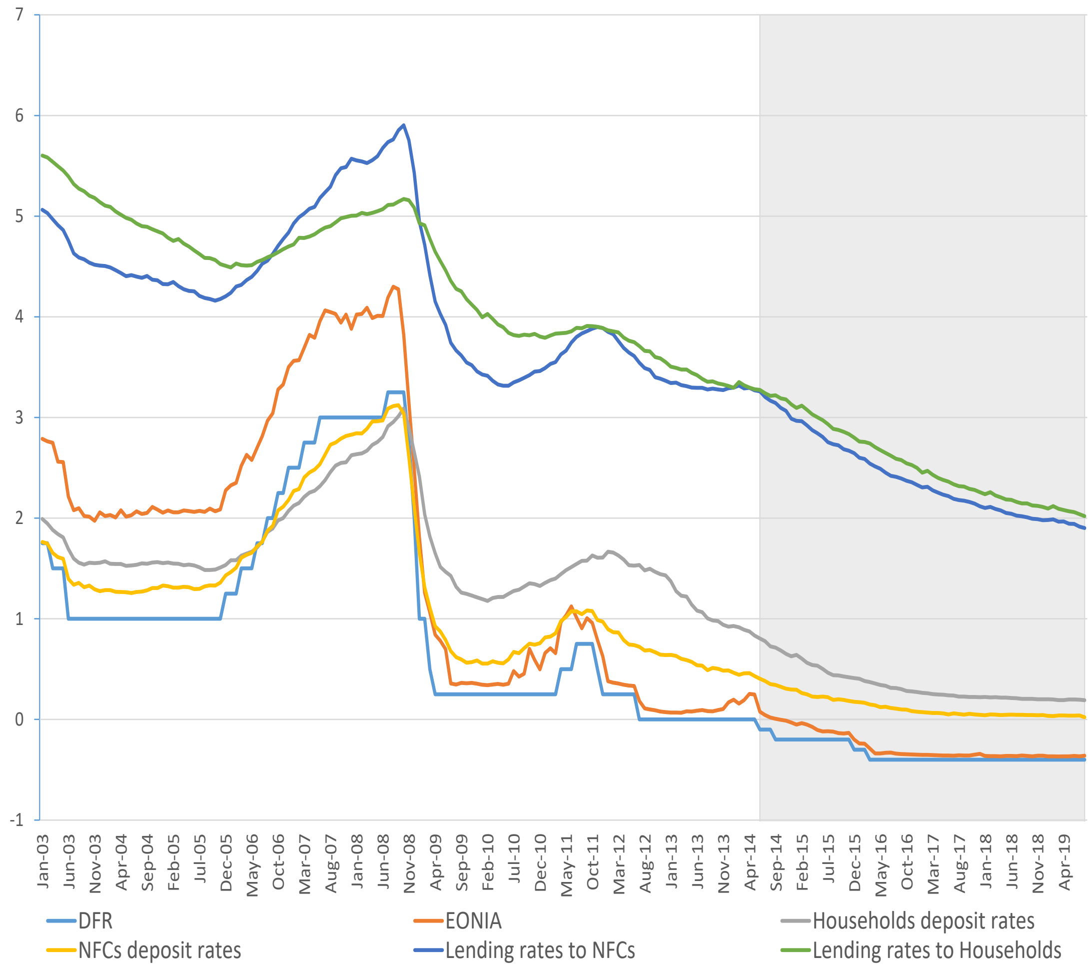
Variable	Definition	StSt value	Data
Commercial Banks			
Dep/TL	Deposits	70.06%	66.6%
BB/TL	Bank Bonds	16.98%	21.8%
N/TL	Net Worth	12.96%	11.5%
DF/TL	Reserves	2.80%	1.28%
Households			
Dep/THA	Deposits	68.69%	44%
Sh/THA	Shares	31.31%	33%[22]
Spreads			
$R^K - R$	Loans	0.0241/4	2.41%
$R^{BB} - R$	Bank Bonds	0.0111/4	1.11%

TL= total banks liabilities; THA = total households assets.
Source: ECB data (spreads, banks assets and liabilities in 2014) and ECB (2016). Data on banks liabilities have been rescaled excluding the interbank borrowing and other assets. Among banks assets we have considered only loans (excluding MFI), reserves and securities. Spreads figures relate to the average ones in 2014.

[22] This figure relates to the sum of "pension/life insurance" (24%) and "mutual funds" (9%). Other componenets of households portfolio are bonds (5%), shares (7%) and other assets (11%)

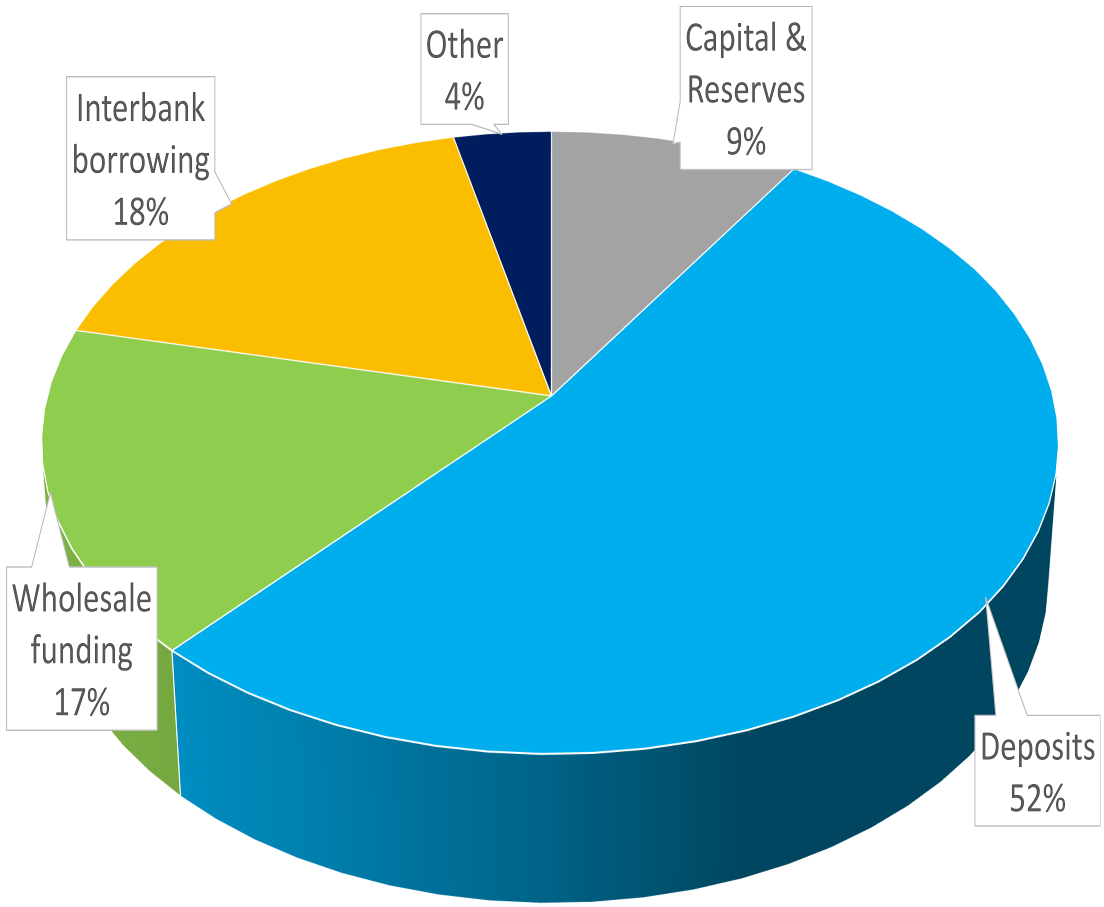
C List of figures

Figure 1: Loan and deposit rates



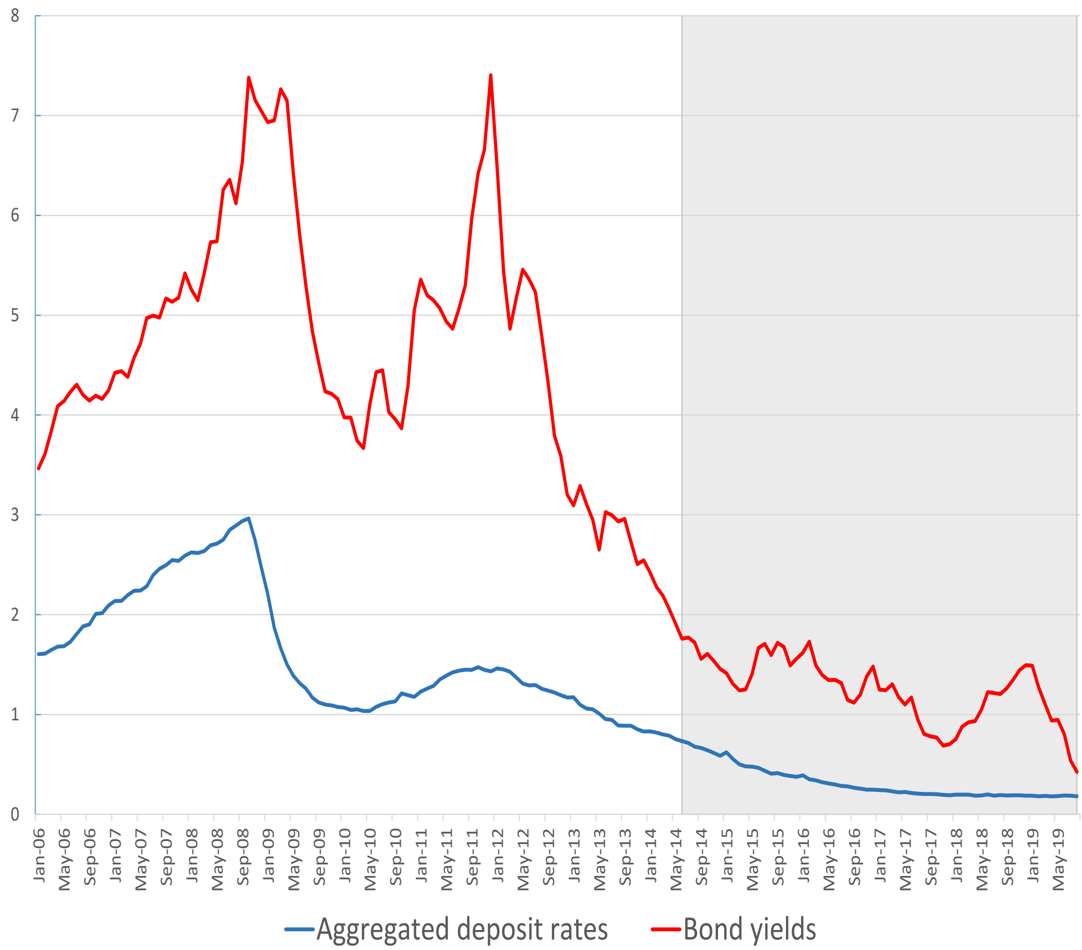
Source: ECB data. Own calculation.

Figure 2: Bank liabilities: composition



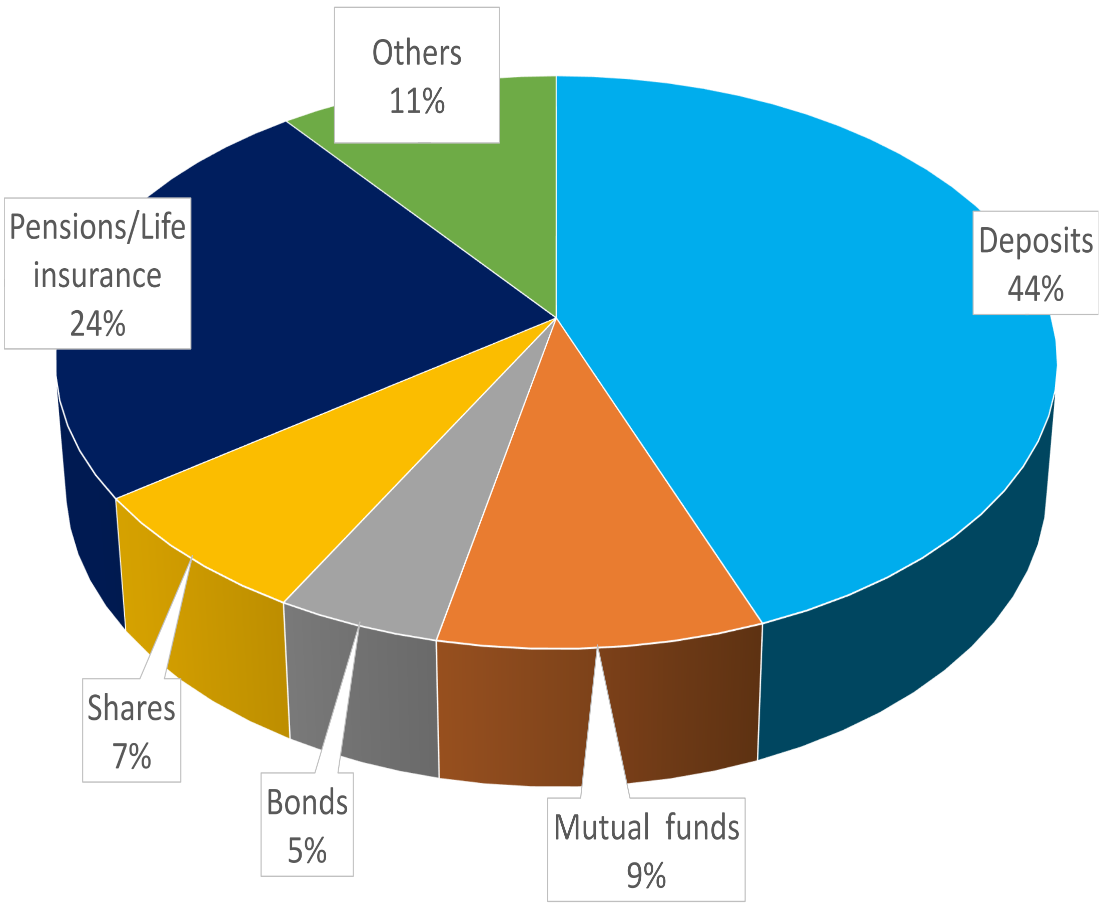
Source: ECB data, 2014. Own calculation.

Figure 3: Bank bond yield and deposit rate



Source: ECB data. Own calculation.

Figure 4: Households financial assets: composition



Source: ECB data. *The Household Finance and Consumption Survey: results from the second wave.* Household Finance and Consumption Network. ECB Statistics Paper Series No. 18/2016

Figure 5: The EJSW-like model

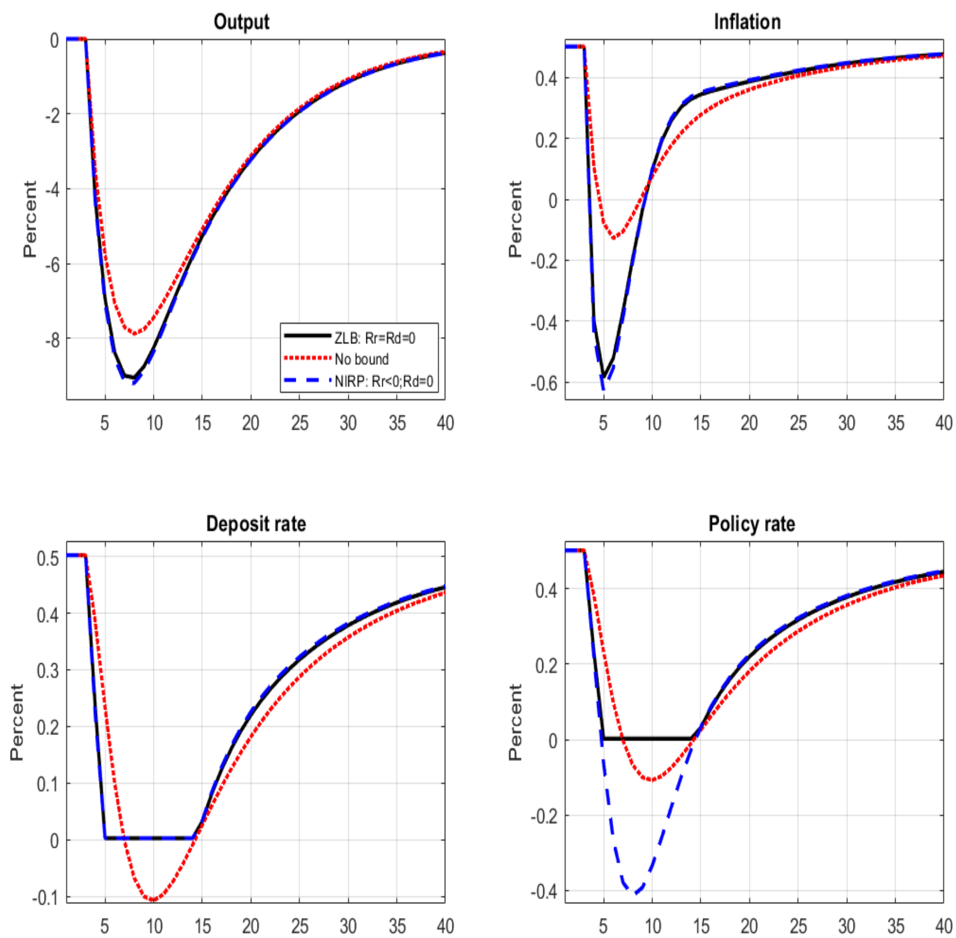


Figure 6: HH gov-bond holding

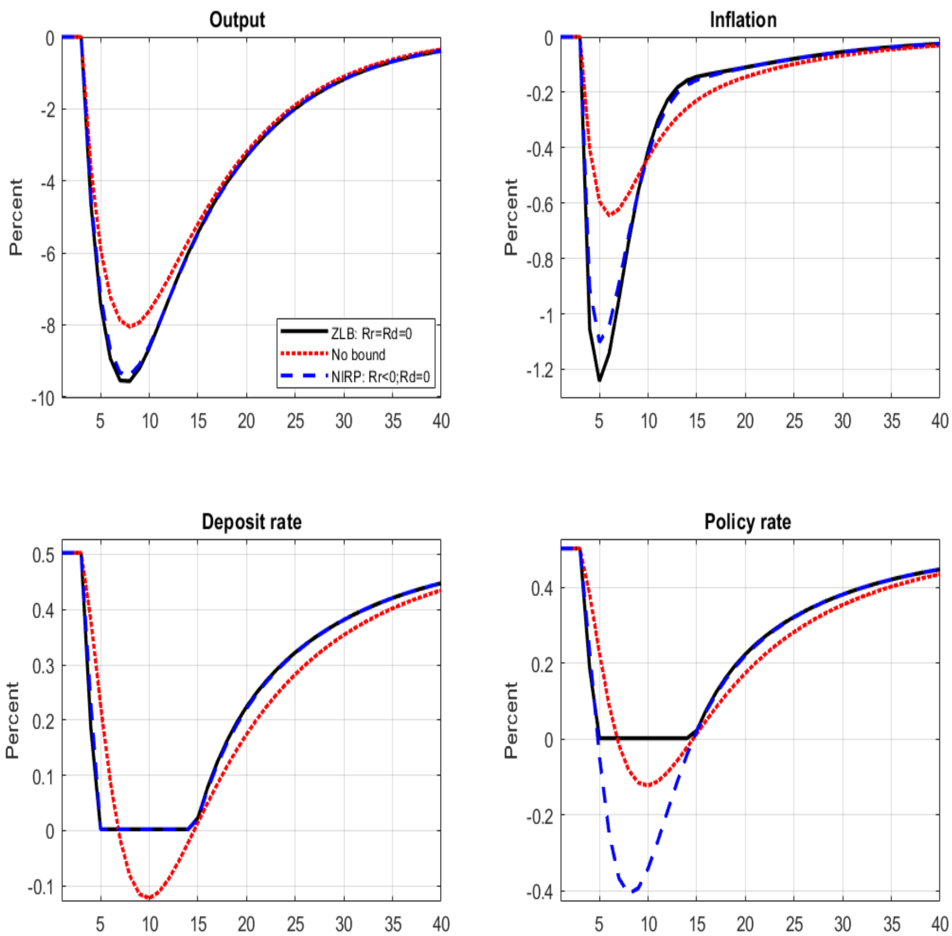


Figure 7: The complete model - 1

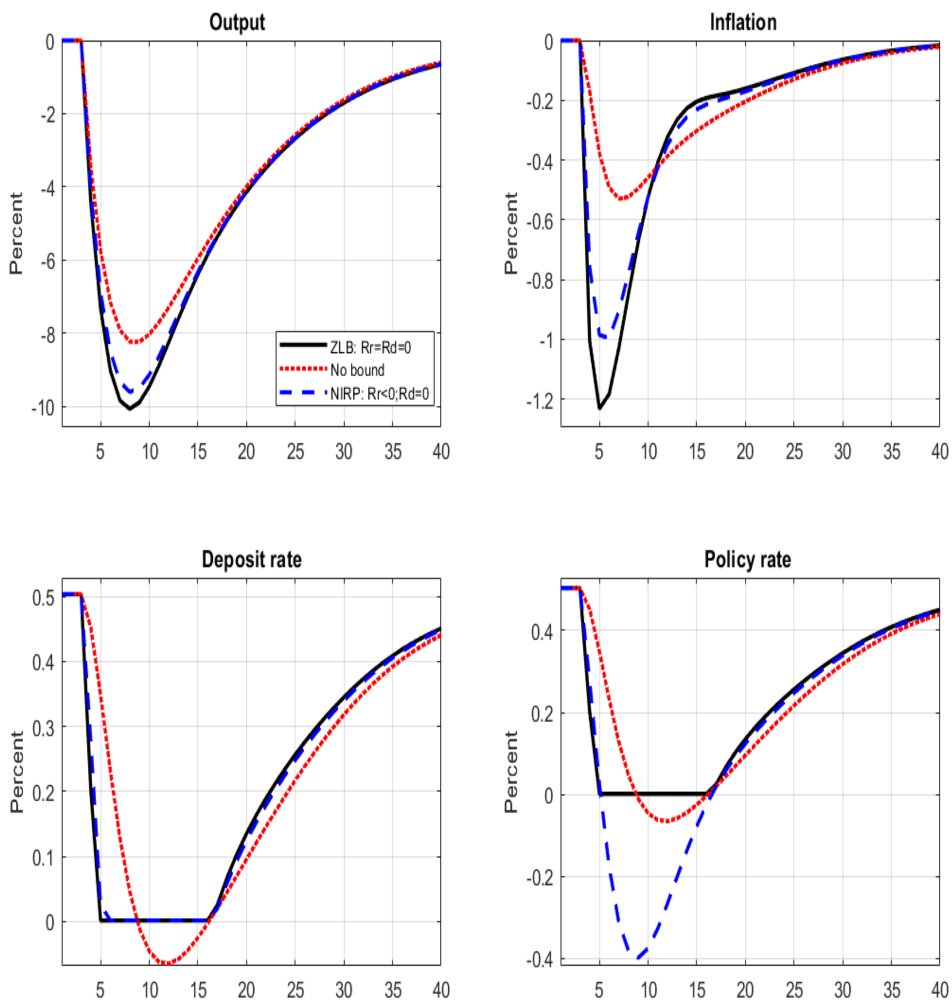


Figure 8: Models comparison - GDP

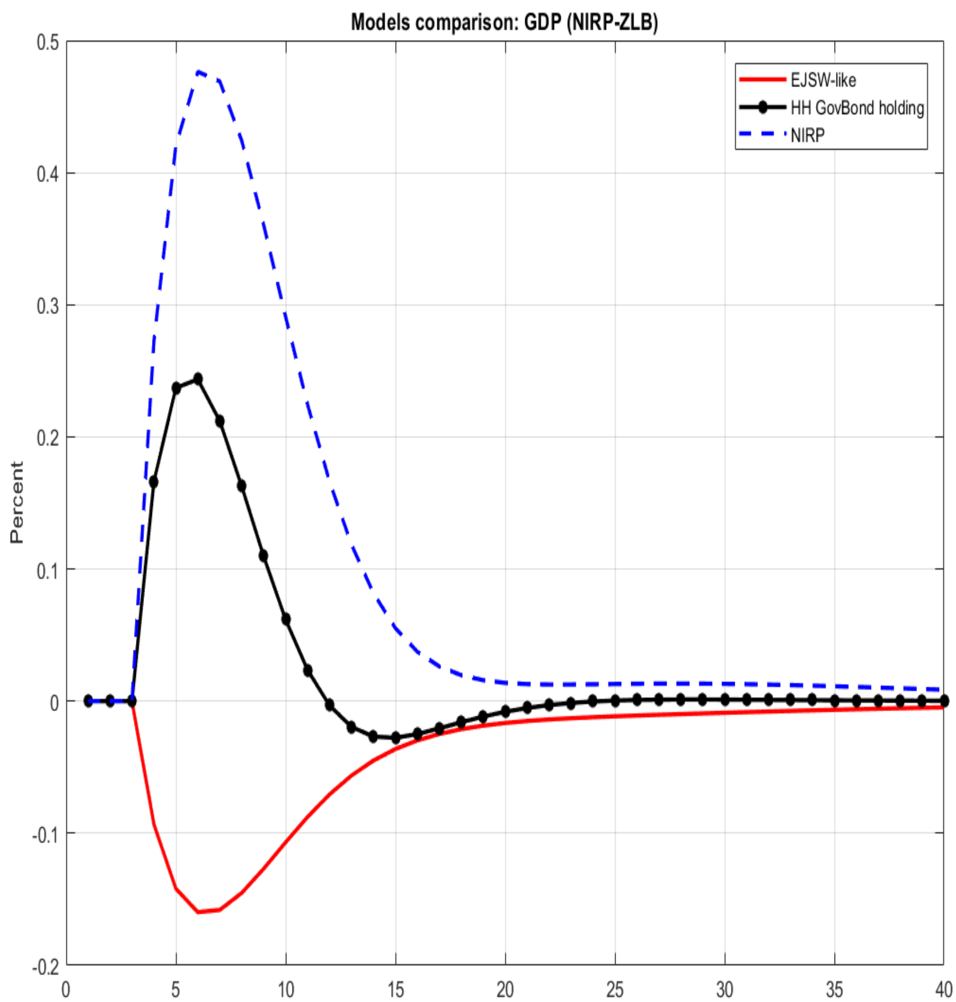


Figure 9: Models comparison - Net Worth

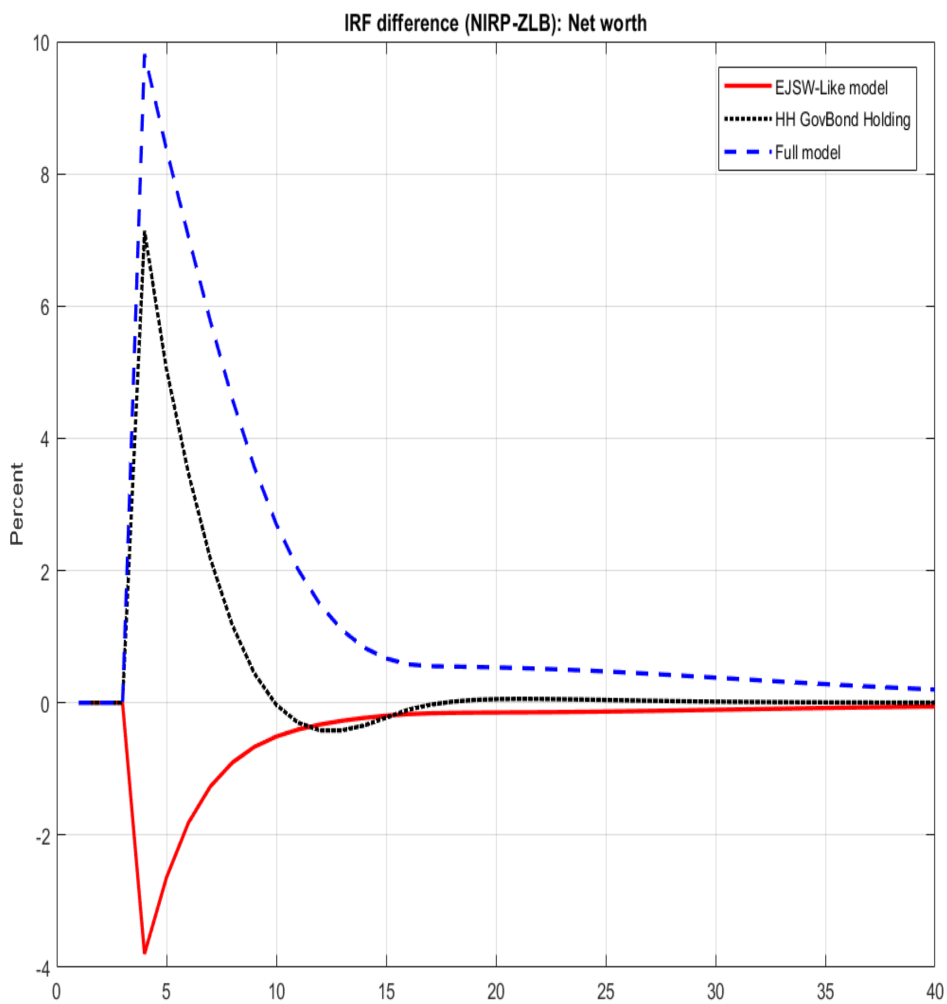


Figure 10: The complete model - 2

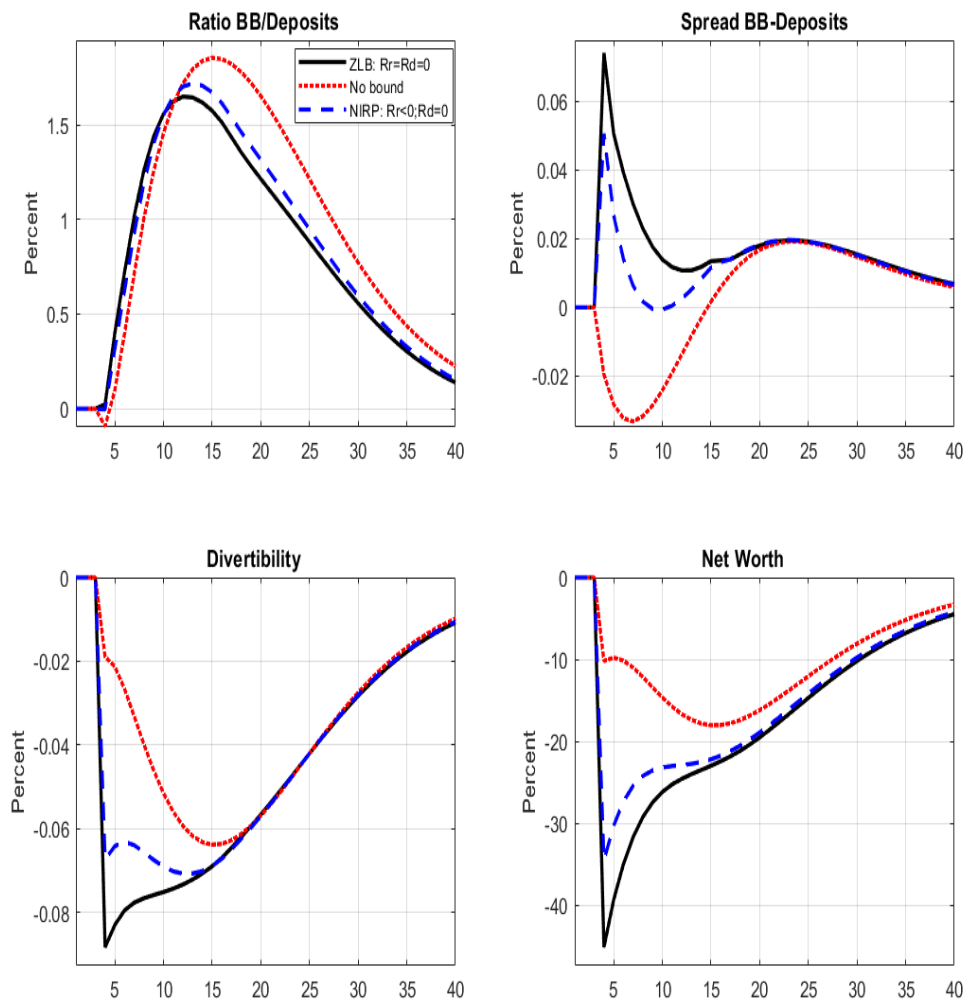


Figure 11: The complete model - 3

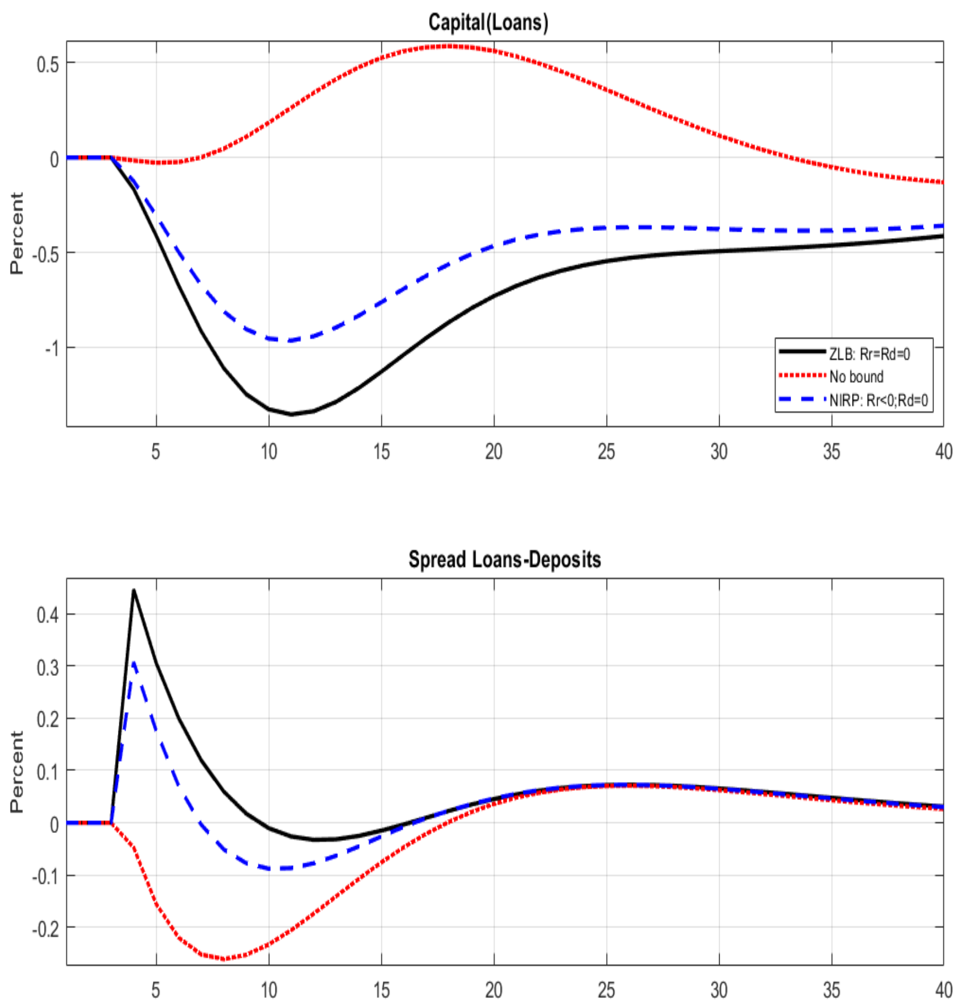


Figure 12: The complete model - 4

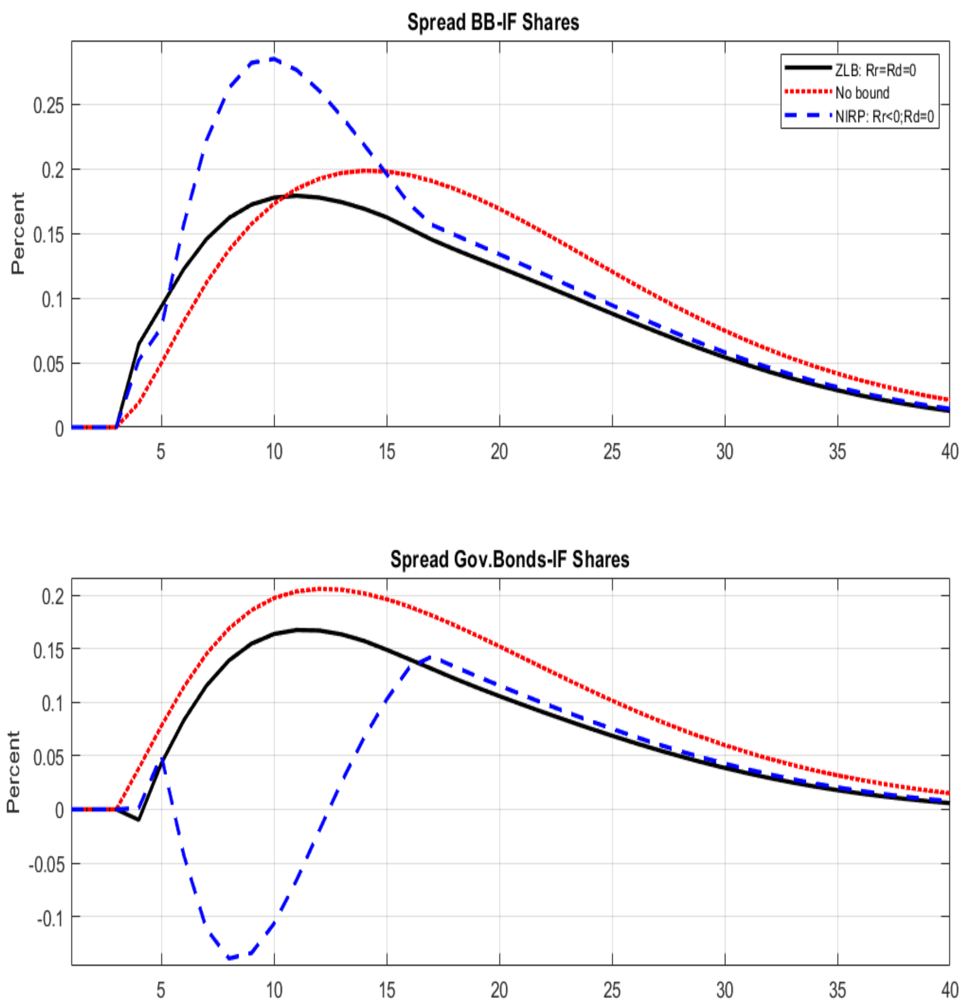


Figure 13: Output and CB net worth under different reserve shares (m)

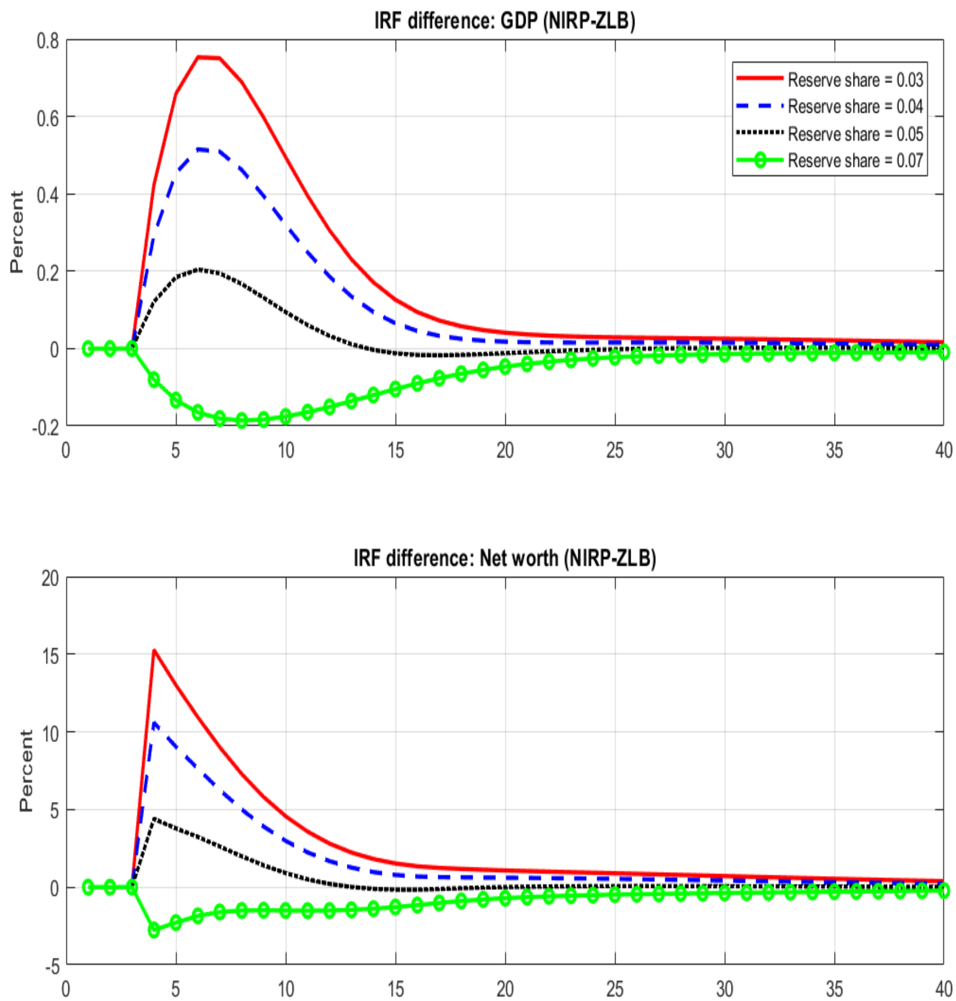


Figure 14: Bank bonds-deposits and loans-deposits spreads under different reserve shares (m)

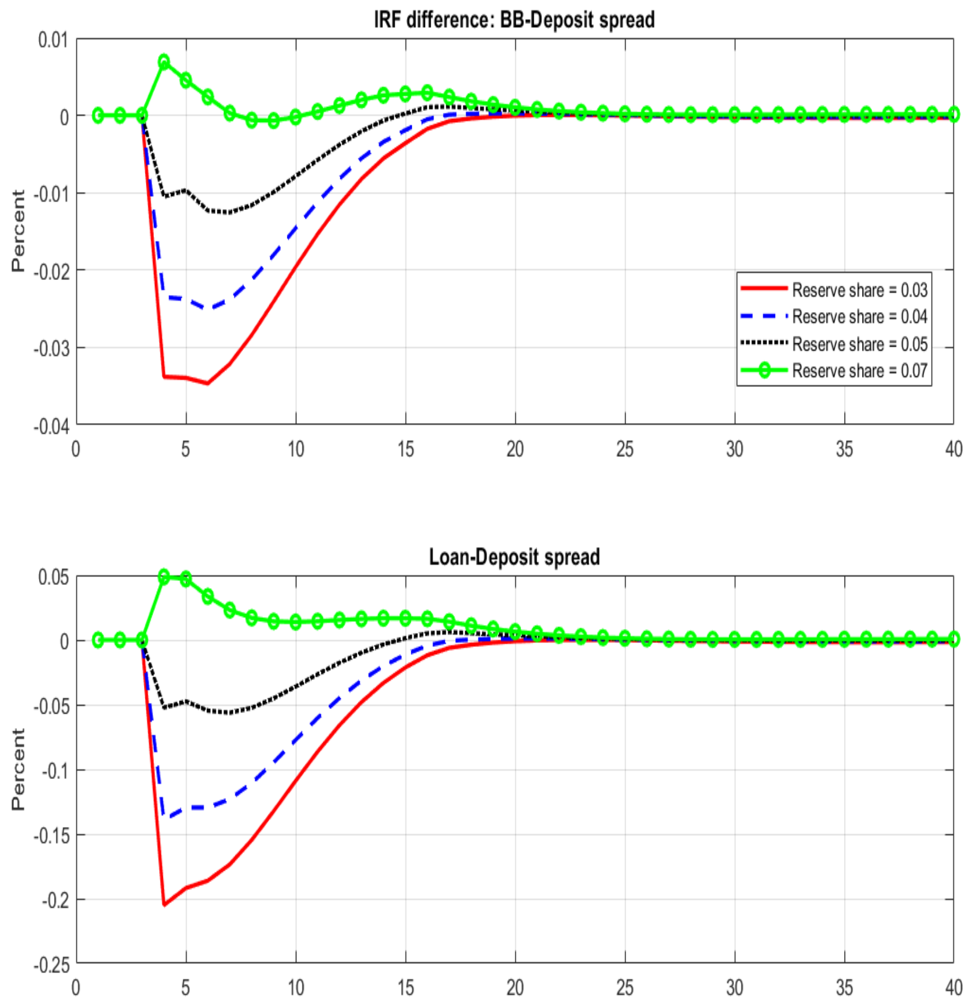


Figure 15: Output and CB net worth under different portfolio adjustment cost (a)

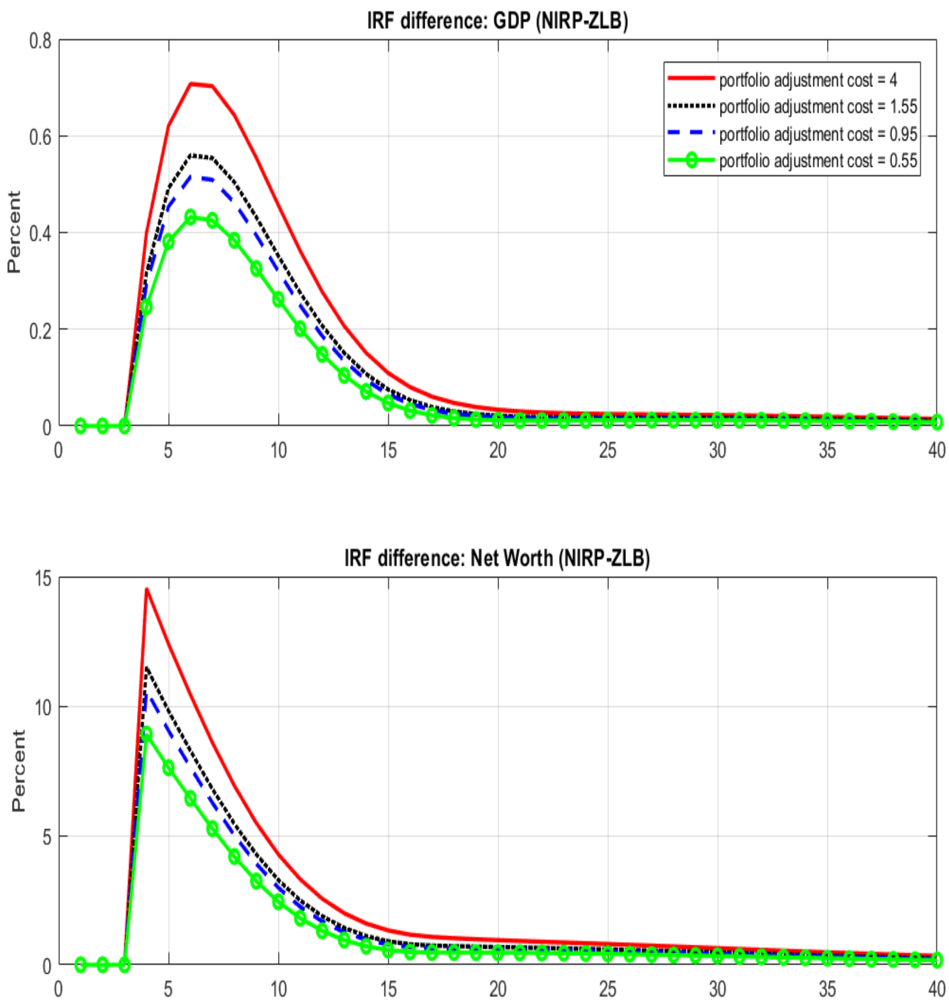


Figure 16: Bank bonds-deposits and loans-deposits spreads under different portfolio adjustment cost (a)

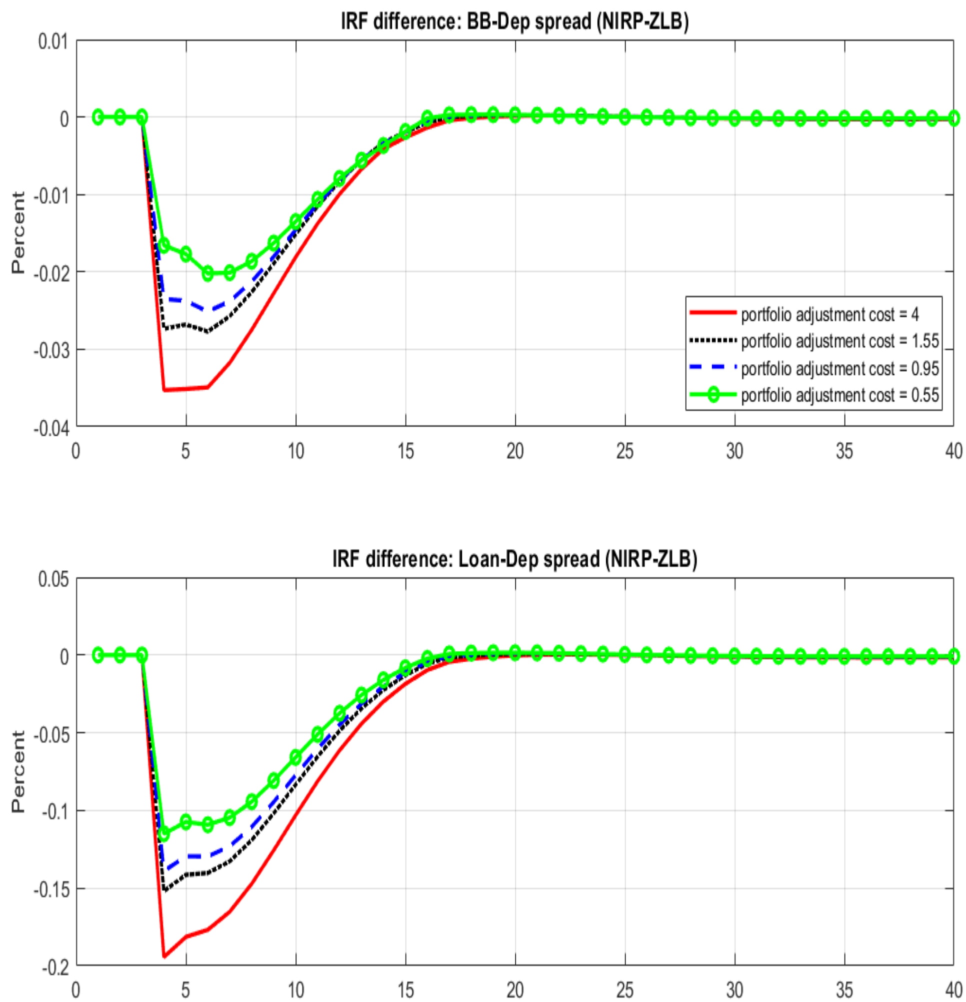


Figure 17: Output under different IF (inverse) cost of investing in bank bonds (ϱ^{IF})

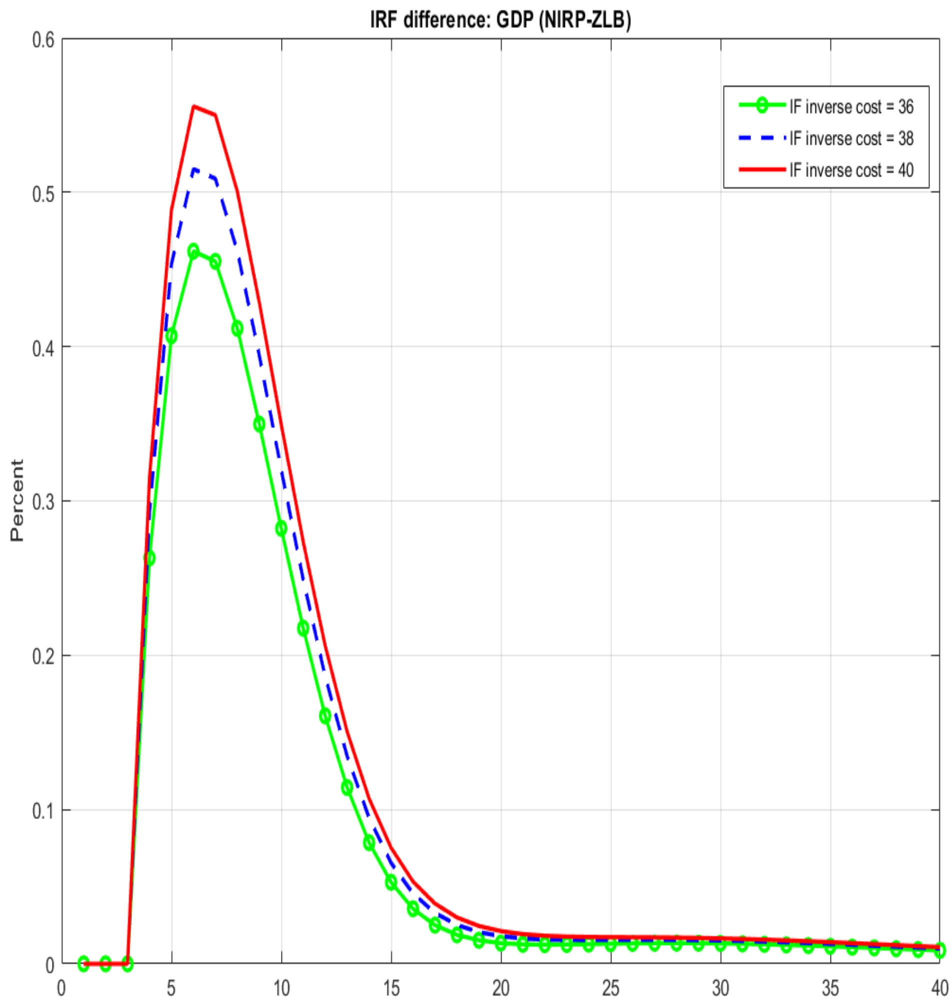


Figure 18: CB net worth under different IF (inverse) cost of investing in bank bonds (ϱ^{IF})

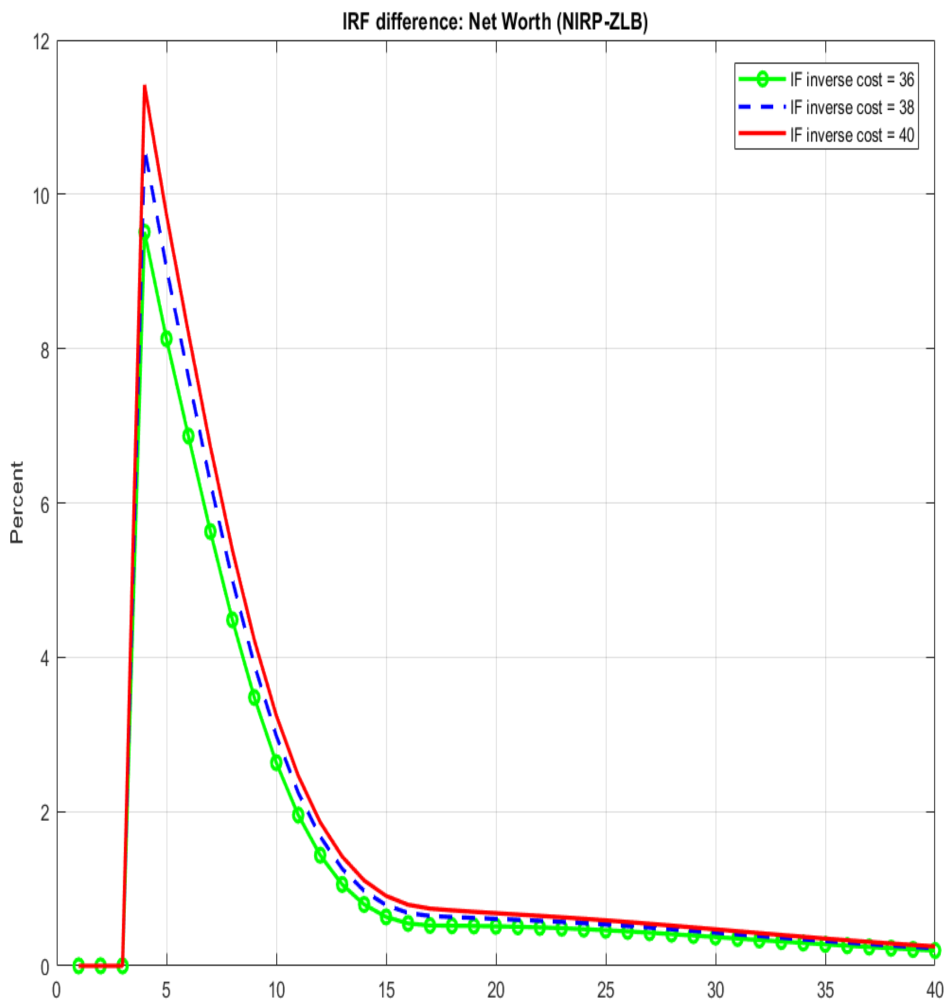


Figure 19: Bank bonds-deposits spread under different IF (inverse) cost of investing in bank bonds (ϱ^{IF})

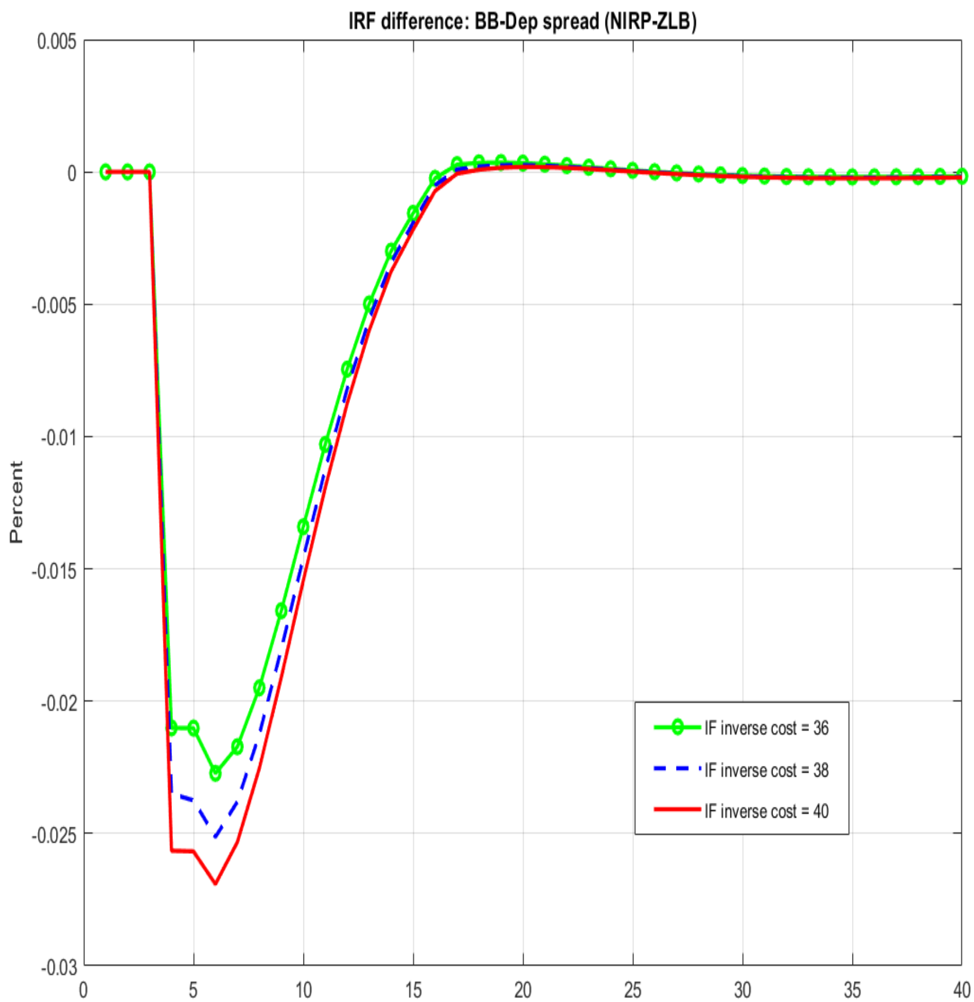


Figure 20: Loans-deposits spread under different IF (inverse) cost of investing in bank bonds $\left(\varrho^{IF}\right)$

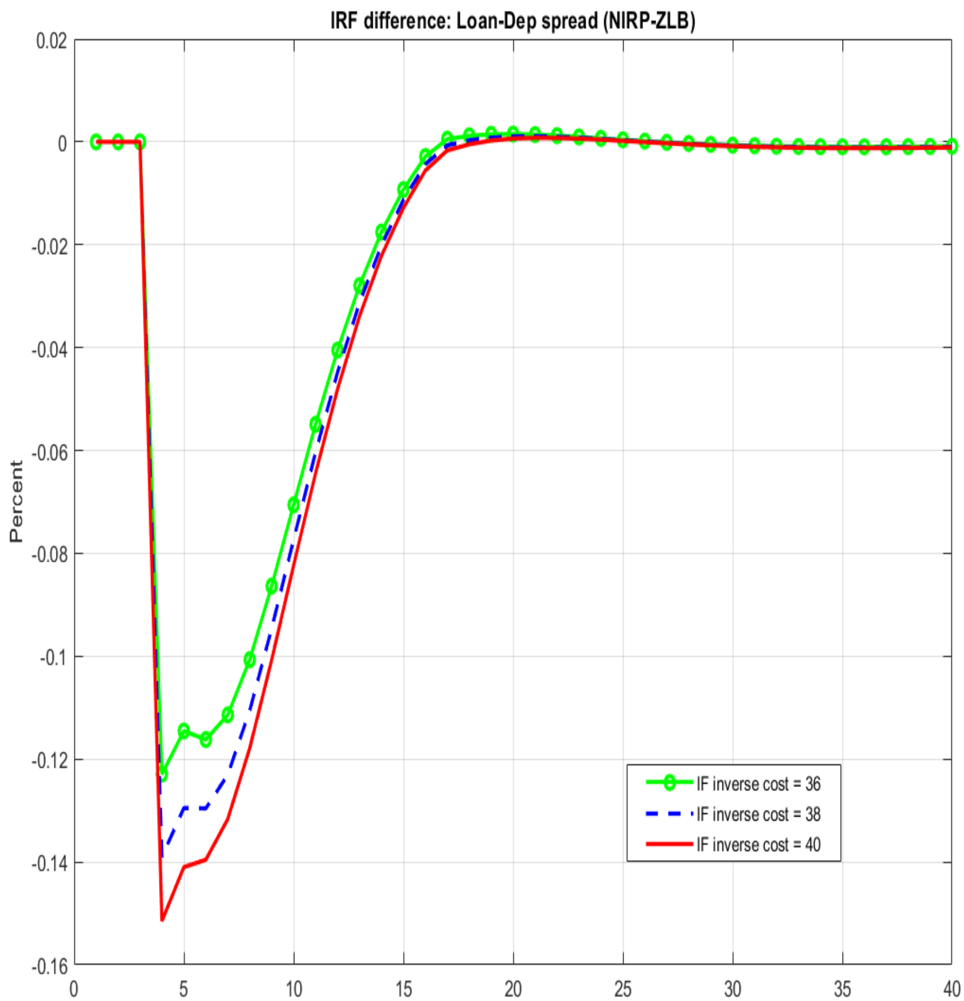


Figure 21: Output and CB net worth under different IF satiation point for government bond holdings $(\bar{B}^g)$

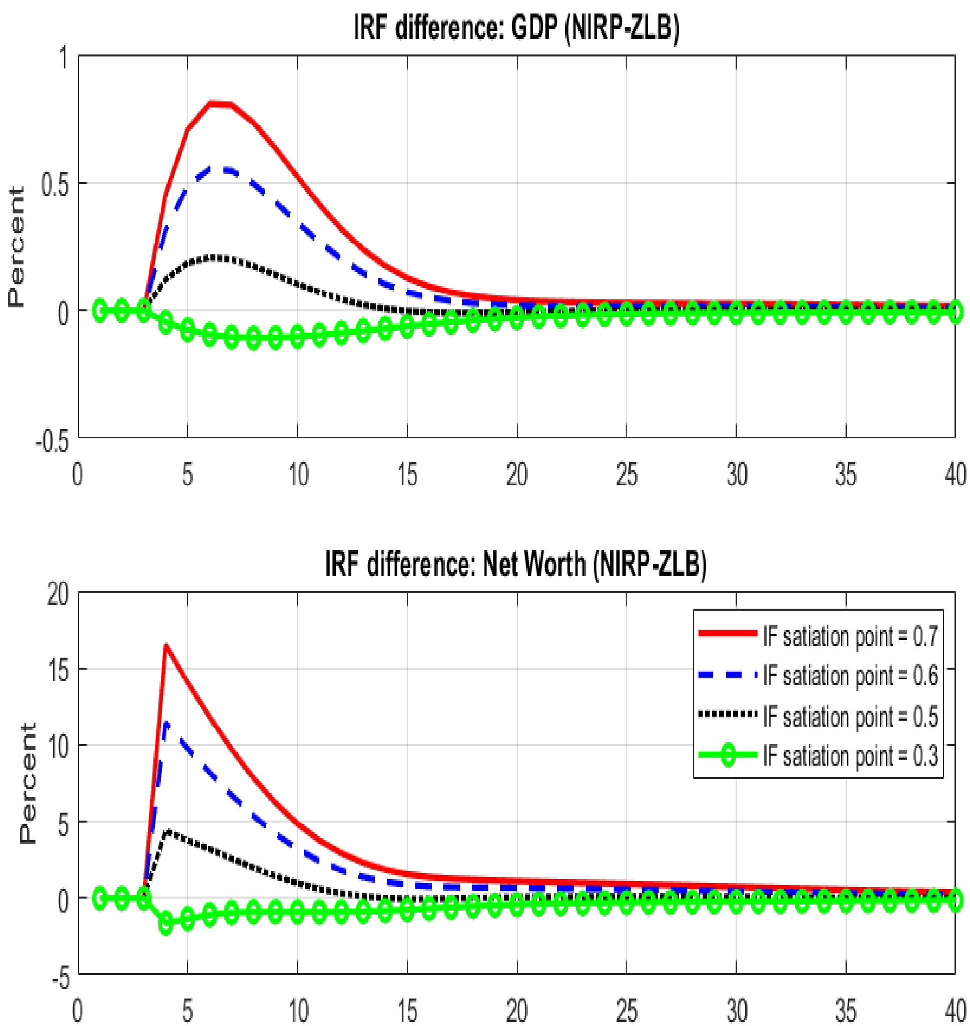


Figure 22: Output and CB net worth under different IF satiation point for government bond holdings $(\bar{B}^g)$