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Abstract

I analyze the effect of unconventional central bank lending operations on output through the credit provision channel, which is especially relevant in light of the European Central Bank's (ECB's) unconventional Longer-Term Refinancing Operations (LTROs) announced at the end of 2011. I construct a DSGE model containing balance-sheet-constrained commercial banks with a portfolio choice between private loans and government bonds. Commercial banks have access to central bank funding, for which they must pledge government bonds as collateral, which creates a link between central bank lending operations and commercial banks' portfolio choice. I find that the LTRO's cumulative impact on output is zero, irrespective of the haircut policy, i.e., the amount of central bank funding obtained for one euro of collateral. The haircut policy, however, allows the central bank to shift output losses between periods. I find that unlike central bank lending operations, a direct recapitalization by the fiscal authority does not induce a shift from private credit.

Keywords: 'Financial Intermediation; Macrofinancial Fragility; Unconventional Monetary Policy'

JEL: E32, E44, E52, G21

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1 Introduction

In December 2011 and February 2012, the European Central Bank (ECB) engaged in unconventional lending operations with the European commercial banking system to prevent a credit contraction, which would have had serious consequences for the macroeconomy (European Central Bank, 2012). These Longer-Term Refinancing Operations (LTROs) featured a long maturity (36 months) and a promise by the ECB to provide as much funding to the commercial banks as demanded against eligible collateral.[1] Commercial banks eventually took out more than €1000 billion in ECB funding, making the LTROs the largest refinancing operation in the history of the ECB. The goal of this paper is to investigate the macroeconomic impact of such unconventional central bank lending by linking such a program to the credit transmission channel.

Such a large program has the potential to affect aggregate investment, as this funding can potentially be used to provide new credit to the real economy. Effects on private credit provision are relevant in the Eurozone, as 80% of debt-financing to non-financial corporations is intermediated by commercial banks (European Central Bank, 2015).[2] In fact, expanding credit was one of the goals of the ECB, as stated by Mario Draghi, president of the ECB:

"...at least the banks will be more inclined to use the money - which was our prime expectation really - to expand credit to the real economy." European Central Bank (2012).

It is not so clear, however, whether the ECB funding was used to provide new loans to the private sector. European commercial banks were undercapitalized at the time (International Monetary Fund, 2011; Hoshi and Kashyap, 2015), which made it more difficult for them to expand the balance sheet to provide new credit. Empirical evidence suggests that lending to the real economy did not expand in Italy, Spain and Portugal, which took out more than 50% of LTRO funding (Bruegel, 2015), while (domestic) bondholdings sharply increased. In addition, Drechsler et al. (2016) find that weakly capitalized banks in the Eurozone borrowed more from the ECB, pledged riskier collateral, and actively invested in distressed sovereign debt after the European sovereign debt crisis began in 2010. Crosignani et al. (2017) finds that Portuguese banks purchased domestic bonds during the LTRO allotment. It is therefore not clear from an empirical point of view whether the funding was used to provide new credit to the real economy.

In this paper I investigate the impact of unconventional central bank lending operations on credit provision to the real economy and, through that channel, on output. Following up on this question, I compare the effectiveness of this policy with that of a recapitalization by the fiscal authority.

[1] Normally, the ECB provides cash loans to commercial banks under the Main Refinancing Operations (MROs) and the Longer-Term Refinancing Operations (LTROs). In exchange for cash loans, commecial banks must pledge eligible collateral. MROs have a maturity of one week, and LTROs of three months.

[2] Throughout the paper, I use 'commercial banks' and 'financial intermediaries' interchangeably to denote the same group of economic agents, which capture all kinds of credit institutions: commercial banks, savings banks, postbanks, and specialized credit institutions, among others.

European commercial banks have been undercapitalized since the financial crisis of 2007-2009 (International Monetary Fund, 2011; Hoshi and Kashyap, 2015). The Gertler and Karadi (2011) framework enables me to capture this feature, which I extend in two directions. First, commercial banks have a portfolio choice between government bonds and private loans, which are used by non-financial corporations to purchase productive 'physical' capital. For details, see Gertler and Karadi (2013) and Bocola (2016). Second, I introduce the possibility of collateralized central bank lending, which represents an alternative form of funding for commercial banks besides net worth and deposits. To obtain central bank funding, commercial banks have to pledge collateral, for which only government bonds are eligible. In line with LTRO policy at the time, the central bank has two instruments for its lending policy: the nominal interest rate on central bank funding and the collateral or haircut policy, which determines how much central bank funding is obtained for one euro of collateral. The haircut is the difference between the two. I model the LTRO by temporarily decreasing the interest rate on central bank funding with respect to the interest rate on deposits.

The main contribution of my paper is linking private credit provision and central bank lending operations by including a collateral constraint that determines how much central bank funding is obtained for one euro of government bonds. The requirement to pledge government bonds as collateral affects the portfolio decision between private loans and government bonds. This setup allows me to investigate the effect of unconventional central bank lending to commercial banks, such as the LTROs of December 2011 and February 2012. Within this framework I am also able to investigate the impact of the haircut policy on the credit provision channel and to explore the role of financial fragility in such operations.

My first result is that unconventional central bank lending to balance-sheet-constrained commercial banks has a contractionary short-run effect and an expansionary long-run effect. I distinguish two competing effects. First is the collateral effect, which has a contractionary effect on output. The LTRO increases the collateral value of government bonds. Commercial banks shift into government bonds and, consequently, must shed private loans. Credit provision to the real economy falls, with a contractionary effect on output.

Second is the subsidy effect, which has an expansionary effect on output. Because the interest rate on central bank funding is below the interest rate on regular deposits, the LTRO reduces funding costs and increases commercial bank profits. Banks' balance sheets recover more quickly, leading to a credit expansion. The collateral effect dominates the short-run effect, but disappears once the LTRO has ended. The subsidy effect is still present and dominates the long-run effect, which leads to an expansion of output.

My second and main result is that unconventional central bank lending does not have a cumulative effect on output. This result holds for different values of the haircut parameter. Interestingly, the haircut policy does have a pronounced effect on the time-pattern of output. A smaller haircut leads to a stronger collateral effect and a steeper short-run output contraction. At the same time, the smaller haircut leads to a stronger economic recovery in the long run through the subsidy effect. The mechanism is as follows. The smaller haircut increases the collateral value and leads to a larger shift into government bonds. More government bonds allow commercial banks to obtain more low-interest-rate central bank funding, thereby increasing commercial bank profits. Through the resulting faster balance sheet recovery, I obtain the expansionary effect that offsets the contractionary collateral effect.

A third result is that the provision of central bank funding, which amounts to an indirect recapitalization of the financial sector, is less effective in stimulating output than a direct recapitalization by the fiscal authority. A direct recapitalization provides commercial banks with new net worth and alleviates banks' balance sheets constraints. Contrary to central bank lending operations, a direct recap does not involve crowding out private loans by government bonds.

My paper is related to several strands of the literature. First, it relates to recent papers that study the transmission to the macroeconomy of shocks to the balance sheets of financial intermediaries (Gertler and Kiyotaki, 2010; Gertler and Karadi, 2011, 2013). In all these models, financial intermediaries face an endogenous leverage constraint that limits the size of the balance sheet for a given amount of net worth. Kirchner and van Wijnbergen (2016) extend this framework by introducing a portfolio choice between private loans and government debt. A debt-financed fiscal expansion increases commercial banks' bondholdings, which crowds out private credit. My framework also features crowding out through an alternative mechanism: the provision of central bank funding at an interest rate below that on deposits increases the collateral value of government bonds and makes government bonds more attractive.

Gertler and Kiyotaki (2010) and Bocola (2016) allow for central bank lending to financial intermediaries, in an otherwise similar setup as my paper. Bocola (2016), who explicitly looks at the LTRO, finds a small positive effect on lending and output because central bank funding relaxes bank balance sheet constraints in this setup. My paper differs in two dimensions: first, central bank funding does not directly relax bank balance sheet constraints, but does so only indirectly by providing debt financing at an interest below that on regular deposit funding. Second, commercial banks must pledge government bonds as collateral, giving rise to the collateral effect, which is absent in Gertler and Kiyotaki (2010) and Bocola (2016). Contrary to Bocola (2016), I find a contractionary short-run effect on private credit provision and output due to the collateral effect.

Contrary to Gertler and Kiyotaki (2010) and Bocola (2016), Schabert (2015) and Hörmann and Schabert (2015) include the requirement to pledge collateral to access central bank lending facilities. These papers find that a smaller haircut has an expansionary effect on output. My paper differs along two dimensions: first, Schabert (2015) and Hörmann and Schabert (2015) explicitly incorporate money holdings, as households face a cash-in-advance constraint for which they can borrow at the central bank. Instead, I consider a cashless economy in which central bank lending is an alternative form of debt financing at an interest rate (possibly) below that on deposits. Second, instead of providing central bank funding to unconstrained households, commercial banks in my model are the only agents in the economy with access to central bank funding. Because commercial banks are balance-sheet-constrained, forcing them to pledge collateral to obtain central bank funding affects the portfolio decision between private loans and government bonds, giving rise to the collateral effect. Contrary to Schabert (2015) and Hörmann and Schabert (2015), I find that the haircut policy does not have a cumulative impact on output, because the expansionary subsidy effect is offset by the short-run collateral effect.

Finally, my paper connects to the literature on government bond accumulation by commercial banks. Becker and Ivashina (2016) find empirical evidence for the crowding out of private loans by increased holdings of government bonds and for financial repression by governments. Crosignani (2016) develops a general equilibrium model in which banks shift into domestic sovereign debt when undercapitalized. Domestic sovereign debt has the highest payoff in the good state of the world, which is the only state banks care about. Banks have limited liability, and therefore do not care about being bankrupt in the bad state of the world. Hence, government bond accumulation by commercial banks arises because of risk shifting. Government bond accumulation in my model arises because commercial banks need government bonds for collateral purposes when the central bank engages in special lending operations with commercial banks.

I describe some stylized facts in section 2. The model description can be found in section 3, while section 4 discusses the calibration of my model. Section 5 presents the results from my simulations, and section 6 concludes the paper.

2 Stylized facts

Credit institutions in the Eurozone play a crucial role in the provision of credit to the real economy, as they intermediate approximately 80% of debt financing to non-financial corporations (European Central Bank, 2015). The LTROs of December 2011 and February 2012 provided credit institutions with fresh liquidity amounting to approximately 10% of Eurozone GDP. However, did the credit institutions use this funding to provide new loans to the real economy? Did they expand their balance sheets? In this section, I present some stylized facts regarding the aggregated balance sheets of Monetary Financial Institutions (MFIs) at the time of the LTROs of December 2011 and February 2012.

Data about the refinancing operations of the ECB were collected from Bruegel (2015), while balance sheet data of MFIs were collected from the ECB's statistical warehouse (European Central Bank, 2015). The time series have a monthly frequency. Balance sheet data of MFIs, excluding the European System of Central Banks, are available at a country level.[3] The vast majority of euro-area MFIs are credit institutions (i.e., commercial banks, savings banks, postbanks, specialized credit institutions, among others) (European Central Bank, 2011b).

[3]MFIs include "credit institutions and non-credit institutions (mainly money market funds) whose business is to receive deposits from entities other than MFIs and to grant credit and/or invest in securities" (European Central Bank, 2011b).

Country use of ECB funding

Figure 1 shows the stock of total refinancing operations in the Eurozone, as well as the country use by MFIs in Italy, Spain and Portugal. Total refinancing operations consist of Main Refinancing Operations (MROs) and Longer-Term Refinancing Operations (LTROs), which differ in their respective maturity. MROs have a maturity of one week, while regular LTROs feature a maturity of three months. Contrary to regular LTROs, the LTROs of December 2011 and February 2012 featured a maturity of 36 months. I show the sum of MROs and LTROs because part of the LTROs of December 2011 and February 2012 were used to repay outstanding MROs and/or roll over outstanding LTROs.

Country use of ECB funding

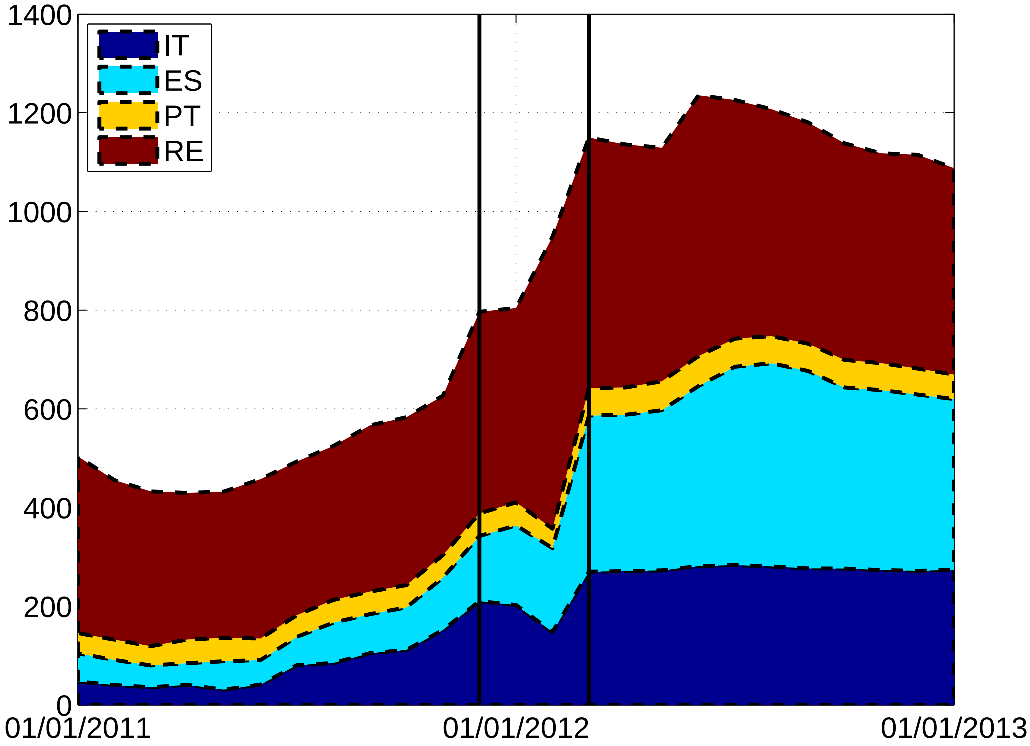


Figure 1: Country use of outstanding MROs and LTROs by MFIs in Italy (IT), Spain (ES), Portugal (PT) and the rest of the Eurozone (RE) in € billion from January 2011 to January 2013. The two vertical lines refer to December 1st, 2011 and March 1st, 2012, which mark the beginning of the period in which the two LTROs took place and the end, respectively. *Source:* Bruegel (2015).

Figure 1 suggests three main observations. First, the stock of total refinancing operations increased by approximately €350 billion during the period in which the two unconventional LTROs were undertaken. The net increase is smaller than the gross increase of €1000 billion, which was mentioned in the introduction, because part of the gross increase has been used to repay outstanding MROs and/or roll over outstanding LTROs. Second, a disproportionate share of the funding went to MFIs in Italy, Spain and Portugal. By March 1st, 2012, more than 50% of total ECB funding had been borrowed by MFIs from these countries, while their cumulative share in Eurozone GDP is less than one-third. Apparently, the LTROs of December 2011 and February 2012 were especially attractive for MFIs in Italy, Spain and Portugal. Third, the use of ECB funding by MFIs from these three countries amounted to a large share of their respective GDP. On March 1st, 2012, ECB funding accounted for €200 billion of debt funding for Italian MFIs, which is close to 20% of Italian GDP. For Spain, this number is as high as €400 billion, which amounts to 40% of Spanish GDP. To sum up, ECB funding constituted a significant source of debt funding for MFIs in Italy, Spain and Portugal.

Balance sheet composition MFIs

Figure 2 shows the total asset holdings of MFIs in Italy, Spain and Portugal. I normalize total asset holdings to 100 on December 1st, 2011 which is one week before the unconventional LTROs were announced by the ECB (European Central Bank, 2011a). The figure suggests a small expansion in total MFI assets during the period in which the two LTROs took place.

Total assets MFIs in Italy, Spain and Portugal

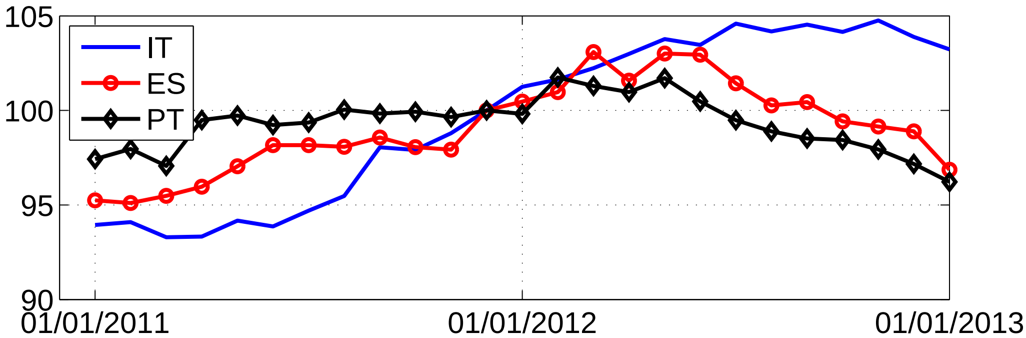


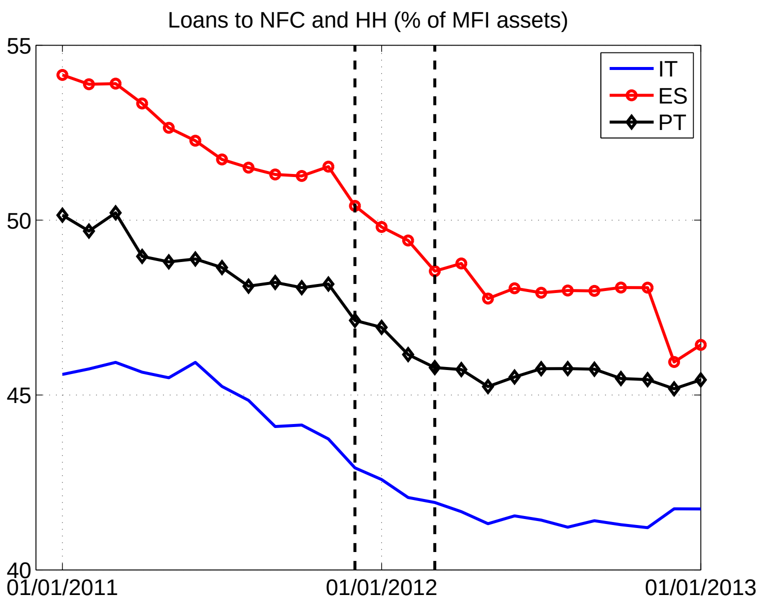
Figure 2: Total assets of Monetary Financial Institutions (MFI's) excluding the European System of Central Banks in Italy (IT), Spain (ES), and Portugal (PT) from January 2011 to January 2013. Levels were rescaled with respect to total assets on December 1st, 2011, which has a value of 100 in all three plots. *Source:* ECB.

A more important question from a macroeconomic point of view is whether credit to non-financial corporations and households expandedwith doubts raised by Panel 3a, which depicts private credit to the real economy as a percentage of total MFI assets: credit fell by one to two percentage points in all three countries during the period in which the two LTROs took place. There seems to be a clear break between credit levels (as a percentage of MFI assets) in the period before December 2011 and those in the period after March 2012 in Portugal and Spain. Although credit as a percentage of total MFI assets also fell in Italy during this period, credit had already been falling in the months before the first intervention, and it is less clear whether the fall can be attributed to the two LTROs. Given that balance sheets expanded very little (Figure 2), the data suggest that private credit intermediation measured in euros fell. The data clearly indicate that a credit expansion, as envisaged by ECB President Draghi, did not occur.

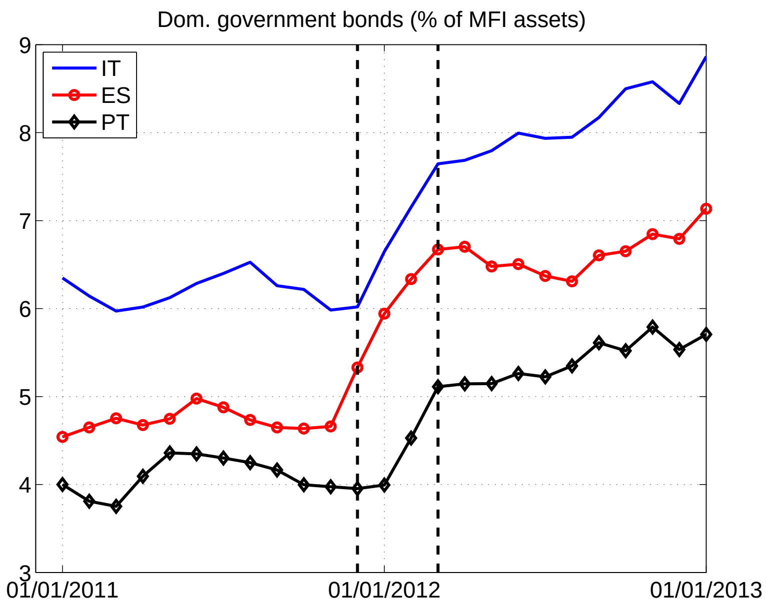
At the same time, Panel 3b shows an increase in domestic government bondholdings of one to one-and-a-half percentage points of total MFI assets for all three countries during the period, amounting to a striking increase of 30% in euros of government bondholdings. This result is in line with the findings of Drechsler et al. (2016) and Crosignani et al. (2017). There is a clear break between government bondholdings in the period before December 2011 and those in the period after March 2012.

These figures give a mixed message: while balance sheets slightly expanded in the direct aftermath of the LTROs, MFIs shifted from private credit to government bonds, given the fraction of total assets invested in a particular asset class. One possible explanation for this finding is that government bonds can easily be pledged as collateral to obtain funding from the ECB. In addition, haircuts, i.e., the amount of central bank funding obtained for one euro of collateral, are usually small for government bonds. Loans to non-financial corporations and households, however, are usually difficult to convert into eligible collateral, and usually come with a larger haircut.

Balance sheet composition MFIs in Italy, Spain and Portugal



(a)



(b)

Figure 3: Balance sheet composition of Monetary Financial Institutions (MFIs) excluding the European System of Central Banks in Italy (IT), Spain (ES), and Portugal (PT) from January 2011 to January 2013. Panel 3a shows loans to non-financial corporations (NFC) and households (HH) as a percentage of total MFI assets. Panel 3b shows domestic government bondholdings as a percentage of total MFI assets. The two dashed vertical lines refer to December 1st, 2011 and March 1st, 2012, respectively, which mark the beginning and the end of the period in which the two LTROs took place, respectively. *Source:* ECB.

3 Model

3.1 Model overview

I consider a standard New-Keynesian model, which includes commercial banks that are balance-sheet-constrained, as in Gertler and Karadi (2011), and have a portfolio choice between private loans and government bonds, as in Gertler and Karadi (2013). The asset side is financed by net worth, deposits and central bank funding. Commercial banks need to pledge collateral in the form of government bonds to obtain funding from the central bank, while private loans are not eligible as collateral. The central bank determines the interest rate on both regular deposits and central bank funding and how much funding commercial banks receive for one euro in government bonds, i.e., the haircut applied to collateral. The central bank can decrease the interest rate on central bank funding in times of financial crises, compared with the interest rate on regular household deposits, and finances its lending operations by issuing deposits to households. Central bank profits and losses are transferred period by period to the fiscal authority.

In addition to commercial banks and a central bank, the economy contains households, a production sector, and a fiscal authority. Each household consists of workers and bankers. Workers supply labor to intermediate goods producers, while bankers run the commercial banks. Intermediate goods producers borrow from commercial banks to purchase physical capital from capital goods producers, who face convex adjustment costs. Labor is hired the next period, together with capital used for the production of the intermediate good. Intermediate goods producers sell their goods to retail goods producers and sell the used capital back to the capital goods producers. Retail goods producers face monopolistic competition and price-stickiness, as in Calvo (1983) and Yun (1996). Final goods producers operate in a perfectly competitive market and purchase from retail goods producers while taking prices as given. The final good is sold to households for consumption, to capital goods producers as investment, and to the government. The government honors outstanding obligations, (potentially) provides financial sector support, covers possible central bank losses, and finances these expenditures by raising lump-sum taxes and issuing (long-term) debt, in a way similar to Woodford (1998, 2001). Fiscal policy is determined via (exogenous) fiscal rules.

3.2 Households

A continuum of households with measure one are infinitely lived, and exhibit identical preferences and asset endowments. Each household consists of bankers and workers. There is perfect consumption insurance within the household, which allows me to keep the representative agent representation. Households obtain utility from consumption c_t, while labor h_t provides disutility. Households receive income from labor at wage rate w_t. Households can invest in one period debt a_t, which consists of deposits d_t and loans to the central bank (CB) d_t^{cb}, which can be treated as perfect substitutes from the household's point of view by assumption, i.e. $a_t = d_t + d_t^{cb}$. Investment of a_{t-1} in period $t-1$ yields repayment of principal a_{t-1} and interest r_t^d in period

t. Households can also invest in government bonds with return r_t^b on their holdings $q_{t-1}^b s_{t-1}^{b,h}$, where q_{t-1}^b is the bond price in period $t-1$, and $s_{t-1}^{b,h}$ the number of bonds purchased in period $t-1$. Besides that, they receive income from profits Π_t from the production sector and the financial sector. Income is used for consumption c_t, investment in one period debt a_t and investment in government bonds $s_t^{b,h}$ at price q_t^b. Households pay a cost for the intermediation of government bonds, which is quadratic in the deviation of the number of bonds from the level $\hat{s}_{b,h}$ to capture in a simple way the limited participation in asset markets by households (Gertler and Karadi, 2013). The government levies lump sum taxes τ_t. Household members derive utility from consumption and leisure, with habit formation in consumption to more realistically capture consumption dynamics, as in Christiano et al. (2005).Households maximize expected life-time utility subject to the budget constraint:

$$\max_{\left\{c_{t+i},h_{t+i},a_{t+i},s_{t+i}^{b,h}\right\}_{i=0}^{\infty}} E_t \qquad \left\{\sum_{i=0}^{\infty}\beta^i\left[\log\left(c_{t+i}-\upsilon c_{t-1+i}\right)-\Psi\frac{h_t^{1+\varphi}}{1+\varphi}\right]\right\}$$

s.t.

$$c_t+\tau_t+a_t+q_t^b s_t^{b,h}+\frac{\kappa_{s_{b,h}}}{2}\left(s_t^{b,h}-\hat{s}_{b,h}\right)^2 \quad = \quad w_t h_t+\left(1+r_t^d\right)a_{t-1}+\left(1+r_t^b\right)q_{t-1}^b s_{t-1}^{b,h}+\Pi_t$$

This will give rise to the following first order conditions:

$$c_t \quad : \quad \lambda_t=\left(c_t-\upsilon c_{t-1}\right)^{-1}-\beta\upsilon E_t\left[\left(c_{t+1}-\upsilon c_t\right)^{-1}\right], \tag{1}$$

$$h_t \quad : \quad \Psi h_t^{\varphi}=\lambda_t w_t, \tag{2}$$

$$a_t \quad : \quad E_t\left[\beta\Lambda_{t,t+1}\left(1+r_{t+1}^d\right)\right]=1, \tag{3}$$

$$s_t^{b,h} \quad : \quad E_t\left\{\beta\Lambda_{t,t+1}\left[\frac{\left(1+r_{t+1}^b\right)q_t^b}{q_t^b+\kappa_{s_{b,h}}\left(s_t^{b,h}-\hat{s}_{b,h}\right)}\right]\right\}=1, \tag{4}$$

where λ_t is the marginal utility of consumption. The household's stochastic discount factor is $\beta\Lambda_{t,t+1}=\beta\lambda_{t+1}/\lambda_t$. Equation (1) denotes the marginal utility from an additional unit of consumption, while equation (2) equates the marginal cost from an additional unit of labor in the form of disutility with the marginal benefit from additional wage income. Equation (3) and (4) weigh the benefit from an additional unit of consumption tomorrow from investing in deposits respectively government bonds, with the cost of lower consumption today.

3.3 Financial intermediaries

3.3.1 Optimization problem

Financial intermediaries channel funds from savers to borrowers. They invest in two asset classes: private loans to intermediate goods producers $s_{j,t}^{k,p}$ and government bonds $s_{j,t}^{b,p}$. Total assets $p_{j,t}$

are given by:

$$p_{j,t} = q_t^k s_{j,t}^{k,p} + q_t^b s_{j,t}^{b,p},$$

where q_t^k is the price of private loans, and q_t^b the price of government bonds. Intermediaries fund their assets through net worth $n_{j,t}$, risk-free household deposits $d_{j,t}$ and central bank funding $d_{j,t}^{cb}$:

$$p_{j,t} = n_{j,t} + d_{j,t} + d_{j,t}^{cb},$$

New net worth is the difference between the return on assets and the return on debt funding. Net worth can be increased through financial sector support by the government, which is proportional to previous period net worth ($n_{j,t}^g = \tau_t^n n_{j,t-1}$). Net worth decreases when the financial sector has to repay previously administered support, which is also proportional to previous period net worth, ($\tilde{n}_{j,t}^g = \tilde{\tau}_t^n n_{j,t-1}$). τ_t^n and $\tilde{\tau}_t^n$ will be defined in section 3.5. The law of motion for individual net worth is given by:

$$\begin{aligned} n_{j,t+1} &= \left(1 + r_{t+1}^k\right) q_t^k s_{j,t}^{k,p} + \left(1 + r_{t+1}^b\right) q_t^b s_{j,t}^{b,p} \\ &- \left(1 + r_{t+1}^d\right) d_{j,t} - \left(1 + r_{t+1}^{cb}\right) d_{j,t}^{cb} + n_{j,t+1}^g - \tilde{n}_{j,t+1}^g \\ &= \left(1 + r_{t+1}^k + \tau_{t+1}^n - \tilde{\tau}_{t+1}^n\right) q_t^k s_{j,t}^{k,p} + \left(1 + r_{t+1}^b + \tau_{t+1}^n - \tilde{\tau}_{t+1}^n\right) q_t^b s_{j,t}^{b,p} \\ &- \left(1 + r_{t+1}^d + \tau_{t+1}^n - \tilde{\tau}_{t+1}^n\right) d_{j,t} - \left(1 + r_{t+1}^{cb} + \tau_{t+1}^n - \tilde{\tau}_{t+1}^n\right) d_{j,t}^{cb}, \end{aligned}$$

where r_t^k is the net real return on private loans in period t, r_t^b the net real return on government bonds, r_t^d the net real return on deposits and r_t^{cb} the net real return on central bank funding. Following Gertler and Karadi (2011), I assume intermediaries are forced to shut down with probability σ, which is i.i.d. and exogenous, both in time and the cross-section. When the intermediary is forced to stop operating, all net worth is paid out to the household, the ultimate owners of the financial intermediary. The financial intermediary maximizes expected future discounted profits:

$$\begin{aligned} & V\left(s_{j,t-1}^{k,p}, s_{j,t-1}^{b,p}, d_{j,t-1}, d_{j,t-1}^{cb}\right) \\ = \; & \max E_t \left\{\beta \Lambda_{t,t+1} \left[(1-\sigma) n_{j,t+1} + \sigma V\left(s_{j,t}^{k,p}, s_{j,t}^{b,p}, d_{j,t}, d_{j,t}^{cb}\right)\right]\right\} \end{aligned}$$

Households face an agency problem when deciding on the amount of funds to save through deposits, as in Gertler and Karadi (2011, 2013): financial intermediaries have the capability to divert assets when moving from the current to the next period. Depositors can force the intermediary into bankruptcy in that case, but will only recoup a fraction $1 - \lambda_a$ of asset class $a = \{k, b\}$. The remaining fraction λ_a of each asset class is paid out as a dividend to the household owning the intermediary. Depositors, however anticipate this possibility, and will in equilibrium only provide deposits up to the point where the continuation value of the intermediary is larger or equal than the opportunity cost of diverting the assets.

$$V\left(s^{k,p}_{j,t-1}, s^{b,p}_{j,t-1}, d_{j,t-1}, d^{cb}_{j,t-1}\right) \geq \lambda_k q^k_t s^{k,p}_{j,t} + \lambda_b q^b_t s^{b,p}_{j,t}. \tag{5}$$

Financial intermediaries have access to central bank funding $d^{cb}_{j,t}$, but are required to pledge collateral in the form of government bonds. The commercial bank remains the legal owner of the bond, and will receive the interest payments from the bond after repayment of $d^{cb}_{j,t}$ to the central bank in period $t+1$, unless the financial intermediary becomes insolvent, a case I abstain from through a proper calibration. The collateral constraint has the following functional form:

$$d^{cb}_{j,t} \leq \theta_t q^b_t s^{b,p}_{j,t}, \tag{6}$$

where θ_t is the haircut parameter that regulates the collateral policy of the central bank, see section 3.5. A low θ_t, or a high haircut, indicates that a commercial bank will obtain little central bank financing for a euro of government bonds. The optimization problem of the financial intermediary can now be formulated:

$$\begin{aligned}
V_{j,t} &= \max_{\left\{s^{k,p}_{j,t}, s^{b,p}_{j,t}, d_{j,t}, d^{cb}_{j,t}\right\}} E_t\left\{\beta\Lambda_{t,t+1}\left[(1-\sigma)\, n_{j,t+1} + \sigma V_{j,t+1}\right]\right\}, \\
& \text{s.t.} \\
V_{j,t} &\geq \lambda_k q^k_t s^{k,p}_{j,t} + \lambda_b q^b_t s^{b,p}_{j,t}, \\
n_{j,t} + d_{j,t} + d^{cb}_{j,t} &= q^k_t s^{k,p}_{j,t} + q^b_t s^{b,p}_{j,t}, \\
n_{j,t} &= \left(1 + r^k_t + \tau^n_t - \tilde{\tau}^n_t\right) q^k_{t-1} s^{k,p}_{j,t-1} + \left(1 + r^b_t + \tau^n_t - \tilde{\tau}^n_t\right) q^b_{t-1} s^{b,p}_{j,t-1} \\
&- \left(1 + r^d_t + \tau^n_t - \tilde{\tau}^n_t\right) d_{j,t-1} - \left(1 + r^{cb}_t + \tau^n_t - \tilde{\tau}^n_t\right) d^{cb}_{j,t-1}, \\
\theta_t q^b_t s^{b,p}_{j,t} &\geq d^{cb}_{j,t},
\end{aligned}$$

where I have abbreviated the value function of the financial intermediary by:

$$V_{j,t} = V\left(s^{k,p}_{j,t-1}, s^{b,p}_{j,t-1}, d_{j,t-1}, d^{cb}_{j,t-1}\right).$$

3.3.2 First order conditions

Appendix A.1 shows that the problem of the financial intermediary leads to the following first-order conditions:

$$\frac{\lambda_b}{\lambda_k} E_t \left[\Omega_{t,t+1} \left(r^k_{t+1} - r^d_{t+1}\right)\right] = E_t \left[\Omega_{t,t+1} \left(r^b_{t+1} - r^d_{t+1}\right)\right] + \theta_t \left(\frac{\psi_t}{1+\mu_t}\right), \tag{7}$$

$$\lambda_k \left(\frac{\mu_t}{1+\mu_t}\right) = E_t \left[\Omega_{t,t+1} \left(r^k_{t+1} - r^d_{t+1}\right)\right], \tag{8}$$

$$\frac{\psi_t}{1+\mu_t} = E_t \left[\Omega_{t,t+1} \left(r^d_{t+1} - r^{cb}_{t+1}\right)\right], \tag{9}$$

$$\eta_t = E_t \left[\Omega_{t,t+1} \left(1 + r^d_{t+1} + \tau^n_{t+1} - \tilde{\tau}^n_{t+1}\right)\right], \tag{10}$$

where μ_t is the Lagrange multiplier on the bank's balance sheet constraint (5), and ψ_t the Lagrangian multiplier on the collateral constraint (6). η_t denotes the shadow value of an additional unit of net worth. $\Omega_{t,t+1} = \beta \Lambda_{t,t+1} \left[(1-\sigma) + \sigma (1+\mu_{t+1}) \eta_{t+1}\right]$ is the intermediaries' stochastic discount factor, and can be interpreted as the household's stochastic discount factor $\beta \Lambda_{t,t+1}$, augmented by an additional term to incorporate the effect of the financial frictions.

First order condition (7) pins down the bank's portfolio choice on the asset side of the balance sheet. The left hand side denotes the marginal benefit to the financial intermediary from investing an additional unit of private loans, valued by the intermediaries' stochastic discount factor, and corrected by the term λ_b/λ_k to reflect the fact that the financial friction is more severe for private loans than for government bonds. The right hand side denotes the marginal cost of giving up an additional unit of government bonds, measured by the credit spread between government bonds and the deposit rate. But government bonds also derive value from the fact that they serve as collateral with which intermediaries can obtain central bank funding, which is reflected by the second term on the right hand side of equation (7).

Equation (8) is the first order condition for private loans. We clearly see that the presence of a binding bank balance sheet constraint ($\mu_t > 0$ in equation (5)) limits the ability of commercial banks to arbitrage away the difference between the expected rate of return on private loans and deposits, since commercial banks cannot expand the balance sheet.

The portfolio choice on the liabilities side of the balance sheet is given by equation (9): an increase in the credit spread between deposits and central bank funding $r^d_{t+1} - r^{cb}_{t+1}$ increases the collateral value of government bonds ψ_t everything else equal, and leads to a shift into government bonds, see (7), which allows the commercial bank to increase the amount of central bank funding.

Equation (10) shows the shadow value of an additional unit of net worth η_t, which is equal to the expected gross return on deposits, discounted by the intermediaries' stochastic discount factor $\Omega_{t,t+1}$. The expected return is augmented by the financial sector support per unit of net worth τ^n_{t+1} and the repayment per unit of net worth $\tilde{\tau}^n_{t+1}$. Using these first order conditions, I can derive the following proposition:

Proposition 1. *central bank lending and the collateral policy only have a first order effect when both the bank balance sheet constraint* (5) *is binding* ***and*** *the interest rate on deposits* r^d_{t+1} *is not equal to the interest rate on central bank funding* r^{cb}_{t+1}.

Lemma 1. *If the bank balance sheet constraint* (5) *is not binding, then there is no first order effect from central bank lending on private credit.*

Proof. Consider optimal choices for the financial intermediary. When equation (5) is not binding, μ_t is equal to zero. From equation (8), we see that the expected return on private loans must equal the expected rate on deposits. The term on the left hand side of equation (7) is zero, and is not affected by ψ_t, which captures the effects from central bank lending. □

Lemma 2. *When the interest rate on deposits* r^d_{t+1} *and central bank funding* r^{cb}_{t+1} *are equal, there is no effect from central bank lending and/or the haircut parameter* θ_t.

Proof. When $r^d_{t+1} = r^{cb}_{t+1}$, we find from equation (9) that $\psi_t = 0$. This implies that the second term on the right hand side of equation (7) drops out. This is the only first order condition where ψ_t, which measures the collateral value of government bonds, and the haircut parameter θ_t show up. Hence, central bank lending does not affect the portfolio decision between private loans and government bonds. □

Proof of Proposition 1. To have an effect from central bank lending, lemma 2 shows that the interest rate on deposits and central bank funding has to differ. Lemma 1 shows that even when the interest rate on deposits and central bank funding is different (captured by $\psi_t > 0$), there is no first order effect unless the bank balance sheet constraint is binding ($\mu_t > 0$). □

Note that when the interest rate on deposits and central bank funding is the same ($\psi_t = 0$), commercial banks are indifferent between the two funding sources, since the collateral value of government bonds is now zero. Deposits and central bank funding are perfect substitutes. Hence I can take the collateral constraint to be binding in my simulations, irrespective of the difference between the interest rate on deposits and that on central bank funding.

Because of the proposition, and the fact that European commercial banks have been undercapitalized since the financial crisis of 2007-2009 (International Monetary Fund, 2011; Hoshi and Kashyap, 2015), I will take both the bank's balance sheet constraint (5) and the collateral constraint (6) to be binding in my simulations. When the bank's balance sheet constraint (5) is binding, I can rewrite it into the following equation:

$$(1 + \mu_t)\,\eta_t n_{j,t} \quad = \quad \lambda_k q^k_t s^{k,p}_{j,t} + \lambda_b q^b_t s^{b,p}_{j,t}, \tag{11}$$

It is clear from equation (11) that the size of the balance sheet is limited by the amount of current net worth $n_{j,t}$.

3.3.3 Aggregate law of motion net worth

The law of motion for aggregate net worth consists of the net worth of the bankers that are allowed to continue operating, together with the aggregate net worth given to new bankers, which is equal to a fraction χ of previous period assets p_{t-1}. Together with net government support $n_t^g - \tilde{n}_t^g$, I obtain the following law of motion:

$$\begin{aligned} n_t &= \sigma\left[\left(r_t^k - r_t^d\right) q_{t-1}^k s_{t-1}^k + \left(r_t^b - r_t^d\right) q_{t-1}^b s_{t-1}^b + \left(r_t^d - r_t^{cb}\right) d_{t-1}^{cb} + \left(1 + r_t^d\right) n_{t-1}\right] \\ &+ \chi p_{t-1} + n_t^g - \tilde{n}_t^g. \end{aligned} \tag{12}$$

I introduce the variable ω_t^k to denote the fraction of assets invested in private loans:

$$\omega_t^k = q_t^k s_t^k / p_t. \tag{13}$$

3.4 Production sector

The production factor is modeled in standard New-Keynesian fashion. I will shortly outline the setup below, with a more detailed exposition in appendix A.2.

3.4.1 Intermediate Goods Producers

A continuum of intermediate goods producers, that face perfect competition, acquire capital $k_{i,t-1}$ from capital producers at the end of period $t-1$ for a price q_{t-1}^k through a state-contingent loan $s_{i,t-1}^k = k_{i,t-1}$ from the financial intermediaries. Next period's profits can credibly be pledged to the intermediaries, as in Gertler and Kiyotaki (2010). After realization of the shocks, the producers hire labour $h_{i,t}$ at a wage w_t, and start producing intermediate goods with previous period capital $k_{i,t-1}$ and labor $h_{i,t}$ as input. After production, the intermediate goods producers pay a state-contingent net real return r_t^k over claims issued in period t, with the following production technology:

$$y_{i,t} = z_t(\xi_t k_{i,t-1})^{\alpha} h_{i,t}^{1-\alpha}.$$

Quality of capital ξ_t and total factor productivity z_t are driven by exogenous AR(1) processes.

Output $y_{i,t}$ is sold to retail firms for a price m_t. The effective capital stock (after depreciation) is sold to the capital producers for a price q_t^k and the proceeds are used to pay back the loans and a net return to the financial intermediaries, after paying wages set in a perfectly competitive labor market:

$$w_t = (1-\alpha)\, m_t y_{i,t} / h_{i,t}, \tag{14}$$

$$1 + r_t^k = \frac{\alpha m_t y_{i,t} / k_{i,t-1} + q_t^k (1-\delta)\, \xi_t}{q_{t-1}^k}. \tag{15}$$

A capital quality shock ξ_t decreases the return on capital for two reasons: production decreases, as capital becomes less productive, reducing the first term of (15). But the capital price q_t^k will fall, leading to a further decrease in the return on capital because of the second term in (15).

3.4.2 Capital Producers

Capital producers purchase the effective capital stock that is left after production (including depreciation), $(1-\delta)\xi_t k_{t-1}$, from the intermediate goods producers. They also purchase an amount i_t of final goods, and convert the old capital stock and newly purchased final goods into new capital. The newly produced capital stock k_t is subsequently sold to the intermediate goods producers at the same price q_t^k that was paid for the capital after production. The capital producers face convex adjustment costs, so that for every unit i_t only $1-\Psi(\iota_t)$ units of capital are produced, with $\iota_t = i_t/i_{t-1}$ representing the change in the investment level. The expression for the capital stock after the capital producers have produced (or output of capital producers) is then:

$$k_t \;=\; (1-\delta)\xi_t k_{t-1} + \left[1-\Psi(\iota_t)\right] i_t, \text{ with } \Psi(\iota_t) = \frac{\gamma}{2}(\iota_t - 1)^2$$

3.4.3 Retail Firms

A continuum of differentiated retail firms indexed by $i \in [0,1]$ transform intermediate goods $y_{i,t}$ into differentiated retail goods $y_{f,t} = y_{i,t}$ under monopolistic competition. Each period, only a random portion $(1-\psi)$ of retail firms is allowed to reset their prices $P_{f,t}$, while the other firms must keep their prices fixed, see Calvo (1983) and Yun (1996). Retail firms face the demand function $y_{f,t} = (P_{f,t}/P_t)^{-\epsilon} y_t$, with $\epsilon > 1$ and price index $P_t^{1-\epsilon} = \int_0^1 P_{f,t}^{1-\epsilon} df$.

3.4.4 Final Goods Producers

Final goods producers purchase the differentiated retail goods $y_{f,t}$ to produce final goods. They face the following technology constraint:

$$y_t^{(\epsilon-1)/\epsilon} = \int_0^1 y_{f,t}^{(\epsilon-1)/\epsilon} df,$$

where ϵ represents the elasticity of substitution between goods bought from the retail firms. Final good producers operate in a perfectly competitive market. Hence they take prices as given, and sell their goods for the same price P_t. Final goods are sold to households and government for consumption, and to capital producers as input for investment.

3.5 Government

3.5.1 Fiscal authority

The government issues b_t long term bonds in period t, and raises $q_t^b b_t$ in revenue, with q_t^b the market price of bonds. I parametrize the maturity structure of government debt like Woodford (1998, 2001). A bond issued in period $t-1$ pays a cash flow r_c in period t, ρr_c in period $t+1$, $\rho^2 r_c$ in period $t+2$, etc. The rate of return r_t^b on a bond purchased in period $t-1$ is given by:

$$1 + r_t^b = \frac{r_c + \rho q_t^b}{q_{t-1}^b}, \tag{16}$$

where ρ pins down the maturity[4] of government debt, see for more details Van der Kwaak and Van Wijnbergen (2014). The government also raises revenue by levying lump sum taxes τ_t on the households and receives profits Π_t^{cb} from the central bank. Government purchases are constant in real terms: $g_t = G$. Furthermore, the government may provide assistance to the financial sector by injecting new net worth n_t^g. The government also receives repayment from previously administered support $\tilde{n}_t^g$. The budget constraint is given by:

$$q_t^b b_t + \tau_t + \tilde{n}_t^g + \Pi_t^{cb} \quad = \quad g_t + n_t^g + \left(1 + r_t^b\right) q_{t-1}^b b_{t-1}. \tag{17}$$

The tax rule of the government is given by a rule which makes sure the intertemporal government budget constraint is satisfied (Bohn, 1998): where $\bar{b}$ is the steady state level of debt. κ_n controls the way government transfers to the financial sector are financed. If $\kappa_n = 0$, support is financed by new debt. $\kappa_n = 1$ implies that the additional spending is completely financed by increasing lump sum taxes. I parametrize government support as follows:

$$\begin{aligned} n_t^g &= \tau_t^n n_{t-1}, \quad \zeta \leq 0, \quad l \geq 0, \\ \tau_t^n &= \zeta \varepsilon_{\xi,t-l}. \end{aligned} \tag{18}$$

Thus the government provides funds to the financial sector if $\zeta < 0$ (a negative shock $\varepsilon_{\xi,t-l}$ to the quality of capital). Depending on the value of l, the government can provide support instantaneously ($l = 0$), or with a lag ($l > 0$). Furthermore, ϑ indicates the extent to which the government needs to be repaid:

$$\tilde{n}_t^g \quad = \quad \vartheta n_{t-e}^g, \quad \vartheta \geq 0, \quad e \geq 1. \tag{19}$$

$\vartheta = 0$ means the support is a gift from the government. In case $\vartheta = 1$, the government aid is a zero interest loan, while a $\vartheta > 1$ implies that the financial intermediaries have to pay interest

[4]The duration of the bond is equal to $\frac{\sum_{j=1}^{\infty} j\beta^j \left(\rho^{j-1} r_c\right)}{\sum_{j=1}^{\infty} \beta^j \left(\rho^{j-1} r_c\right)}$

over the support received earlier.[5] The parameter e denotes the amount of time after which the government aid has to be paid back.

3.5.2 Central Bank Conventional Interest Rate Policy

The Central Bank sets the nominal interest rate on deposits r_t^n according to a standard Taylor rule, in order to minimize output and inflation deviations:

$$r_t^n = (1-\rho_r)\left[r^n + \kappa_\pi(\pi_t - \bar{\pi}) + \kappa_y \log(y_t/y_{t-1}) + \kappa_\xi\left(\xi_t - \bar{\xi}\right)\right] + \rho_r r_{t-1}^n + \varepsilon_{r,t}, \quad (20)$$

where $\varepsilon_{r,t} \sim N(0, \sigma_r^2)$, and $\kappa_\pi > 1$ and $\kappa_y > 0$ (active monetary policy). The parameter $\bar{\pi}$ is the target inflation rate. The term $\kappa_\xi\left(\xi_t - \bar{\xi}\right)$ can be interpreted as a conventional monetary stimulus in times of financial crises. The real interest rate on deposits then equals:

$$1 + r_t^d = (1 + r_{t-1}^n)/\pi_t. \quad (21)$$

3.5.3 Central Bank Balance Sheet Policy

Besides conventional interest rate policy, the central bank lends d_t^{cb} to the commercial banking system. In order to obtain access to this facility, commercial banks are required to provide collateral in the form of government bonds, see equation (6). Collateral is needed in order for the creditor to recoup the principal in case of a debtor's bankruptcy. A haircut is applied to protect the creditor from capital losses on the collateral.

The central bank has two instruments for its balance sheet policy. It controls the nominal interest rate $r_t^{n,cb}$ on central bank funding provided to commercial banks, and the haircut parameter θ_t applied to the collateral. For a given interest rate $r_t^{n,cb}$ and haircut parameter θ_t, the central bank provides as much funding as demanded by the commercial banks, in line with the Fixed Rate Full Alotment policy of the ECB after October 2008.[6] The central bank can lower the nominal interest rate $r_t^{n,cb}$ in times of crisis with respect to the interest rate on regular deposit funding r_t^n by increasing the credit spread Γ_t^{cb}:

$$r_t^{n,cb} = r_t^n - \Gamma_t^{cb}. \quad (22)$$

The credit spread Γ_t^{cb} between the nominal rate on deposits and the nominal rate on central bank funding is given by:

$$\Gamma_t^{cb} = \bar{\Gamma}_{cb} + \varkappa_{cb}\left(\xi_t - \bar{\xi}\right), \quad (23)$$

[5] The case where $\vartheta > 1$ happened in the Netherlands, where financial intermediaries received government aid with a penalty rate of 50 percent. EU state support rules usually require financial intermediaries to repay previously received state support with a penalty rate.

[6] Before October 2008, the ECB used to auction a given amount of funding against eligible collateral, with the interest rate being determined in the auctioning process. In October 2008, the ECB switched to a Fixed Rate Full Alotment policy, under which the ECB sets the collateral haircuts and the interest rate, and provides commercial banks with the funding demanded (European Central Bank, 2015).

where $\bar{\Gamma}_{cb}$ is the steady state credit spread. When $\varkappa_{cb} < 0$, a financial crisis increases the interest rate spread between deposits and central bank funding, decreasing funding costs for commercial banks.

The second policy instrument is the haircut parameter θ_t that is applied to the collateral. From equation (6) we see that a commercial bank delivering $q_t^b s_{j,t}^b$ in government bonds, provides the commercial bank $\theta_t q_t^b s_{j,t}^b$ units of central bank funding. Hence the collateral haircut is $1-\theta_t$. A higher value of θ_t allows the commercial bank to obtain more central bank funding for the same number of government bonds, which increases the collateral value of government bonds. The haircut parameter θ_t is possibly time-varying, and is given by the following process:

$$\theta_t = \bar{\theta} + \varkappa_{d,cb} \left(\xi_t - \bar{\xi} \right), \tag{24}$$

where $\bar{\theta}$ is the steady state haircut parameter, which increases in a financial crisis by setting $\varkappa_{d,cb} < 0$. The asset side of the central bank balance sheet consists of loans d_t^{cb} to commercial banks on which it receives a nominal interest rate $r_t^{n,cb}$. The liabilities consist of household deposits[7] on which it pays the nominal deposit rate r_t^n. Central bank profits (or losses) are passed on to the fiscal authority period by period. Hence central bank net worth is zero, and liabilities consist solely of household deposits. Real central bank profits (or actually losses, since $r_{t-1}^{n,cb} \leq r_{t-1}^n$), are given by:

$$\Pi_t^{cb} = \left(\frac{1 + r_{t-1}^{n,cb}}{\pi_t} \right) d_{t-1}^{cb} - \left(\frac{1 + r_{t-1}^n}{\pi_t} \right) d_{t-1}^{cb} = \left(r_t^{cb} - r_t^d \right) d_{t-1}^{cb}, \tag{25}$$

where π_t is the gross inflation rate, and the net real return on central bank funding r_t^{cb} is given by:

$$1 + r_t^{cb} = \frac{1 + r_{t-1}^{n,cb}}{\pi_t}. \tag{26}$$

Note that without the central bank intervention, commercial banks would have to pay the interest rate r_t^d. Hence the central bank losses Π_t^{cb} can be interpreted as the subsidy given by the central bank to the commercial banks.

3.6 Market clearing

In equilibrium, the total number of private loans k_t must equal the total number of loans provided by the financial intermediaries. Similarly, the total bond supply must equal the bonds purchased

[7] Central banks in most advanced economies are not directly financed through deposits, but through interest bearing commercial bank reserves. I could model this by including commercial bank reserves on the asset side of commercial banks. Commercial banks would not be capable of diverting commercial bank reserves in such a setup because the central bank is in charge of the reserve system. Commercial banks are not balance-sheet-constrained in financing commercial bank reserves in such a setup. Hence explicitly modelling commercial bank reserves is equivalent to letting the central bank be financed directly by household deposits, see also Gertler and Karadi (2011)

by the household sector and financial intermediaries:

$$k_t = s_t^{k,p}, \tag{27}$$

$$b_t = s_t^{b,h} + s_t^{b,p}. \tag{28}$$

The aggregate resource constraint is given by:

$$y_t = c_t + i_t + g_t + \frac{1}{2}\kappa_{s_{b,h}} \left(s_t^{b,h} - \hat{s}_{b,h} \right)^2. \tag{29}$$

3.7 Equilibrium

The resulting equilibrium definition can be found in appendix D.2, which gioves a complete description of the model can be found including the standard first order conditions that have been left out in the main text.

4 Calibration

I calibrate the model on a quarterly frequency. I solve the model using a perturbation method that solves for the policy function with a first-order approximation around the non-stochastic steady state. The parameter values can be found in Table 1. Most of the parameter values are common in the literature on DSGE models, or frequently used in models containing financial frictions. I follow Gertler and Karadi (2011) for these parameters. Standard parameter values are the subjective discount factor β, the habit formation parameter υ, the inverse Frisch elasticity φ, the elasticity of substitution for final goods producers ϵ, the Calvo probability of keeping prices fixed ψ, the capital share in output α, the investment adjustment parameter γ, and the smoothing parameters for production ρ_z and the quality of capital ρ_ξ. Parameters regarding conventional monetary policy are set at relatively standard values. The interest rate smoothing parameter ρ_r is set at 0.4, to reflect a more aggressive response of conventional monetary policy, which is in normal times in the range of $0.8 - 0.9$.

Other coefficients are calibrated to match specific targets: the relative utility weight of labor Ψ is calibrated to have the steady state labor supply equal 1/3. A crucial parameter in my analysis is the intermediation cost for households on bond holdings $\kappa_{s_{b,h}}$. This affects the elasticity of household demand for government bonds in response to changes in the bond price. When commercial banks want to increase their bond holdings because of central bank funding provided at an attractive interest rate, this parameter indicates how willing households are to sell government bonds to commercial banks. I set $\kappa_{s_{b,h}}$ equal to 0.0025. For this parameter value, a decrease in the interest rate on central bank funding of 50 basispoints on impact with respect to the interest rate on deposits leads to an increased recourse to central bank funding of apprxoimately 5% of annual steady state GDP, which is on the conservative side in comparison with the cumulative take up of LTRO funding in December 2011 and February 2012, as was

Parameter	Value	Definition
Households		
β	0.990	Discount rate
υ	0.815	Degree of habit formation
Ψ	3.6023	Relative utility weight of labor
φ	0.276	Inverse Frisch elasticity of labor supply
$\kappa_{s_{b,h}}$	0.0025	Constant portfolio adjustment cost function
$\hat{s}_{b,h}$	1.6656	Reference level portfolio adjustment cost function
Financial Intermediaries		
λ_k	0.3861	Fraction of private loans that can be diverted
λ_b	0.1930	Fraction of gov't bonds that can be diverted
χ	0.0026	Proportional transfer to entering bankers
σ	0.95	Survival rate of the bankers
Intermediate good firms		
ϵ	4.176	Elasticity of substitution
ψ	0.779	Calvo probability of keeping prices fixed
α	0.330	Effective capital share
Capital good firms		
γ	1.728	Investment adjustment cost parameter
δ	0.0592	Depreciation rate
Autoregressive components		
ρ_z	0.95	Autoregressive component of productivity
ρ_ξ	0.66	Autoregressive component of capital quality
ρ_r	0.4	Interest rate smoothing parameter
Policy		
r_c	0.04	Real payment to government bondholder
ρ	0.96	Parameter government debt duration (5 yrs)
κ_b	0.050	Tax feedback parameter from government debt
κ_π	1.500	Inflation feedback on nominal interest rate
κ_y	0.125	Output feedback on nominal interest rate
Shocks		
σ_z	0.010	Standard deviation productivity shock
σ_ξ	0.050	Standard deviation capital quality shock
σ_r	0.0025	Standard deviation interest rate surprise shock

Table 1: Model parameters.

shown in Section 2.

Other parameters are calibrated to match data from the periphery of the Eurozone, where most LTRO funding was taken up.[8] I target the steady state investment-GDP ratio and the steady state government spending-GDP ratio, and set both to 0.2, in line with long term average values in the periphery. The depreciation rate δ is calibrated to target the steady state investment-GDP ratio and a steady state credit spread Γ_k between private loans and deposits of 50 basispoints (quarterly), which is the average difference between the interest rate on total loans to non-financial corporations and total overnight deposits to households and non-profit institutions in the periphery of the Eurozone over the period from July 2010 to June 2011.

The steady state leverage ratio is targeted by taking monthly country level data on Monetary Financial Institutions (MFIs) excluding the European System of Central Banks (ESCB) from the European Central Bank (2015). I aggregate total MFI assets from the periphery countries, as well as MFI capital and reserves. I divide aggregate MFI assets over aggregate MFI capital and reserves to find a monthly time-series for the average MFI leverage ratio, which was equal to 12 in the beginning of 2011. Due to the fact that the cash flows from private loans are the residual after wages have been paid out, private loans are more like equity than debt in my model. Taking a leverage ratio of 12 would therefore overstate fluctuations in net worth. Hence I reduce the steady state leverage ratio to 6, a procedure also applied by Gertler and Karadi (2013).

The parameter σ is set in such a way that the average survival period for bankers is 20 quarters. To make sure that this parameter value is not driving the model results, I investigate the model response for different values of σ in Appendix E. I calibrate the diversion parameter for government bonds λ_b to equal 0.5 times the diversion rate for private loans λ_k, as in Gertler and Karadi (2013). To make sure that this value does not drive my results, I investigate the model response for different values of λ_b in Appendix E. The steady state value of the haircut parameter $\bar{\theta}$ is set to 0.95, implying a steady state haircut of 5% on government bonds pledged to the central bank as collateral, which is in line with the haircut on periphery sovereign debt at the time. The steady state spread Γ_{cb} between the interest rate on deposits and central bank lending facilities is equal to zero, reflecting the fact that these facilities only have value to commercial banks in times of financial crisis, and are otherwise perfect substitutes.

I calibrate the steady state government liabilities $\bar{q}_b\bar{b}$ to be equal to 100% of annual steady state output, in line with the average debt level in the periphery at the start of the crisis in 2011. The average duration of government bonds is 5 years and can be calculated from the stress tests performed by the European Banking Authority (2011). The cash flow payment to the bondholder r_c is set to 0.04, in line with coupon payments on long term government debt. The tax feedback parameter κ_b is set to 0.05 in order to guarantee intertemporal solvency of the budget constraint of the fiscal authority. The effect of this parameter is limited, because taxes are lump-sum in my model. We set the steady state fraction of government bonds placed at commercial banks to be

[8]The Eurozone periphery consists of Greece, Ireland, Italy, Portugal, and Spain in my calibration

equal to 25% of total government bonds, approximately equal to the average fraction of periphery bonds placed at periphery banks. A financial crisis is initiated as in Gertler and Karadi (2011) by having a one standard deviation capital quality shock of $\sigma_\xi = 0.050$, and an autoregressive component of $\rho_\xi = 0.66$.

I conduct several robustness checks in Appendix E. I will perform this check along two dimensions. First, I will change some of the key parameters of the model. A second line of robustness checks is along the dimension of model specification. I perform these checks to make sure that my model results do not depend on some arbitrary parameter choice or a particular model specification.

5 Results

In this section I discuss the results from the model simulations. I first simulate a financial crisis with no additional support measures to explain the general mechanism of the model. I then proceed to look at the case where the interest rate on central bank funding is decreased with respect to the interest rate on regular deposits, capturing the LTROs of December 2011 and February 2012. I continue by investigating the impact of different haircut parameters, and I conclude by comparing the effect of the LTRO with the effect of an immediate debt-financed recapitalization by the fiscal authority.

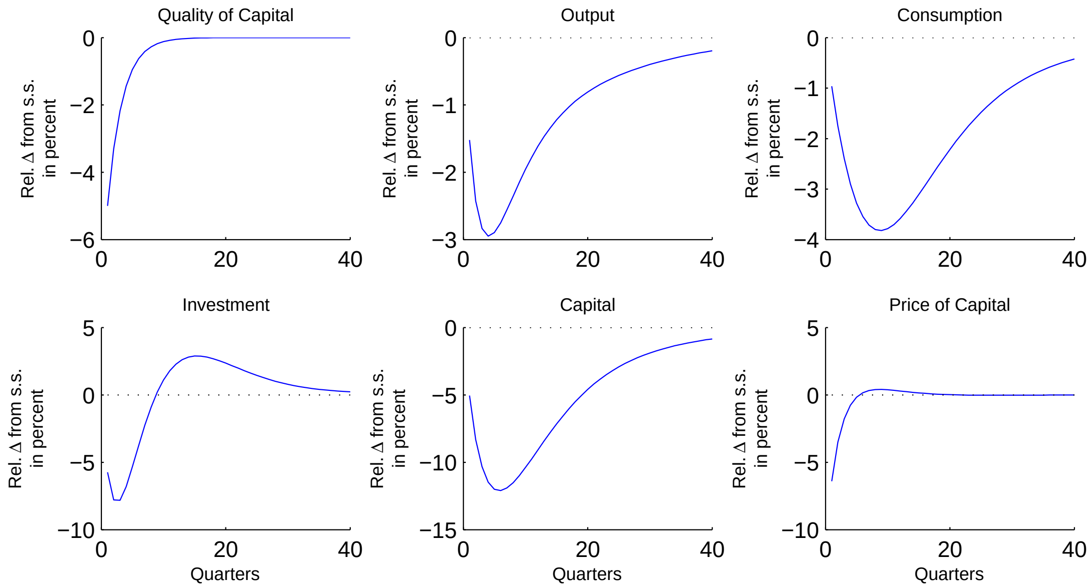
5.1 Financial crisis impact, no additional policy

I start by inspecting the response of the economy to a financial crisis in Figure 4, where the financial crisis is initiated through a capital quality shock ξ_t of 5% compared with the steady state, as in Gertler and Karadi (2011). For now, I abstain from a policy intervention by the central bank. The capital quality shock deteriorates the return on private loans, and hence commercial banks suffer losses, as can be seen from equation (15). Net worth falls, and (commercial) bank balance sheet constraints tighten. Credit spreads and (expected) interest rates increase, reducing the demand for private loans and capital, which leads to a drop in the price of capital. Remember that the capital is sold by intermediate goods producers after production, and the proceeds are used to repay the loan from the commercial bank. Hence a lower capital price leads to additional losses on the outstanding loans to the intermediate goods producers. Net worth of commercial banks falls further, leading to a second round of interest rate increases.

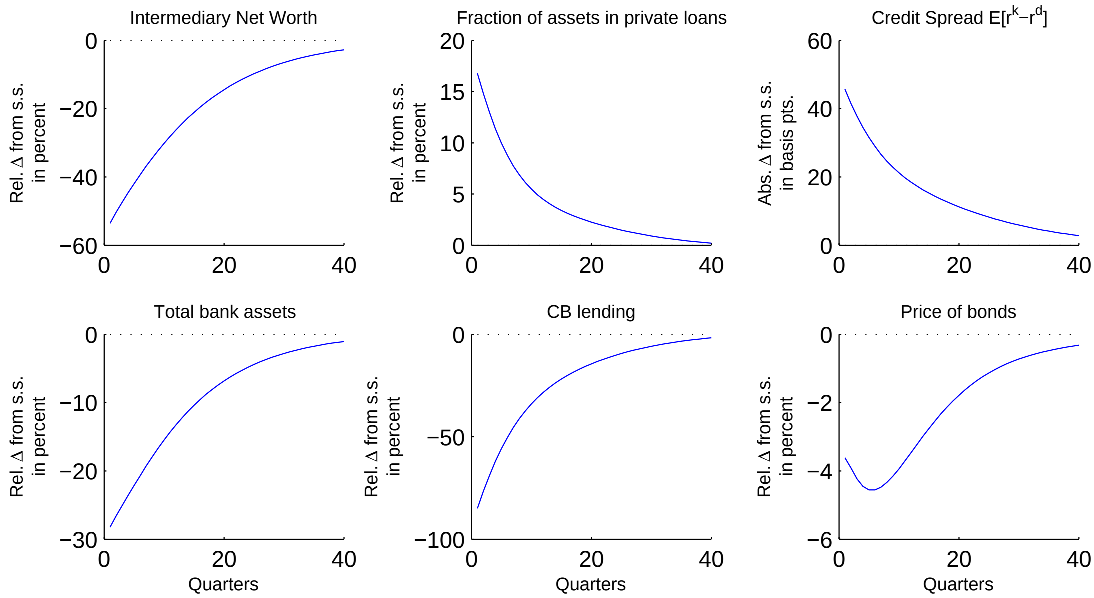
Balance sheet tightening of commercial banks does not only affect credit spreads on private loans, but also induces commercial banks to sell government bonds. Bond prices go down, and impose capital losses on existing bondholders, resulting in an additional fall in commercial banks' net worth on top of the losses on private loans, further tightening bank balance sheet constraints. Since the interest rate on deposits and central bank funding are equal, it follows from equation (9) that the collateral value of government bonds is zero. Commercial banks shrink their balance sheet by selling government bonds to the household sector, thereby increasing the fraction of the balance sheet invested in private credit, see panel "Fraction of assets in private loans". As previously mentioned, banks can only sell government bonds to households, but not private loans. A lower bond price makes it more attractive for households (who are not balance-sheet-constrained) to purchase additional government bonds. When commercial banks offload government bonds to households, central bank lending falls along by approximately 80% with respect to the steady state.

Lower private credit provision adversely affects the real economy: investment drops by 8% with respect to steady state, and a lower capital stock leads to lower wages and reduced household income. The wealth effect causes consumption to fall, generating, together with the fall in investment, a drop in output of almost 3%.

Financial crisis impact, no additional policy intervention



(a)



(b)

Figure 4: Impulse response functions for the case with no additional policy. The financial crisis is initiated through a negative capital quality shock of 5 percent relative to the steady state.

5.2 No additional policy vs. unconventional monetary policy

In this section I will derive my first result. Consider the effect of an unconventional central bank intervention in Figure 5. I compare the no intervention case from section 5.1 (blue, solid) with a policy that entails an increase in the interest rate spread Γ_t^{cb} between the nominal interest rate on deposits and the central bank lending facilities of 50 quarterly basis points on impact (red, slotted) to simulate the LTRO intervention by the ECB in December 2011 and February 2012.[9]

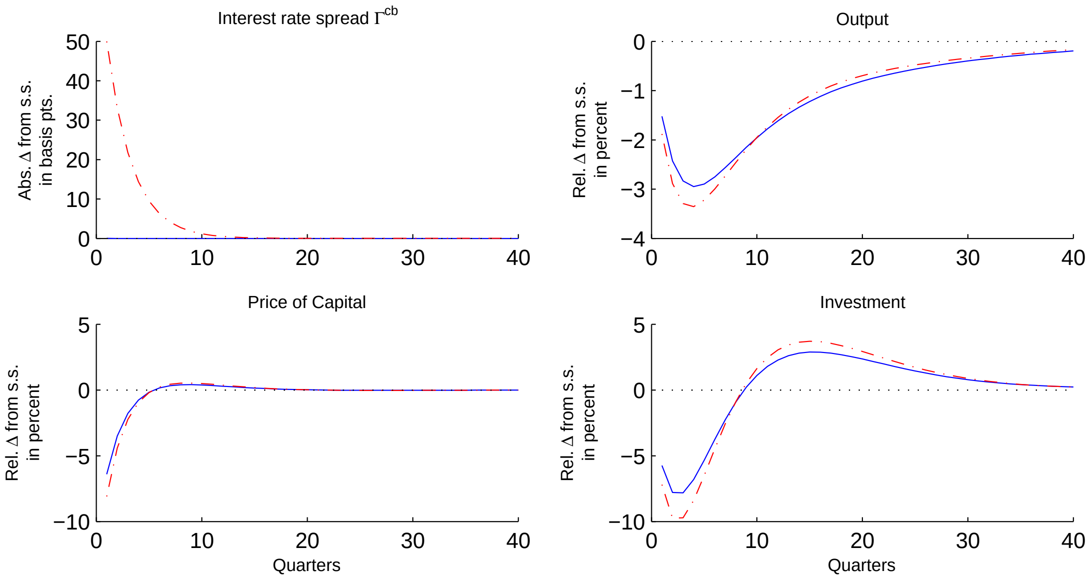
The lower interest rate induces commercial banks to shift from funding through regular deposits to central bank funding, which increases net worth everything else equal. It follows from equation (9) that the (collateral) value of a government bond to commercial banks increases: not only does a bond produce a cash flow in the future, it also allows the intermediary to gain immediate access to additional central bank funding. However, since intermediaries are balance-sheet-constrained, purchasing more government bonds also forces them to shift out of private loans ("Fraction of assets in private loans"), which are not eligible as collateral. Demand for private loans is reduced, and pushes down the price of capital further, leading to additional capital losses on private loans. Net worth falls further, and tightens bank balance sheet constraints, leading to a second round of interest rate increases on private loans and additional capital losses. The credit spread between private loans and deposits increases on impact by 75 basis points compared with the no intervention case. Net worth drops with respect to the no intervention case on impact. The shift out of private loans initially leads to a substantial drop in investment and pushes down the trough of output by almost 0.5%. Note, however, that the low-interest-rate on central bank funding allows an expansion of commercial banks' balance sheets ("Total bank assets"). The extra space on the balance sheet, though, is not used to expand lending to the real economy, but to purchase additional government bonds.

The lower interest rate on central bank funding, however, increases commercial bank profits, and leads (except in the initial period) to higher net worth compared with the no intervention case. But as long as the interest rate on central bank funding is below that on deposit funding, intermediaries will invest a larger fraction of their balance sheet in government bonds, thereby crowding out private credit. Commercial banks, however, are better capitalized after the period of lower interest rates on central bank funding has ended, and have more space on their balance sheets to finance capital purchases by the intermediate goods producers. Investment increases with respect to the no intervention case, leading to a faster recovery along the entire time path once the intervention has ended.

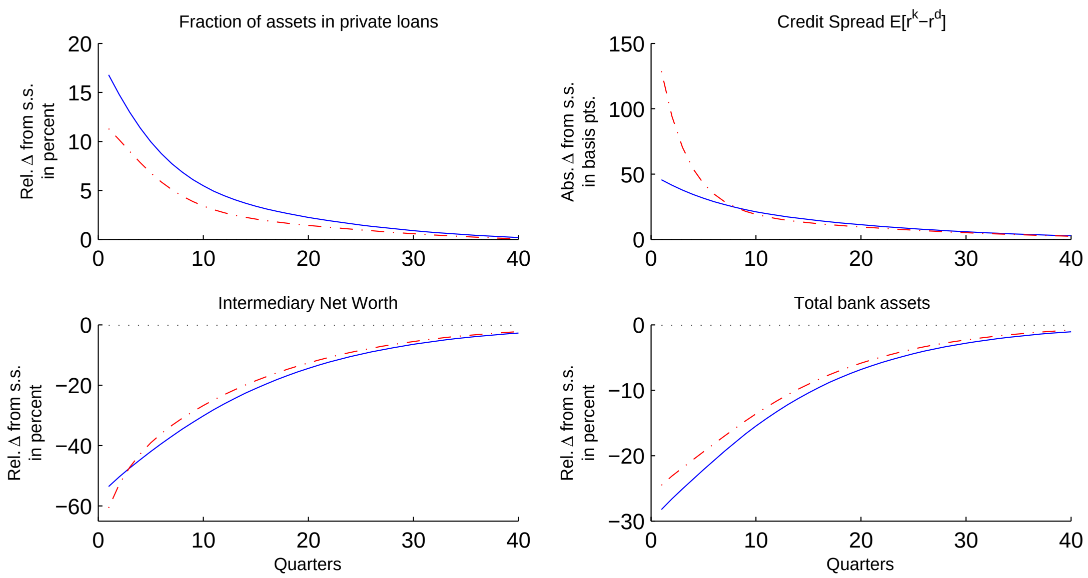
In the short run, these results contradict the regular narrative concerning a monetary expansion, in which lower interest rates lead to higher output. Instead, the collateral effect dominates the subsidy effect. The key reason is the fact that commercial banks are balance sheet constrai-

[9] Under the LTRO, commercial banks were allowed to borrow for 3 years at a nominal interest rate equal to the MRO rate, which is the short term policy rate of the ECB. The difference with the 1-year Euribor, a measure of unsecured interbank funding is at least 1%, see also Figure 10 in appendix C. I therefore take an annual spread between central bank lending facilities and deposits of 2% since the LTRO has a maturity of 3 years, compared with a 1 year maturity of the 1-year Euribor. This gives a quarterly credit spread of 50 basis points.

Financial crisis impact, no additional policy vs. unconventional monetary policy



(a)



(b)

Figure 5: Impulse response functions for the case from section 5.1 with no additional policy (blue, solid) vs. the LTRO, represented by a decrease in the nominal interest rate on central bank lending facilities of 50 basis points on impact with respect to the nominal interest rate on regular deposit funding (red, slotted). The financial crisis is initiated through a negative capital quality shock of 5 percent relative to the steady state.

ned, and cannot increase their holdings of government bonds, necessary as collateral, without shedding private loans. In the long run, central bank lending at an interest rate below that on deposits amounts to an indirect recapitalization of commercial banks, which leads to a stronger economic recovery.

My results seem to be in line with the data surrounding the period in which the LTRO was undertaken by the ECB: just as in the data, we see a portfolio shift from private loans to government bonds. This would explain why credit to the real economy did not expand in the aftermath of the LTRO, contrary to the expectations of ECB President Draghi, alluded to in the introduction.

The results clearly introduce a trade-off for policymakers: if they are concerned about the short run, unconventional central bank lending operations such as the LTRO do not seem to be a good idea, due to the contractionary short run impact. But when they are concerned about the long run, the intervention is beneficial, as it supports the long run recovery by delivering a commercial banking system that is better capitalized. This raises two questions. First, is the cumulative effect of the central bank intervention positive or negative? Second, can the haircut policy, indicated by θ_t, affect the outcome, and if so how?

5.3 The cumulative intervention effect and the role of the haircut policy θ_t

In this section I will derive the main result of my paper. We saw in the previous section that the collateral effect dominates the short run effect, while the subsidy effect dominates the long run effect. This leads us to the question whether the cumulative effect of increased central bank lending is positive or negative. I therefore introduce the cumulative discounted multiplier μ_D:

$$\mu_D = \frac{\sum_s \beta^s \left(y_{t+s}^{cbp} - y_{t+s}^{np} \right)}{\sum_s \beta^s \left(d_{t+s}^{cb,cbp} - d_{t+s}^{cb,np} \right)},$$

where x_{t+s}^{cbp} denotes the value of variable x in period $t+s$ under the central bank intervention, and x_{t+s}^{np} the value of variable x in period $t+s$ under the no policy case. Figure 6 displays μ_D versus the haircut parameter θ_t. We clearly see that μ_D is basically zero, and hardly changes as I vary θ_t. This results in two conclusions: first, cumulatively, the subsidy effect and the collateral effect offset each other, with a net effect that is zero. Second, μ_D hardly changes as the haircut parameter θ_t is varied. This suggests that the collateral policy of the central bank has no macroeconomic effects. This seems counterintuitive, given the way the central bank intervention affected the real economy in the previous section, see Figure 5.

Central bank intervention: discounted cumulative multiplier μ_D vs. θ_t

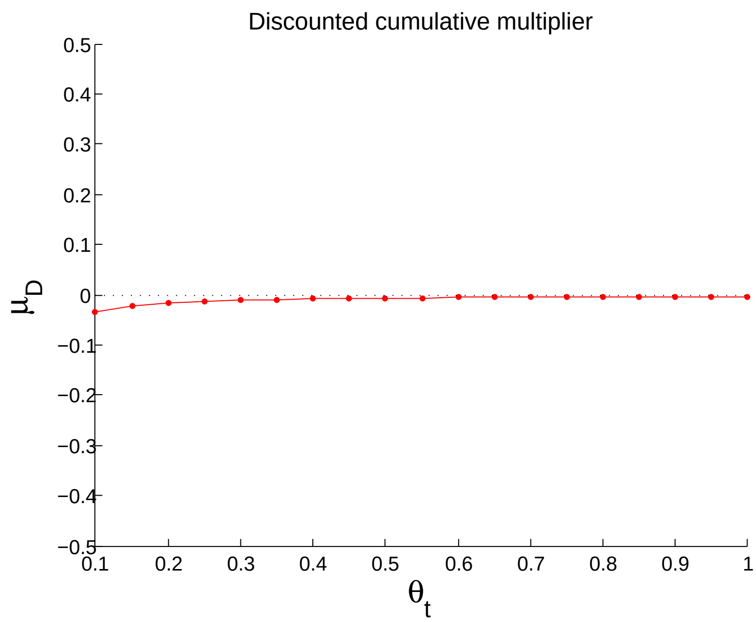


Figure 6: Discounted cumulative multiplier μ_D vs. θ_t for the central bank intervention of section 5.2, where θ_t is the haircut parameter of the central bank.

We therefore turn to Figure 7, which is the result from the same comparison between no additional policy and unconventional central bank lending as in Figure 5 but for several steady state values of the haircut parameter θ_t. Figure 7 shows the difference between the two policies, expressed as a percentage of steady state output. The upper panel displays the difference in central bank lending, while the lower panel displays the difference in output.

Variation in haircut parameter θ_t

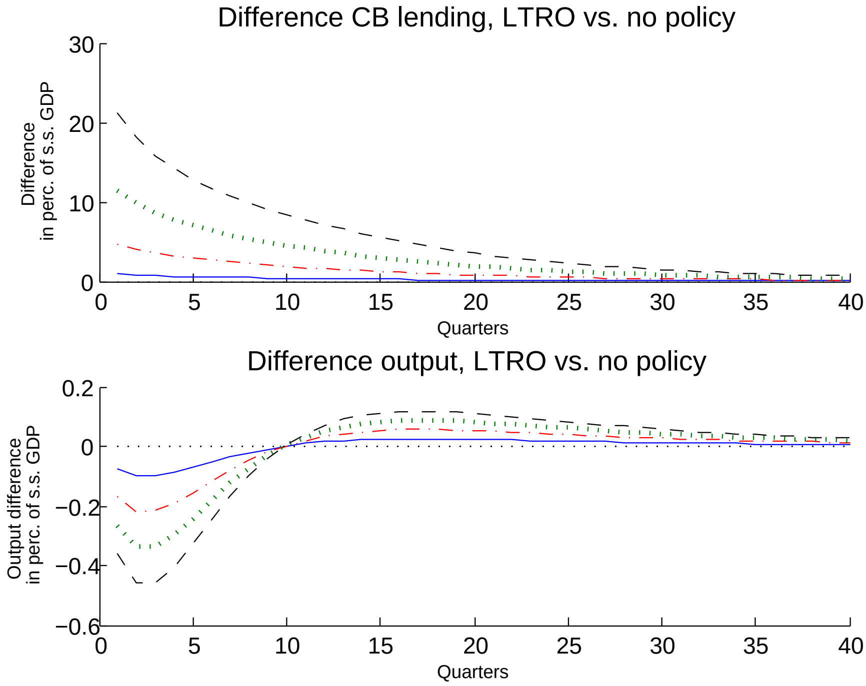


Figure 7: Both panels display the difference between the case where the nominal interest rate on central bank lending facilities is lowered by 50 basis points with respect to the nominal interest rate on regular deposit funding on impact (LTRO) and the no intervention case for different steady state values of the haircut parameter θ_t. The blue solid line refers to $\theta_t = 0.20$, the red slotted line to $\theta_t = 0.45$, the green dotted line to $\theta_t = 0.70$, and the black dashed line to $\theta_t = 0.95$. The upper panel displays the difference in central bank (CB) lending, while the lower panel displays the difference in output.

Contrary to the results in Figure 6, we see that the haircut parameter θ_t has a large effect on output and central bank lending. A smaller haircut (larger θ_t) leads to a stronger collateral effect and a steeper short-run output contraction. In the long run, however, a smaller θ_t leads to a stronger subsidy effect and, through this effect, to a stronger economic recovery.

This can be explained in the following way: the smaller haircut leads to a larger collateral value: commercial banks obtain more low-interest-rate central bank funding for one euro of collateral. The higher collateral value induces more crowding out of private loans by government bonds and leads to a stronger collateral effect. Commercial bank profits, however, increase, as a larger share of the balance sheet is financed through low-interest-rate central bank funding. The recovery of bank balance sheets is accelerated, and leads to a stronger subsidy effect and a long-run credit expansion. Long-run output increases, and offsets the stronger initial contractionary impact.

Figures 6 and 7 lead to a clear conclusion regarding the effectiveness of providing low-interest-rate central bank funding: the cumulative effect from the intervention compared with the no intervention case is basically zero. Hence the policy is not very effective in stimulating output, irrespective of the haircut parameter θ_t. This rather ineffective policy, however, does not imply that the central bank cannot affect the real economy. Quite the contrary, the haircut parameter θ_t allows the central bank to influence the time path of the recovery, and shift output losses between periods. Setting a high θ_t induces commercial banks to shift into government bonds (with a stronger collateral effect and a short run contractionary impact) but indirectly recapitalizes commercial banks because of a stronger subsidy effect. Reducing θ_t mitigates the short run contractionary impact of the central bank policy, but leaves commercial banks weaker capitalized once the central bank intervention has ended. But no matter what haircut policy θ_t the central bank pursues, the cumulative impact with respect to the no intervention cases is basically zero. This leaves the question whether other policies are more effective in stimulating private credit provision and output. I will address this question in the next section.

5.4 Unconventional monetary policy vs. immediate recapitalization

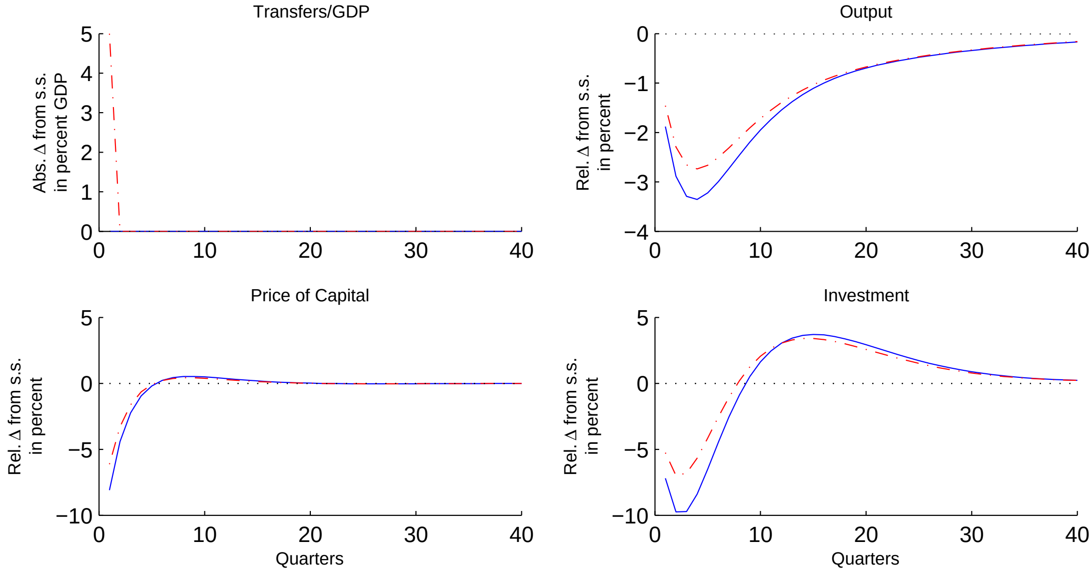
We have seen in the previous section that unconventional central bank lending operations are rather ineffective, despite the fact that the commercial banking sector is indirectly recapitalized through the provision of central bank funding at an interest rate below that on deposits. I therefore investigate in Figure 8 whether a direct recapitalization by the fiscal authority is more effective. The blue solid line refers to the central bank intervention from section 5.2, while the red slotted line refers to an immediate debt-financed recapitalization of 1.25% of annual steady state output, see equation (18).

We clearly see that the debt-financed recap has a positive effect compared with the central bank intervention, which is most striking in the initial quarters of the financial crisis: the credit spread falls, and the drop in net worth, output and investment is substantially mitigated. There are two key reasons why the recap seems to be more effective. First, commercial banks immediately receive new net worth, in contrast to the indirect recap by the central bank, in which commercial banks are gradually recapitalized through lower interest rates on central bank funding. A direct recap therefore immediately alleviates bank balance sheet constraints, allowing commercial banks to expand the balance sheet at once.

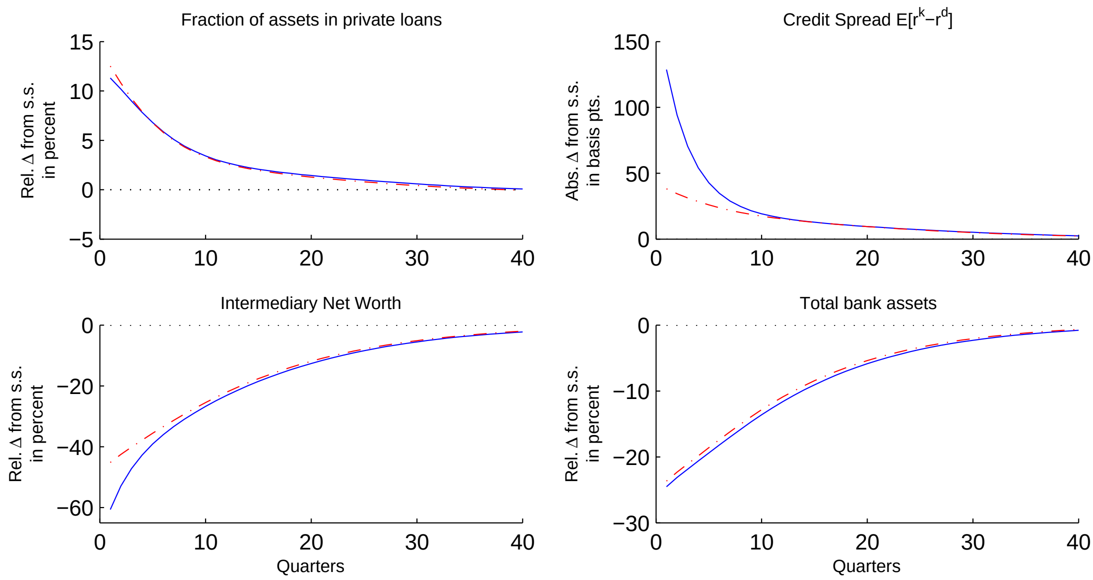
The second reason is the fact that, contrary to the central bank intervention, a direct recap does not increase the collateral value of government bonds. The interest rate on household deposits and the central bank lending facilities is the same under the direct recap policy, and hence the collateral value, indicated by ψ_t in equation (9) is zero. Commercial banks do not have an incentive to load up on government bonds, as is the case under the unconventional central bank intervention. The collateral effect is therefore absent under the direct recap policy, see also equation (7), and only the subsidy effect is present.

Even though the initial drop in net worth is almost 20% larger under the unconventional central bank policy, net worth levels have converged after approximately 10 quarters. The credit spread between private loans and deposits, which measures not only the tightness of the bank balance sheet constraint, but also the profitability of private loans if no new shocks arrive, is much larger under the unconventional central bank policy. As long as the credit spread is larger under the unconventional monetary policy case, net worth accumulation is faster, resulting in a convergence of net worth. The collateral value of government bonds is zero under both policies after approximately 10 quarters, and net worth and other credit market conditions are basically the same, resulting in similar long run macroeconomic outcomes.

Financial crisis impact: unconventional monetary policy vs. immediate recap



(a)



(b)

Figure 8: Impulse response functions for the case from section 5.2 with a decrease in the nominal interest rate on central bank lending facilities of 50 basis points on impact with respect to the nominal interest rate on regular deposit funding (blue, solid) vs. the case where the commercial banking system receives new net worth equal to 1.25% of annual GDP (red, slotted) through an immediate debt-financed recapitalization by the fiscal authority. The financial crisis is initiated through a negative capital quality shock of 5 percent relative to the steady state.

6 Conclusion

The European Central Bank (ECB) conducted in December 2011 and February 2012 the largest refinancing operation in its history by providing the European commercial banking system with more than € 1000 billion in funding. One of the goals of the program, as stated by ECB president Draghi, was to expand credit to the real economy. Commercial banks within the Eurozone play a crucial role in this respect, as more than 80% of debt financing to non-financial corporations is intermediated by commercial banks. Empirical evidence, though, suggests that rather than expanding private credit, the ECB funding was used to purchase additional government bonds. In this paper I investigate whether unconventional central bank lending operations can expand credit provision to the real economy, and through that channel stimulate output.

I construct a DSGE model with balance-sheet-constrained commercial banks that have a portfolio choice between private loans and government bonds. The central bank provides funding to commercial banks, for which commercial banks pledge collateral in the form of government bonds. I model the LTRO intervention of the ECB by decreasing the interest rate on central bank funding with respect to that on regular deposit funding. I contribute to the literature by linking private credit provision and central bank lending operations through a collateral constraint which determines how much central bank funding is obtained for one euro of government bonds pledged as collateral. Government bonds therefore have a collateral value, which affects the portfolio decision of the commercial bank.

I find a contractionary short-run effect, but an expansionary long-run effect on credit provision and output when the central bank engages in unconventional lending operations with a balance-sheet-constrained commercial banking system. The provision of central bank funding at an interest rate below that on deposits induces commercial banks to shift from private credit to government bonds, an effect referred to as the collateral effect, which has a contractionary short-run effect on output. Bank balance sheets recover faster, however, as profits increase due to lower interest rate payments, which increases credit provision and output in the long run, referred to as the subsidy effect.

My main result is that there is no cumulative effect on output with respect to the no intervention case. This result is independent of the haircut policy of the central bank. A smaller haircut provides commercial banks with more central bank funding for one euro of government bonds pledged as collateral, and induces a shift from private loans to government bonds, which increases the contractionary impact of the collateral effect. At the same time, the shift into government bonds allows the commercial banks to finance a larger fraction of their balance sheet through central bank funding, thereby decreasing interest rate payments and increasing commercial bank profits: the stronger collateral effect implies a stronger long-run subsidy effect, which offsets the collateral effect. Even though the cumulative impact on output is zero, the haircut policy allows the central bank to shift output gains and losses over time.

I find that an immediate debt-financed recapitalization is more effective in expanding private credit than unconventional central bank lending operations. The recap instantaneously increases net worth of commercial banks and alleviates bank balance sheet constraints, similar to the unconventional lending operations, but does not induce commercial banks to shift into government bonds. Credit to the real economy expands, and leads to an increase in output across the entire time path.

My model explains why banks did not expand credit to the real economy in response to the LTROs of December 2011 and February 2012. The LTROs, which were particularly attractive for banks in Italy, Spain and Portugal, increased the collateral value of government bonds, as they could be used to get additional LTRO funding. To buy more government bonds, banks had to shift from private credit, as they were undercapitalized at the time (Hoshi and Kashyap, 2015). To avoid this collateral effect, governments could have recapitalized the banking sector directly or through European funds, which is more likely to have expanded credit provision to the real economy than the LTROs.

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A Mathematical derivations: Price stickiness & Monetary Policy

A.1 Financial intermediaries

In the main text, the collateral constraint is given by $d^{cb}_{j,t} \leq \theta_t q^b_t s^{b,p}_{j,t}$. In this appendix I will apply a more general formulation, namely $d^{cb}_{j,t} \leq \theta_t \kappa_t s^{b,p}_{j,t}$, where κ_t can be equal to:

$$\kappa_t = \begin{cases} q^b_t & \text{"Regular collateral constraint";} \\ 1 & \text{"No risk-adjustment collateral constraint".} \end{cases}$$

I also include the possibility of financial sector net worth support by the government $n^g_{j,t} = \tau^n_t n_{j,t-1}$ and repayment of earlier provided support $\tilde{n}^g_{j,t} = \tilde{\tau}^n_t n_{j,t-1}$. The law of motion for net worth, which includes recapitalizations by the government and financial sector repayments is given by:

$$\begin{aligned}
n_{j,t+1} &= \left(1+r^k_{t+1}\right) q^k_t s^{k,p}_{j,t} + \left(1+r^b_{t+1}\right) q^b_t s^{b,p}_{j,t} \\
&- \left(1+r^d_{t+1}\right) d_{j,t} - \left(1+r^{cb}_{t+1}\right) d^{cb}_{j,t} + n^g_{j,t+1} - \tilde{n}^g_{j,t+1} \\
&= \left(1+r^k_{t+1}\right) q^k_t s^{k,p}_{j,t} + \left(1+r^b_{t+1}\right) q^b_t s^{b,p}_{j,t} \\
&- \left(1+r^d_{t+1}\right) d_{j,t} - \left(1+r^{cb}_{t+1}\right) d^{cb}_{j,t} + \tau^n_{t+1} n_{j,t} - \tilde{\tau}^n_{t+1} n_{j,t} \\
&= \left(1+r^k_{t+1}\right) q^k_t s^{k,p}_{j,t} + \left(1+r^b_{t+1}\right) q^b_t s^{b,p}_{j,t} \\
&- \left(1+r^d_{t+1}\right) d_{j,t} - \left(1+r^{cb}_{t+1}\right) d^{cb}_{j,t} \\
&+ \left(\tau^n_{t+1} - \tilde{\tau}^n_{t+1}\right) \left(q^k_t s^{k,p}_{j,t} + q^b_t s^{b,p}_{j,t} - d_{j,t} - d^{cb}_{j,t}\right) \\
&= \left(1+r^k_{t+1} + \tau^n_{t+1} - \tilde{\tau}^n_{t+1}\right) q^k_t s^{k,p}_{j,t} + \left(1+r^b_{t+1} + \tau^n_{t+1} - \tilde{\tau}^n_{t+1}\right) q^b_t s^{b,p}_{j,t} \\
&- \left(1+r^d_{t+1} + \tau^n_{t+1} - \tilde{\tau}^n_{t+1}\right) d_{j,t} - \left(1+r^{cb}_{t+1} + \tau^n_{t+1} - \tilde{\tau}^n_{t+1}\right) d^{cb}_{j,t},
\end{aligned}$$

Now we remember the optimization problem of the financial intermediary:

$$\begin{aligned}
V_{j,t} &= \max_{\left\{s^{k,p}_{j,t}, s^{b,p}_{j,t}, d_{j,t}, d^{cb}_{j,t}\right\}} E_t \left\{\beta \Lambda_{t,t+1} \left[(1-\sigma) n_{j,t+1} + \sigma V_{j,t+1}\right]\right\}, \\
& \text{s.t.} \\
V_{j,t} &\geq \lambda_k q^k_t s^{k,p}_{j,t} + \lambda_b q^b_t s^{b,p}_{j,t}, \\
n_{j,t} + d_{j,t} + d^{cb}_{j,t} &\geq q^k_t s^{k,p}_{j,t} + q^b_t s^{b,p}_{j,t}, \\
n_{j,t} &= \left(1+r^k_t + \tau^n_t - \tilde{\tau}^n_t\right) q^k_{t-1} s^{k,p}_{j,t-1} + \left(1+r^b_t + \tau^n_t - \tilde{\tau}^n_t\right) q^b_{t-1} s^{b,p}_{j,t-1} \\
&- \left(1+r^d_t + \tau^n_t - \tilde{\tau}^n_t\right) d_{j,t-1} - \left(1+r^{cb}_t + \tau^n_t - \tilde{\tau}^n_t\right) d^{cb}_{j,t-1}, \\
\theta_t \kappa_t s^{b,p}_{j,t} &\geq d^{cb}_{j,t}
\end{aligned}$$

where we have abbreviated the value function of the financial intermediary by $V_{j,t} = V\left(s^{k,p}_{j,t-1}, s^{b,p}_{j,t-1}, d_{j,t-1}, d^{cb}_{j,t-1}\right)$. We set up the accompanying Lagrangian of the problem:

$$\begin{aligned}
\mathcal{L} &= (1+\mu_t) E_t \Big\{\beta \Lambda_{t,t+1} \Big[(1-\sigma) \Big(\left(1+r^k_{t+1} + \tau^n_{t+1} - \tilde{\tau}^n_{t+1}\right) q^k_t s^{k,p}_{j,t} + \left(1+r^b_{t+1} + \tau^n_{t+1} - \tilde{\tau}^n_{t+1}\right) q^b_t s^{b,p}_{j,t} \\
&- \left(1+r^d_{t+1} + \tau^n_{t+1} - \tilde{\tau}^n_{t+1}\right) d_{j,t} - \left(1+r^{cb}_{t+1} + \tau^n_{t+1} - \tilde{\tau}^n_{t+1}\right) d^{cb}_{j,t}\Big) + \sigma V\left(s^{k,p}_{j,t}, s^{b,p}_{j,t}, d_{j,t}, d^{cb}_{j,t}\right)\Big]\Big\} \\
&- \mu_t \lambda_k q^k_t s^{k,p}_{j,t} - \mu_t \lambda_b q^b_t s^{b,p}_{j,t} \\
&+ \chi_t \Big[\left(1+r^k_t + \tau^n_t - \tilde{\tau}^n_t\right) q^k_{t-1} s^{k,p}_{j,t-1} + \left(1+r^b_t + \tau^n_t - \tilde{\tau}^n_t\right) q^b_{t-1} s^{b,p}_{j,t-1} \\
&- \left(1+r^d_t + \tau^n_t - \tilde{\tau}^n_t\right) d_{j,t-1} - \left(1+r^{cb}_t + \tau^n_t - \tilde{\tau}^n_t\right) d^{cb}_{j,t-1} - q^k_t s^{k,p}_{j,t} - q^b_t s^{b,p}_{j,t} + d_{j,t} + d^{cb}_{j,t}\Big] \\
&+ \psi_t \left(\theta_t \kappa_t s^{b,p}_{j,t} - d^{cb}_{j,t}\right).
\end{aligned}$$

This gives rise to the following first order conditions:

$$\begin{aligned}
s_{j,t}^{k,p} &: (1+\mu_t) E_t \left\{ \beta\Lambda_{t,t+1} \left[(1-\sigma)\left(1+r_{t+1}^k+\tau_{t+1}^n-\tilde{\tau}_{t+1}^n\right) q_t^k + \sigma \frac{\partial V\left(s_{j,t}^{k,p}, s_{j,t}^{b,p}, d_{j,t}, d_{j,t}^{cb}\right)}{\partial s_{j,t}^{k,p}} \right] \right\} \\
&- \mu_t\lambda_k q_t^k - \chi_t q_t^k = 0, \qquad (30) \\
s_{j,t}^{b,p} &: (1+\mu_t) E_t \left\{ \beta\Lambda_{t,t+1} \left[(1-\sigma)\left(1+r_{t+1}^b+\tau_{t+1}^n-\tilde{\tau}_{t+1}^n\right) q_t^b + \sigma \frac{\partial V\left(s_{j,t}^{k,p}, s_{j,t}^{b,p}, d_{j,t}, d_{j,t}^{cb}\right)}{\partial s_{j,t}^{b,p}} \right] \right\} \\
&- \mu_t\lambda_b q_t^b - \chi_t q_t^b + \psi_t\theta_t\kappa_t = 0, \qquad (31) \\
d_{j,t} &: (1+\mu_t) E_t \left\{ \beta\Lambda_{t,t+1} \left[(1-\sigma)\left(1+r_{t+1}^d+\tau_{t+1}^n-\tilde{\tau}_{t+1}^n\right)(-1) + \sigma \frac{\partial V\left(s_{j,t}^{k,p}, s_{j,t}^{b,p}, d_{j,t}, d_{j,t}^{cb}\right)}{\partial d_{j,t}} \right] \right\} \\
&+ \chi_t = 0, \qquad (32) \\
d_{j,t}^{cb} &: (1+\mu_t) E_t \left\{ \beta\Lambda_{t,t+1} \left[(1-\sigma)\left(1+r_{t+1}^{cb}+\tau_{t+1}^n-\tilde{\tau}_{t+1}^n\right)(-1) + \sigma \frac{\partial V\left(s_{j,t}^{k,p}, s_{j,t}^{b,p}, d_{j,t}, d_{j,t}^{cb}\right)}{\partial d_{j,t}^{cb}} \right] \right\} \\
&+ \chi_t - \psi_t = 0, \qquad (33)
\end{aligned}$$

with complementary slackness conditions:

$$\begin{aligned}
\mu_t &: \left[V\left(s_{j,t-1}^{k,p}, s_{j,t-1}^{b,p}, d_{j,t-1}, d_{j,t-1}^{cb}\right) - \lambda_k q_t^k s_{j,t}^{k,p} - \lambda_b q_t^b s_{j,t}^{b,p} \right] \mu_t = 0, \qquad (34) \\
\chi_t &: \Big[\left(1+r_t^k+\tau_t^n-\tilde{\tau}_t^n\right) q_{t-1}^k s_{j,t-1}^{k,p} + \left(1+r_t^b+\tau_t^n-\tilde{\tau}_t^n\right) q_{t-1}^b s_{j,t-1}^{b,p} \\
&- \left(1+r_t^d+\tau_t^n-\tilde{\tau}_t^n\right) d_{j,t-1} - \left(1+r_t^{cb}+\tau_t^n-\tilde{\tau}_t^n\right) d_{j,t-1}^{cb} - q_t^k s_{j,t}^{k,p} - q_t^b s_{j,t}^{b,p} + d_{j,t} + d_{j,t}^{cb} \Big] \chi_t = 0, \qquad (35) \\
\psi_t &: \left(\theta_t\kappa_t s_{j,t}^b - d_{j,t}^{cb}\right) \psi_t = 0. \qquad (36)
\end{aligned}$$

Now we apply the envelope theorem to find the derivatives:

$$\begin{aligned}
\frac{\partial V\left(s_{j,t-1}^{k,p}, s_{j,t-1}^{b,p}, d_{j,t-1}, d_{j,t-1}^{cb}\right)}{\partial s_{j,t-1}^{k,p}} &= \chi_t\left(1+r_t^k+\tau_t^n-\tilde{\tau}_t^n\right) q_{t-1}^k, \qquad (37) \\
\frac{\partial V\left(s_{j,t-1}^{k,p}, s_{j,t-1}^{b,p}, d_{j,t-1}, d_{j,t-1}^{cb}\right)}{\partial s_{j,t-1}^{b,p}} &= \chi_t\left(1+r_t^b+\tau_t^n-\tilde{\tau}_t^n\right) q_{t-1}^b, \qquad (38) \\
\frac{\partial V\left(s_{j,t-1}^{k,p}, s_{j,t-1}^{b,p}, d_{j,t-1}, d_{j,t-1}^{cb}\right)}{\partial d_{j,t-1}} &= -\chi_t\left(1+r_t^d+\tau_t^n-\tilde{\tau}_t^n\right), \qquad (39) \\
\frac{\partial V\left(s_{j,t-1}^{k,p}, s_{j,t-1}^{b,p}, d_{j,t-1}, d_{j,t-1}^{cb}\right)}{\partial d_{j,t-1}^{cb}} &= -\chi_t\left(1+r_t^{cb}+\tau_t^n-\tilde{\tau}_t^n\right). \qquad (40)
\end{aligned}$$

Subsititution of the envelope conditions (37) - (40) with (30) - (33), we find the following relation between the different assets:

$$s_{j,t}^{k,p} \quad : \quad \lambda_k \left(\frac{\mu_t}{1+\mu_t}\right) + \frac{\chi_t}{1+\mu_t} = E_t \left\{\beta \Lambda_{t,t+1} \left[(1-\sigma) + \sigma \chi_{t+1}\right] \left(1 + r_{t+1}^k + \tau_{t+1}^n - \tilde{\tau}_{t+1}^n\right)\right\}, \tag{41}$$

$$\begin{aligned} s_{j,t}^{b,p} \quad &: \quad \lambda_b \left(\frac{\mu_t}{1+\mu_t}\right) + \frac{\chi_t}{1+\mu_t} - \left(\frac{\kappa_t}{q_t^b}\right) \theta_t \left(\frac{\psi_t}{1+\mu_t}\right) \\ &= E_t \left\{\beta \Lambda_{t,t+1} \left[(1-\sigma) + \sigma \chi_{t+1}\right] \left(1 + r_{t+1}^b + \tau_{t+1}^n - \tilde{\tau}_{t+1}^n\right)\right\}, \end{aligned} \tag{42}$$

$$d_{j,t} \quad : \quad \frac{\chi_t}{1+\mu_t} = E_t \left\{\beta \Lambda_{t,t+1} \left[(1-\sigma) + \sigma \chi_{t+1}\right] \left(1 + r_{t+1}^d + \tau_{t+1}^n - \tilde{\tau}_{t+1}^n\right)\right\}, \tag{43}$$

$$d_{j,t}^{cb} \quad : \quad \frac{\chi_t}{1+\mu_t} - \frac{\psi_t}{1+\mu_t} = E_t \left\{\beta \Lambda_{t,t+1} \left[(1-\sigma) + \sigma \chi_{t+1}\right] \left(1 + r_{t+1}^{cb} + \tau_{t+1}^n - \tilde{\tau}_{t+1}^n\right)\right\}. \tag{44}$$

Now we define the following variables:

$$\eta_t = \frac{\chi_t}{1+\mu_t}, \tag{45}$$

$$\nu_t^k = \lambda_k \left(\frac{\mu_t}{1+\mu_t}\right) + \frac{\chi_t}{1+\mu_t} = \lambda_k \left(\frac{\mu_t}{1+\mu_t}\right) + \eta_t \tag{46}$$

$$\nu_t^b = \lambda_b \left(\frac{\mu_t}{1+\mu_t}\right) + \frac{\chi_t}{1+\mu_t} - \left(\frac{\kappa_t}{q_t^b}\right) \theta_t \left(\frac{\psi_t}{1+\mu_t}\right) = \lambda_b \left(\frac{\mu_t}{1+\mu_t}\right) + \eta_t - \left(\frac{\kappa_t}{q_t^b}\right) \theta_t \left(\frac{\psi_t}{1+\mu_t}\right) \tag{47}$$

$$\eta_t^{cb} = \frac{\chi_t}{1+\mu_t} - \frac{\psi_t}{1+\mu_t} = \eta_t - \frac{\psi_t}{1+\mu_t} \tag{48}$$

We remember that we can rewrite (45) into $\chi_t = (1+\mu_t)\,\eta_t$. Subsitution of (45) - (48). This gives rise to the following first order conditions:

$$\nu_t^k = E_t \left\{\beta \Lambda_{t,t+1} \left[(1-\sigma) + \sigma (1+\mu_{t+1})\, \eta_{t+1}\right] \left(1 + r_{t+1}^k + \tau_{t+1}^n - \tilde{\tau}_{t+1}^n\right)\right\}, \tag{49}$$

$$\nu_t^b = E_t \left\{\beta \Lambda_{t,t+1} \left[(1-\sigma) + \sigma (1+\mu_{t+1})\, \eta_{t+1}\right] \left(1 + r_{t+1}^b + \tau_{t+1}^n - \tilde{\tau}_{t+1}^n\right)\right\}, \tag{50}$$

$$\eta_t = E_t \left\{\beta \Lambda_{t,t+1} \left[(1-\sigma) + \sigma (1+\mu_{t+1})\, \eta_{t+1}\right] \left(1 + r_{t+1}^d + \tau_{t+1}^n - \tilde{\tau}_{t+1}^n\right)\right\}, \tag{51}$$

$$\eta_t^{cb} = E_t \left\{\beta \Lambda_{t,t+1} \left[(1-\sigma) + \sigma (1+\mu_{t+1})\, \eta_{t+1}\right] \left(1 + r_{t+1}^{cb} + \tau_{t+1}^n - \tilde{\tau}_{t+1}^n\right)\right\}. \tag{52}$$

Now we assume a particular function for the value function, and will later check whether our first order conditions are consistent with it:

$$V_{j,t} = V\left(s^{k,p}_{j,t-1}, s^{b,p}_{j,t-1}, d_{j,t-1}, d^{cb}_{j,t-1}\right) = \nu^k_t q^k_t s^{k,p}_{j,t} + \nu^b_t q^b_t s^{b,p}_{j,t} - \eta_t d_{j,t} - \eta^{cb}_t d^{cb}_{j,t}$$

Substitution of the first order conditions (46) - (48) in the value function of the typical financial intermediary gives the following expression:

$$\begin{aligned}
V_{j,t} &= \nu^k_t q^k_t s^{k,p}_{j,t} + \nu^b_t q^b_t s^{b,p}_{j,t} - \eta_t d_{j,t} - \eta^{cb}_t d^{cb}_{j,t} \\
&= \left[\lambda_k\left(\frac{\mu_t}{1+\mu_t}\right) + \eta_t\right] q^k_t s^{k,p}_{j,t} + \left[\lambda_b\left(\frac{\mu_t}{1+\mu_t}\right) + \eta_t - \left(\frac{\kappa_t}{q^b_t}\right)\theta_t\left(\frac{\psi_t}{1+\mu_t}\right)\right] q^b_t s^{b,p}_{j,t} \\
&- \eta_t d_{j,t} - \left(\eta_t - \frac{\psi_t}{1+\mu_t}\right) d^{cb}_{j,t} \\
&= \eta_t\left(q^k_t s^{k,p}_{j,t} + q^b_t s^{b,p}_{j,t} - d_{j,t} - d^{cb}_{j,t}\right) \\
&+ \frac{\mu_t}{1+\mu_t}\left(\lambda_k q^k_t s^{k,p}_{j,t} + \lambda_b q^b_t s^{b,p}_{j,t}\right) - \frac{\psi_t}{1+\mu_t}\left(\theta_t \kappa_t s^{b,p}_{j,t} - d^{cb}_{j,t}\right) \\
&= \eta_t n_{j,t} + \frac{\mu_t}{1+\mu_t}\left(\lambda_k q^k_t s^{k,p}_{j,t} + \lambda_b q^b_t s^{b,p}_{j,t}\right),
\end{aligned}$$

where the term with ψ_t drops out because of the slackness condition (36). We can now rewrite the leverage constraint:

$$\begin{aligned}
V_{j,t} &\geq \lambda_k q^k_t s^{k,p}_{j,t} + \lambda_b q^b_t s^{b,p}_{j,t} \Longrightarrow \\
\eta_t n_{j,t} + \frac{\mu_t}{1+\mu_t}\left(\lambda_k q^k_t s^{k,p}_{j,t} + \lambda_b q^{b,p}_t s^{b}_{j,t}\right) &\geq \lambda_k q^k_t s^{k,p}_{j,t} + \lambda_b q^b_t s^{b,p}_{j,t} \Longrightarrow \\
\left(1 - \frac{\mu_t}{1+\mu_t}\right)\left(\lambda_k q^k_t s^{k,p}_{j,t} + \lambda_b q^b_t s^{b,p}_{j,t}\right) &\leq \eta_t n_{j,t} \Longrightarrow \\
\lambda_k q^k_t s^{k,p}_{j,t} + \lambda_b q^b_t s^{b,p}_{j,t} &\leq (1+\mu_t)\,\eta_t n_{j,t}.
\end{aligned}$$

Now we substitute the expressions for the shadow values of the different asset classes in the expression for the expected discounted profits of the financial intermediary to obtain the following expression:

$$\begin{aligned}
V_{j,t} &= \max E_t \left\{\beta\Lambda_{t,t+1}\left[(1-\sigma) n_{j,t+1} + \sigma V_{j,t+1}\right]\right\} \\
&= E_t\left(\beta\Lambda_{t,t+1}\left\{(1-\sigma) n_{j,t+1} + \sigma\left[\eta_{t+1} n_{j,t+1} + \frac{\mu_{t+1}}{1+\mu_{t+1}}\left(\lambda_k q^k_{t+1} s^{k,p}_{j,t+1} + \lambda_b q^b_{t+1} s^{b,p}_{j,t+1}\right)\right]\right\}\right) \\
&= E_t\left(\beta\Lambda_{t,t+1}\left\{(1-\sigma) n_{j,t+1} + \sigma\left[\eta_{t+1} n_{j,t+1} + \frac{\mu_{t+1}}{1+\mu_{t+1}}\left(1+\mu_{t+1}\right)\eta_{t+1} n_{j,t+1}\right]\right\}\right) \\
&= E_t\left\{\beta\Lambda_{t,t+1}\left[(1-\sigma) n_{j,t+1} + \sigma\left(1+\mu_{t+1}\right)\eta_{t+1} n_{j,t+1}\right]\right\} \\
&= E_t\left\{\beta\Lambda_{t,t+1}\left[(1-\sigma) + \sigma\left(1+\mu_{t+1}\right)\eta_{t+1}\right] n_{j,t+1}\right\} \\
&= E_t\Big\{\beta\Lambda_{t,t+1}\left[(1-\sigma) + \sigma\left(1+\mu_{t+1}\right)\eta_{t+1}\right]\Big[\left(1+r^k_{t+1}+\tau^n_{t+1}-\tilde{\tau}^n_{t+1}\right) q^k_t s^{k,p}_{j,t} \\
&+ \left(1+r^b_{t+1}+\tau^n_{t+1}-\tilde{\tau}^n_{t+1}\right) q^b_t s^{b,p}_{j,t} - \left(1+r^d_{t+1}+\tau^n_{t+1}-\tilde{\tau}^n_{t+1}\right) d_{j,t} - \left(1+r^{cb}_{t+1}+\tau^n_{t+1}-\tilde{\tau}^n_{t+1}\right) d^{cb}_{j,t}\Big]\Big\}
\end{aligned}$$

Comparing with the initial guess for the solution, we obtain the following first order conditions:

$$\nu^k_t = E_t\left\{\beta\Lambda_{t,t+1}\left[(1-\sigma)+\sigma\left(1+\mu_{t+1}\right)\eta_{t+1}\right]\left(1+r^k_{t+1}+\tau^n_{t+1}-\tilde{\tau}^n_{t+1}\right)\right\}, \tag{53}$$

$$\nu^b_t = E_t\left\{\beta\Lambda_{t,t+1}\left[(1-\sigma)+\sigma\left(1+\mu_{t+1}\right)\eta_{t+1}\right]\left(1+r^b_{t+1}+\tau^n_{t+1}-\tilde{\tau}^n_{t+1}\right)\right\}, \tag{54}$$

$$\eta_t = E_t\left\{\beta\Lambda_{t,t+1}\left[(1-\sigma)+\sigma\left(1+\mu_{t+1}\right)\eta_{t+1}\right]\left(1+r^d_{t+1}+\tau^n_{t+1}-\tilde{\tau}^n_{t+1}\right)\right\}, \tag{55}$$

$$\eta^{cb}_t = E_t\left\{\beta\Lambda_{t,t+1}\left[(1-\sigma)+\sigma\left(1+\mu_{t+1}\right)\eta_{t+1}\right]\left(1+r^{cb}_{t+1}+\tau^n_{t+1}-\tilde{\tau}^n_{t+1}\right)\right\}. \tag{56}$$

We see that the solutions (49) - (52) and (53) - (56) coincide, and hence that our initial guess for the value function is correct. The law of motion for aggregate net worth is given by:

$$\begin{aligned}
n_t &= \sigma\Big[\left(r^k_t - r^d_t\right) q^k_{t-1} s^{k,p}_{t-1} + \left(r^b_t - r^d_t\right) q^b_{t-1} s^{b,p}_{t-1} \\
&+ \left(r^d_t - r^{cb}_t\right) d^{cb}_{t-1} + \Big(1+r^d_t\Big) n_{t-1}\Big] + \chi p_{t-1} + n^g_t - \tilde{n}^g_t
\end{aligned} \tag{57}$$

A.1.1 Financial Sector First Order Conditions

The resulting first order conditions for the financial sector are now given by:

$$
\begin{aligned}
\nu_t^k &= \lambda_k \left(\frac{\mu_t}{1+\mu_t}\right) + \frac{\chi_t}{1+\mu_t} && (58)\\
\nu_t^b &= \lambda_b \left(\frac{\mu_t}{1+\mu_t}\right) + \frac{\chi_t}{1+\mu_t} - \left(\frac{\kappa_t}{q_t^b}\right)\theta_t\left(\frac{\psi_t}{1+\mu_t}\right) && (59)\\
\eta_t &= \frac{\chi_t}{1+\mu_t}, && (60)\\
\eta_t^{cb} &= \frac{\chi_t}{1+\mu_t} - \frac{\psi_t}{1+\mu_t} && (61)\\
\nu_t^k &= E_t\left\{\beta\Lambda_{t,t+1}\left[(1-\sigma)+\sigma\left(1+\mu_{t+1}\right)\eta_{t+1}\right]\left(1+r_{t+1}^k+\tau_{t+1}^n-\tilde{\tau}_{t+1}^n\right)\right\}, && (62)\\
\nu_t^b &= E_t\left\{\beta\Lambda_{t,t+1}\left[(1-\sigma)+\sigma\left(1+\mu_{t+1}\right)\eta_{t+1}\right]\left(1+r_{t+1}^b+\tau_{t+1}^n-\tilde{\tau}_{t+1}^n\right)\right\}, && (63)\\
\eta_t &= E_t\left\{\beta\Lambda_{t,t+1}\left[(1-\sigma)+\sigma\left(1+\mu_{t+1}\right)\eta_{t+1}\right]\left(1+r_{t+1}^d+\tau_{t+1}^n-\tilde{\tau}_{t+1}^n\right)\right\}, && (64)\\
\eta_t^{cb} &= E_t\left\{\beta\Lambda_{t,t+1}\left[(1-\sigma)+\sigma\left(1+\mu_{t+1}\right)\eta_{t+1}\right]\left(1+r_{t+1}^{cb}+\tau_{t+1}^n-\tilde{\tau}_{t+1}^n\right)\right\}. && (65)\\
\left(1+\mu_t\right)\eta_t n_{j,t} &\geq \lambda_k q_t^k s_{j,t}^{k,p} + \lambda_b q_t^b s_{j,t}^{b,p}, && (66)\\
n_t &= \sigma\Big[\left(r_t^k-r_t^d\right)q_{t-1}^k s_{t-1}^{k,p} + \left(r_t^b-r_t^d\right)q_{t-1}^b s_{t-1}^{b,p} \\
&+ \left(r_t^d-r_t^{cb}\right)d_{t-1}^{cb} + \Big(1+r_t^d\Big)n_{t-1}\Big] + \chi p_{t-1} + n_t^g - \tilde{n}_t^g && (67)\\
d_t^{cb} &= \theta_t\kappa_t s_t^{b,p} && (68)
\end{aligned}
$$

A.1.2 Further simplification of the F.O.C.'s for mathematical proofs

Now we combine some of the F.O.C.'s found in section A.1.1 to obtain a better economic understanding and more intuition. We start by combining (58) and (59), while substituting (60) for $\chi_t/(1+\mu_t)$ to obtain:

$$\nu_t^b - \eta_t = \frac{\lambda_b}{\lambda_k}\left(\nu_t^k - \eta_t\right) - \left(\frac{\kappa_t}{q_t^b}\right)\theta_t\left(\frac{\psi_t}{1+\mu_t}\right)$$

Substitution of the expressions (62), (63) and (64) reaults in the following equation:

$$\frac{\lambda_b}{\lambda_k}E_t\left[\Omega_{t,t+1}\left(r_{t+1}^k-r_{t+1}^d\right)\right] = E_t\left[\Omega_{t,t+1}\left(r_{t+1}^b-r_{t+1}^d\right)\right] + \left(\frac{\kappa_t}{q_t^b}\right)\theta_t\left(\frac{\psi_t}{1+\mu_t}\right), \qquad (69)$$

where $\Omega_{t,t+1} = \beta\Lambda_{t,t+1}\left[(1-\sigma)+\sigma\left(1+\mu_{t+1}\right)\eta_{t+1}\right]$ refers to the stochastic discount factor of the financial intermediaries, which is equal to the household's stochastic discount factor, augmented to incorporate the financial frictions.

Now we combine (60) and (61) to obtain the following relation between theshadow value on deposit funding and central bank funding:

$$\frac{\psi_t}{1+\mu_t} = \eta_t - \eta_t^{cb}.$$

Substitution of (64) and (65) gives rise to the following relation:

$$\frac{\psi_t}{1+\mu_t} = E_t\left[\Omega_{t,t+1}\left(r_{t+1}^d - r_{t+1}^{cb}\right)\right]. \tag{70}$$

By these substitutions, we have removed the four shadow values ν_t^k, ν_t^b, η_t^{cb}, and χ_t. Thus we get the following set of F.O.C.'s:

$$\begin{aligned}
\frac{\lambda_b}{\lambda_k}E_t\left[\Omega_{t,t+1}\left(r_{t+1}^k - r_{t+1}^d\right)\right] &= E_t\left[\Omega_{t,t+1}\left(r_{t+1}^b - r_{t+1}^d\right)\right] + \left(\frac{\kappa_t}{q_t^b}\right)\theta_t\left(\frac{\psi_t}{1+\mu_t}\right), && (71)\\
\lambda_k\left(\frac{\mu_t}{1+\mu_t}\right) &= E_t\left[\Omega_{t,t+1}\left(r_{t+1}^k - r_{t+1}^d\right)\right], && (72)\\
\frac{\psi_t}{1+\mu_t} &= E_t\left[\Omega_{t,t+1}\left(r_{t+1}^d - r_{t+1}^{cb}\right)\right], && (73)\\
\eta_t &= E_t\left[\Omega_{t,t+1}\left(1 + r_{t+1}^d + \tau_{t+1}^n - \tilde{\tau}_{t+1}^n\right)\right], && (74)\\
\left(1+\mu_t\right)\eta_t n_{j,t} &\geq \lambda_k q_t^k s_{j,t}^{k,p} + \lambda_b q_t^b s_{j,t}^{b,p}, && (75)\\
n_t &= \sigma\Big[\left(r_t^k - r_t^d\right)q_{t-1}^k s_{t-1}^{k,p} + \left(r_t^b - r_t^d\right)q_{t-1}^b s_{t-1}^{b,p} \\
&+ \left(r_t^d - r_t^{cb}\right)d_{t-1}^{cb} + \Big(1 + r_t^d\Big)n_{t-1}\Big] + \chi p_{t-1} + n_t^g - \tilde{n}_t^g, && (76)\\
d_t^{cb} &= \theta_t\kappa_t s_t^{b,p}, && (77)\\
\Omega_{t,t+1} &= \beta\Lambda_{t,t+1}\left[\left(1-\sigma\right) + \sigma\left(1+\mu_{t+1}\right)\eta_{t+1}\right]. && (78)
\end{aligned}$$

A.2 Production Process

A.2.1 Capital Producers

At the end of period t, when the intermediate goods firms have produced, the capital producers buy the remaining stock of capital $(1-\delta)\xi_t k_{t-1}$ from the intermediate goods producers at a price q_t^k. They combine this capital with goods bought from the final goods producers (investment i_t) to produce next period's beginning of period capital stock k_t. This capital is being sold to the intermediate goods producers at a price q_t^k. We assume that the capital producers face convex adjustment costs when transforming the final goods bought into capital goods, set up such that changing the level of gross investment is costly. Hence we get:

$$k_t = (1-\delta)\xi_t k_{t-1} + [1-\Psi(\iota_t)]i_t, \quad \Psi(x) = \frac{\gamma}{2}(x-1)^2, \quad \iota_t = i_t/i_{t-1}. \tag{79}$$

ξ_t represents a capital quality shock which will be discussed later. Profits are passed on to the households, who own the capital producers. The profit at the end of period t equals:

$$\Pi_t^c \quad = \quad q_t^k k_t - q_t^k(1-\delta)\xi_t k_{t-1} - i_t.$$

The capital producers maximize expected current and (discounted) future profits (where we substitute in (79)):

$$\max_{\{i_{t+i}\}_{i=0}^{\infty}} E_t\Big[\sum_{i=0}^{\infty}\beta^i\Lambda_{t,t+i}\Big(q_{t+i}^k\big(1-\Psi(\iota_{t+i})\big)i_{t+i} - i_{t+i}\Big)\Big].$$

Differentiation with respect to investment gives the first order condition for the capital producers:

$$q_t^k\big(1-\Psi(\iota_t)\big) - 1 - q_t^k\iota_t\Psi'(\iota_t) + \beta E_t\Lambda_{t,t+1}q_{t+1}^k\iota_{t+1}^2\Psi'(\iota_{t+1}) = 0,$$

which gives the following expression for the price of capital:

$$\frac{1}{q_t^k} = 1 - \frac{\gamma}{2}\Big(\frac{i_t}{i_{t-1}} - 1\Big)^2 - \frac{\gamma i_t}{i_{t-1}}\Big(\frac{i_t}{i_{t-1}} - 1\Big) + \beta E_t\Big[\Lambda_{t,t+1}\frac{q_{t+1}^k}{q_t^k}\Big(\frac{i_{t+1}}{i_t}\Big)^2\gamma\Big(\frac{i_{t+1}}{i_t} - 1\Big)\Big]. \tag{80}$$

A.2.2 Intermediate Goods Producers

We remember that period t profits are given by:

$$\Pi_{i,t} \quad = \quad m_t z_t(\xi_t k_{i,t-1})^{\alpha}h_{i,t}^{1-\alpha} + q_t^k(1-\delta)\xi_t k_{i,t-1} - (1+r_t^k)q_{t-1}^k k_{i,t-1} - w_t h_{i,t}.$$

The intermediate goods producing firms maximize expected current and future profits using the household's stochastic discount factor $\beta^s\Lambda_{t,t+s}$ (since they are owned by the households), taking all prices as given:

$$\max_{\{k_{t+s},h_{t+s}\}_{s=0}^{\infty}} E_t\Big[\sum_{s=0}^{\infty}\beta^s\Lambda_{t,t+s}\Pi_{i,t+s}\Big].$$

The first order conditions belonging to this problem are given by:

$$\begin{aligned} k_{i,t} \quad &: \quad E_t\Big[\beta\Lambda_{t,t+1}q_t^k(1+r_{t+1}^k)\Big] = E_t\Big[\beta\Lambda_{t,t+1}\big(\alpha m_{t+1}y_{i,t+1}/k_{i,t} + q_{t+1}^k(1-\delta)\xi_{t+1}\big)\Big], \\ h_{i,t} \quad &: \quad w_t = (1-\alpha)m_t y_{i,t}/h_{i,t}. \end{aligned}$$

In equilibrium profits will be zero. By substituting the first order condition for the wage rate into the zero-profit condition $\Pi_{i,t} = 0$, we can find an expression for the ex-post return on capital:

$$r_t^k \quad = \quad (q_{t-1}^k)^{-1}\big(\alpha m_t y_{i,t}/k_{i,t-1} + q_t^k(1-\delta)\xi_t\big) - 1.$$

Now we rewrite the first order condition for labor and the expression for the ex-post return on capital to find the factor demands:

$$\begin{aligned} k_{i,t-1} &= \alpha m_t y_{i,t}/[q^k_{t-1}(1+r^k_t) - q^k_t(1-\delta)\xi_t], \\ h_{i,t} &= (1-\alpha)m_t y_{i,t}/w_t. \end{aligned}$$

By substituting the factor demands into the production technology function, we get for the relative intermediate output price m_t:

$$m_t = \alpha^{-\alpha}(1-\alpha)^{\alpha-1} z_t^{-1} \left(w_t^{1-\alpha} \left[q^k_{t-1}(1+r^k_t)\xi_t^{-1} - q^k_t(1-\delta) \right]^{\alpha} \right). \tag{81}$$

A.2.3 Retail firms

Retail firms purchase goods ($y_{i,t}$) from the intermediate goods producing firms for a nominal price P^m_t, and convert these into retail goods ($y_{f,t}$). These goods are sold for a nominal price $P_{f,t}$ to the final goods producer. It takes one intermediate goods unit to produce one retail good ($y_{i,t} = y_{f,t}$). All the retail firms produce a differentiated retail good by assumption, therefore operate in a monopolistically competitive market, and charge a markup over the input price earning them profits $(P_{f,t} - P^m_t)y_{f,t}$.

Each period, only a fraction $1-\psi$ of retail firms is allowed to reset their price, while the ψ remaining firms are not allowed to do so, like in Calvo (1983) and Yun (1996). The firms allowed to adjust prices are randomly selected each period. Once selected, they set prices so as to maximize expected current and future profits, using the stochastic discount factor $\beta^s \Lambda_{t,t+s}(P_t/P_{t+s})$:

$$\max_{P_{f,t}} E_t \Big[\sum_{s=0}^{\infty} (\beta\psi)^s \Lambda_{t,t+s}(P_t/P_{t+s})[P_{f,t} - P^m_{t+s}] \Big] y_{f,t+s},$$

where $y_{f,t} = (P_{f,t}/P_t)^{-\epsilon} y_t$ is the demand function. y_t is the output of the final goods producing firms, and P_t the general price level. Symmetry implies that all firms allowed to reset their prices choose the same new price (P^*_t). Differentiation with respect to $P_{f,t}$ and using symmetry then yields:

$$\frac{P^*_t}{P_t} = \frac{\epsilon}{\epsilon-1} \frac{E_t \sum_{s=0}^{\infty} (\beta\psi)^s \lambda_{t+s} P^{\epsilon}_{t+s} P_t^{-\epsilon} m_{t+s} y_{t+s}}{E_t \sum_{s=0}^{\infty} (\beta\psi)^s \lambda_{t+s} P^{\epsilon-1}_{t+s} P_t^{1-\epsilon} y_{t+s}}.$$

Defining the relative price of the firms that are allowed to reset their prices as $\pi^*_t = P^*_t/P_t$ and gross inflation as $\pi_t = P_t/P_{t-1}$, we can rewrite this as:

$$\pi^*_t = \frac{\epsilon}{\epsilon-1} \frac{\Xi_{1,t}}{\Xi_{2,t}}, \tag{82}$$

$$\Xi_{1,t} = \lambda_t m_t y_t + \beta\psi E_t \pi^{\epsilon}_{t+1} \Xi_{1,t+1}, \tag{83}$$

$$\Xi_{2,t} = \lambda_t y_t + \beta\psi E_t \pi^{\epsilon-1}_{t+1} \Xi_{2,t+1}. \tag{84}$$

The aggregate price level equals:

$$P_t^{1-\epsilon} = (1-\psi)(P_t^*)^{1-\epsilon} + \psi P_{t-1}^{1-\epsilon}.$$

Dividing by $P_t^{1-\epsilon}$ yields the following law of motion:

$$(1-\psi)(\pi_t^*)^{1-\epsilon} + \psi \pi_t^{\epsilon-1} = 1. \tag{85}$$

A.2.4 Final Goods Producers

Final goods firms purchase intermediate goods which have been repackaged by the retail firms in order to produce the final good. The technology that is applied in producing the final good is given by $y_t^{(\epsilon-1)/\epsilon} = \int_0^1 y_{f,t}^{(\epsilon-1)/\epsilon} df$, where $y_{f,t}$ is the output of the retail firm indexed by f. ϵ is the elasticity of substitution between the intermediate goods purchased from the different retail firms. The final goods firms face perfect competition, and therefore take prices as given. Thus they maximize profits by choosing $y_{f,t}$ such that $P_t y_t - \int_0^1 P_{f,t} y_{f,t} df$ is maximized. Taking the first order conditions with respect to $y_{f,t}$, gives the demand function of the final goods producers for the retail goods. Substitution of the demand function into the technology constraint gives the relation between the price level of the final goods and the price level of the individual retail firms:

$$\begin{aligned} y_{f,t} &= (P_{f,t}/P_t)^{-\epsilon} y_t, \\ P_t^{1-\epsilon} &= \int_0^1 P_{f,t}^{1-\epsilon} df. \end{aligned}$$

A.2.5 Aggregation

Substituting $y_{f,t} = y_{i,t} = y_t \big(P_{f,t}/P_t\big)^{-\epsilon}$ into the factor demands derived earlier yields:

$$h_{i,t} = (1-\alpha) m_t y_{f,t}/w_t, \quad k_{i,t-1} = \alpha m_t y_{f,t}/[q_{t-1}^k(1+r_t^k) - q_t^k(1-\delta)\xi_t].$$

Aggregation over all firms i gives us aggregate labor and capital:

$$h_t = (1-\alpha) m_t y_t \mathcal{D}_t/w_t, \quad k_{t-1} = \alpha m_t y_t \mathcal{D}_t/[q_{t-1}^k(1+r_t^k) - q_t^k(1-\delta)\xi_t],$$

where $\mathcal{D}_t = \int_0^1 \big(P_{f,t}/P_t\big)^{-\epsilon} df$ denotes the price dispersion. It is given by the following recursive form:

$$\mathcal{D}_t = (1-\psi)(\pi_t^*)^{-\epsilon} + \psi \pi_t^{\epsilon} \mathcal{D}_{t-1}. \tag{86}$$

The aggregate capital-labor ratio is equal to the individual capital-labor ratio:

$$k_{t-1}/h_t \;=\; \alpha(1-\alpha)^{-1} w_t/[q_{t-1}^k(1+r_t^k) - q_t^k(1-\delta)\xi_t] = k_{i,t-1}/h_{i,t}. \tag{87}$$

Now calculate aggregate supply by aggregating $y_{i,t} = z_t(\xi_t k_{i,t-1})^\alpha h_{i,t}^{1-\alpha}$:

$$\int_0^1 z_t(\xi_t k_{i,t-1})^\alpha h_{i,t}^{1-\alpha} di = z_t \xi_t^\alpha \Big(\frac{k_{t-1}}{h_t}\Big)^\alpha \int_0^1 h_{i,t} di = z_t(\xi_t k_{t-1})^\alpha {h_t}^{1-\alpha},$$

while aggregation over $y_{i,t}$ gives:

$$\int_0^1 y_{i,t} df = y_t \int_0^1 \big(P_{f,t}/P_t\big)^{-\epsilon} df = y_t \mathcal{D}_t.$$

So we get the following relation for aggregate supply y_t:

$$y_t \mathcal{D}_t = z_t(\xi_t k_{t-1})^\alpha {h_t}^{1-\alpha}. \tag{88}$$

Parameter	Value	Definition
Households		
$\bar{h}$	1/3	Labor supply
Financial intermediaries		
$\bar{\phi}$	6	Leverage ratio
Γ_k	0.0050	Quarterly credit spread $E[r^k - r^d]$
Γ_{cb}	0	Quarterly credit spread $E[r^d - r^{cb}]$
$\bar{\theta}$	0.95	Haircut parameter
λ_b/λ_k	0.5	Diversion rate bonds over private loans
Government policy		
$\bar{i}/\bar{y}$	0.2	Investment-output ratio
$\bar{g}/\bar{y}$	0.2	Gov't spending-output ratio
$\bar{q}_b\bar{b}/\bar{y}$	4	Gov't liabilities-output ratio (quarterly)
$\bar{s}_b/\bar{b}$	0.25	Fraction of gov't financing by banks

Table 2: Calibration targets for the NK version of the model.

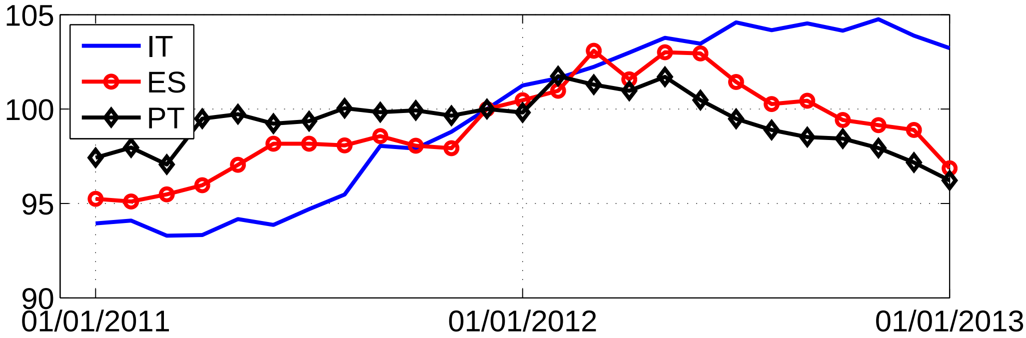
B Calibration

Parameter	Value	Definition
Households		
β	0.990	Discount rate
υ	0.815	Degree of habit formation
Ψ	3.6023	Relative utility weight of labor
φ	0.276	Inverse Frisch elasticity of labor supply
$\kappa_{s_{b,h}}$	0.0025	Constant portfolio adjustment cost function
$\hat{s}_{b,h}$	1.6656	Reference level portfolio adjustment cost function
Financial Intermediaries		
λ_k	0.3861	Fraction of private loans that can be diverted
λ_b	0.1930	Fraction of gov't bonds that can be diverted
χ	0.0026	Proportional transfer to entering bankers
σ	0.95	Survival rate of the bankers
Intermediate good firms		
ϵ	4.176	Elasticity of substitution
ψ	0.779	Calvo probability of keeping prices fixed
α	0.330	Effective capital share
Capital good firms		
γ	1.728	Investment adjustment cost parameter
δ	0.0592	Depreciation rate
Autoregressive components		
ρ_z	0.95	Autoregressive component of productivity
ρ_ξ	0.66	Autoregressive component of capital quality
ρ_r	0.4	Interest rate smoothing parameter
Policy		
r_c	0.04	Real payment to government bondholder
ρ	0.96	Parameter government debt duration (5 yrs)
κ_b	0.050	Tax feedback parameter from government debt
κ_π	1.500	Inflation feedback on nominal interest rate
κ_y	0.125	Output feedback on nominal interest rate
Shocks		
σ_z	0.010	Standard deviation productivity shock
σ_ξ	0.050	Standard deviation capital quality shock
σ_r	0.0025	Standard deviation interest rate surprise shock

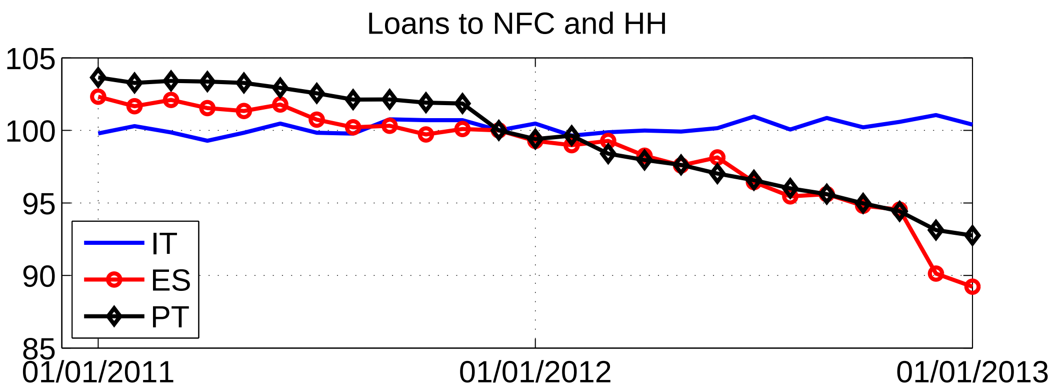
Table 3: Model parameters for the NK version.

C Additional Figures

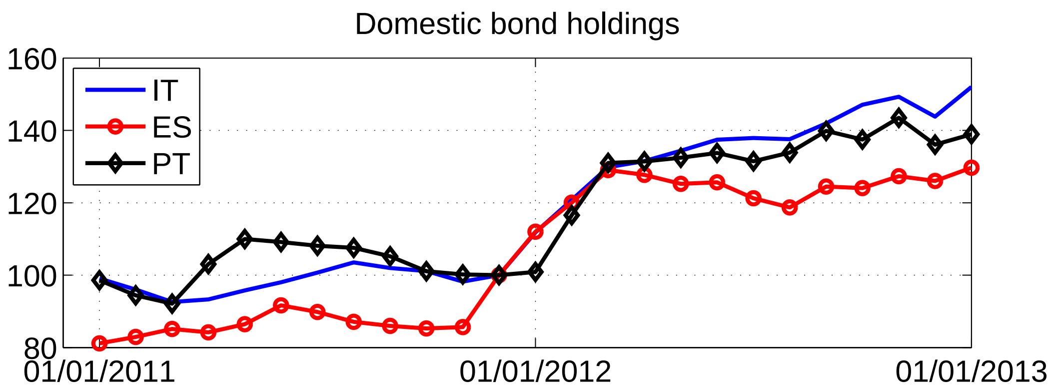
Asset holdings MFIs in Italy, Spain and Portugal



(a)



(b)



(c)

Figure 9: Asset holdings of Monetary Financial Institutions (MFIs) excluding the European System of Central Banks in Italy (IT), Spain (ES), and Portugal (PT) from January 2011 to January 2013. Panel 9a shows total assets, Panel 9b shows loans to non financial corporations (NFC) and households (HH), while Panel 9c shows domestic bond holdings. Levels have been rescaled with respect to asset holdings on December 1st, 2011, which has a value of 100 in all three plots. *Souce:* ECB.

Money market rates

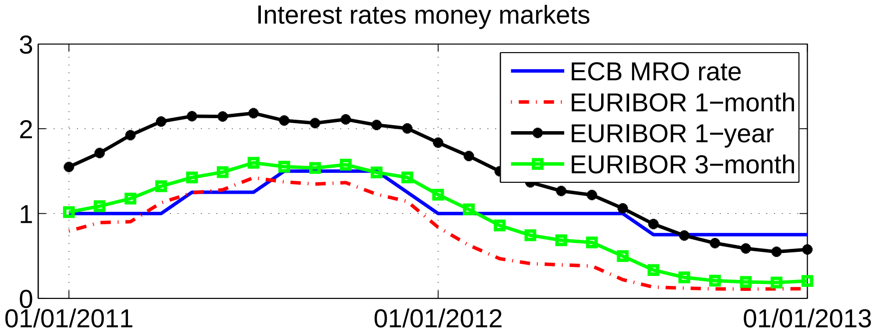


Figure 10: The ECB MRO (Main Refninancing Operation) rate is charged on collateralized loans with a maturity of 1 week from the ECB. The MRO rate is the ECB's main instrument for conducting monetary policy. EURIBOR (Euro InterBank Offered Rate) rates are money market rates at which commercial banks can obtain unsecured funding in the European interbank market. *Source*: European Central Bank (2015).

D First Order Conditions & Equilibrium

D.1 First Order Conditions

The first order conditions given below include the possibility of a recapitalization of the financial sector by the government, as well as repayment of previously administered government support. This gives four additional variables that are not present in the model description of the model in the main part of the paper. These variables are $\{n_t^g, \tilde{n}_t^g, \tau_t^n, \tilde{\tau}_t^n\}$. I retrieve the model from the main part of the paper by setting these four variables equal to zero. The household's first order conditions are given by:

$$\lambda_t = (c_t - \upsilon c_{t-1})^{-1} - \beta \upsilon E_t \left[(c_{t+1} - \upsilon c_t)^{-1} \right], \tag{89}$$

$$\Psi h_t^{\varphi} = \lambda_t w_t, \tag{90}$$

$$1 = E_t \left[\beta \frac{\lambda_{t+1}}{\lambda_t} \left(1 + r_{t+1}^d \right) \right], \tag{91}$$

$$1 = E_t \left[\beta \frac{\lambda_{t+1}}{\lambda_t} \left(\frac{\left(1 + r_{t+1}^b\right) q_t^b}{q_t^b + \kappa_{s_{b,h}} \left(s_t^{b,h} - \hat{s}_{b,h} \right)} \right) \right]. \tag{92}$$

First order conditions for financial intermediaries are given by:

$$\frac{\lambda_b}{\lambda_k} E_t \left[\Omega_{t,t+1}\left(r^k_{t+1} - r^d_{t+1}\right)\right] = E_t\left[\Omega_{t,t+1}\left(r^b_{t+1} - r^d_{t+1}\right)\right] + \left(\frac{\kappa_t}{q^b_t}\right)\theta_t\left(\frac{\psi_t}{1+\mu_t}\right), \tag{93}$$

$$\lambda_k\left(\frac{\mu_t}{1+\mu_t}\right) = E_t\left[\Omega_{t,t+1}\left(r^k_{t+1} - r^d_{t+1}\right)\right], \tag{94}$$

$$\frac{\psi_t}{1+\mu_t} = E_t\left[\Omega_{t,t+1}\left(r^d_{t+1} - r^{cb}_{t+1}\right)\right], \tag{95}$$

$$\eta_t = E_t\left[\Omega_{t,t+1}\left(1 + r^d_{t+1} + \tau^n_{t+1} - \tilde{\tau}^n_{t+1}\right)\right], \tag{96}$$

$$(1+\mu_t)\,\eta_t n_{j,t} = \lambda_k q^k_t s^{k,p}_{j,t} + \lambda_b q^b_t s^{b,p}_{j,t}, \tag{97}$$

$$\begin{aligned} n_t &= \sigma\Big[\left(r^k_t - r^d_t\right) q^k_{t-1} s^{k,p}_{t-1} + \left(r^b_t - r^d_t\right) q^b_{t-1} s^{b,p}_{t-1} \\ &+ \left(r^d_t - r^{cb}_t\right) d^{cb}_{t-1} + \Big(1 + r^d_t\Big) n_{t-1}\Big] + \chi p_{t-1} + n^g_t - \tilde{n}^g_t, \end{aligned} \tag{98}$$

$$d^{cb}_t = \theta_t q^b_t s^{b,p}_t, \tag{99}$$

$$p_t = q^k_t s^k_t + q^b_t s^b_t, \tag{100}$$

$$p_t = n_t + d_t + d^{cb}_t, \tag{101}$$

$$\phi_t = p_t / n_t, \tag{102}$$

$$\omega^k_t = q^k_t s^k_t / p_t, \tag{103}$$

where $\Omega_{t,t+1} = \beta\Lambda_{t,t+1}\left\{(1-\sigma) + \sigma\left(1+\mu_{t+1}\right)\eta_{t+1}\right\}$. Price setting conditions are given by:

$$\pi^*_t = \frac{\epsilon}{\epsilon - 1}\frac{\Xi_{1,t}}{\Xi_{2,t}}, \tag{104}$$

$$\Xi_{1,t} = \lambda_t m_t y_t + \beta\psi E_t \pi^{\epsilon}_{t+1}\Xi_{1,t+1}, \tag{105}$$

$$\Xi_{2,t} = \lambda_t y_t + \beta\psi E_t \pi^{\epsilon-1}_{t+1}\Xi_{2,t+1}, \tag{106}$$

$$1 = (1-\psi)(\pi^*_t)^{1-\epsilon} + \psi\pi^{\epsilon-1}_t, \tag{107}$$

$$\mathcal{D}_t = (1-\psi)(\pi^*_t)^{-\epsilon} + \psi\pi^{\epsilon}_t\mathcal{D}_{t-1}. \tag{108}$$

Production equations are given by:

$$m_t = \alpha^{-\alpha}(1-\alpha)^{\alpha-1} z_t^{-1}\left(w_t^{1-\alpha}\left[q^k_{t-1}(1+r^k_t)\xi_t^{-1} - q^k_t(1-\delta)\right]^{\alpha}\right), \tag{109}$$

$$k_{t-1}/h_t = \alpha(1-\alpha)^{-1} w_t / [q^k_{t-1}(1+r^k_t) - q^k_t(1-\delta)\xi_t], \tag{110}$$

$$k_t = (1-\delta)\,\xi_t k_{t-1} + \left(1 - \frac{\gamma}{2}\left[\frac{i_t}{i_{t-1}} - 1\right]^2\right) i_t, \tag{111}$$

$$\frac{1}{q^k_t} = 1 - \frac{\gamma}{2}\left(\frac{i_t}{i_{t-1}} - 1\right)^2 - \frac{\gamma i_t}{i_{t-1}}\left(\frac{i_t}{i_{t-1}} - 1\right) + \beta E_t\left[\Lambda_{t,t+1}\frac{q^k_{t+1}}{q^k_t}\left(\frac{i_{t+1}}{i_t}\right)^2\gamma\left(\frac{i_{t+1}}{i_t} - 1\right)\right], \tag{112}$$

$$y_t\mathcal{D}_t = z_t(\xi_t k_{t-1})^{\alpha} {h_t}^{1-\alpha}. \tag{113}$$

The first order conditions for the fiscal authority are given by:

$$
\begin{aligned}
1+r_t^b &= \frac{r_c+\rho q_t^b}{q_{t-1}^b}, && (114)\\
q_t^b b_t+\tau_t+\tilde{n}_t^g+\Pi_t^{cb} &= g_t+n_t^g+\left(1+r_t^b\right)q_{t-1}^b b_{t-1}, && (115)\\
g_t &= G, && (116)\\
\tau_t &= \bar{\tau}+\kappa_b(b_{t-1}-\bar{b})+\kappa_n n_t^g, && (117)\\
n_t^g &= \tau_t^n n_{t-1}, && (118)\\
\tau_t^n &= \zeta\varepsilon_{\xi,t-l}, && (119)\\
\tilde{n}_t^g &= \vartheta n_{t-e}^g, && (120)\\
\tilde{\tau}_t^n &= n_t^g/n_{t-1}. && (121)
\end{aligned}
$$

The first order conditions for the central bank are given by:

$$
\begin{aligned}
r_t^n &= (1-\rho_r)\left(r^n+\kappa_\pi\left[\pi_t-\bar{\pi}\right]+\kappa_y\log\left[y_t/y_{t-1}\right]+\kappa_\xi\left[\xi_t-\bar{\xi}\right]\right)+\rho_r r_{t-1}^n+\varepsilon_{r,t}, && (122)\\
1+r_t^d &= \left(1+r_{t-1}^n\right)/\pi_t, && (123)\\
r_t^{n,cb} &= r_t^n-\Gamma_t^{cb}, && (124)\\
1+r_t^{cb} &= \left(1+r_{t-1}^{n,cb}\right)/\pi_t, && (125)\\
\Gamma_t^{cb} &= \bar{\Gamma}_{cb}+\varkappa_{cb}\left(\xi_t-\bar{\xi}\right), && (126)\\
\theta_t &= \bar{\theta}+\varkappa_{d,cb}\left(\xi_t-\bar{\xi}\right), && (127)\\
\Pi_t^{cb} &= \left(r_t^{cb}-r_t^d\right)d_{t-1}^{cb}, && (128)
\end{aligned}
$$

Market clearing conditions are given by:

$$
\begin{aligned}
k_t &= s_t^k, && (129)\\
b_t &= s_t^b+s_t^{b,h}, && (130)\\
a_t &= d_t+d_t^{cb}, && (131)\\
y_t &= c_t+i_t+g_t+\frac{1}{2}\kappa_{s_{b,h}}\left(s_t^{b,h}-\hat{s}_{b,h}\right)^2. && (132)
\end{aligned}
$$

And finally, exogenous processes are given by:

$$
\begin{aligned}
\log(z_t) &= \rho_z\log(z_{t-1})+\varepsilon_{z,t}, && (133)\\
\log(\xi_t) &= \rho_a\log(\xi_{t-1})+\varepsilon_{\xi,t}. && (134)
\end{aligned}
$$

D.2 Equilibrium Conditions

Let $c_{t-1}, s_{t-1}^{b,h}, a_{t-1}, s_{t-1}^{k,p}, s_{t-1}^{b,p}, n_{t-1}, d_{t-1}^{cb}, p_{t-1}, k_{t-1}, i_{t-1}, b_{t-1}, y_{t-1}, \mathcal{D}_{t-1}, r_{t-1}^n, r_{t-1}^{n,cb}, z_t, \xi_t$ be the state vector. A recursive competitive equilibrium is a sequence of quantities and prices $c_t, \lambda_t, h_t, s_t^{b,h}$,

$a_t, \eta_t, \mu_t, \psi_t, \phi_t, n_{t,} s_t^k, s_t^b, p_t, d_t, d_t^{cb}, \omega_t^k, q_t^k, q_t^b, r_t^k, r_t^b, r_t^d, r_t^{cb}, w_t, m_t, \pi_t, \pi_t^*, \Xi_t^1, \Xi_t^2, \mathcal{D}_t, i_t, k_t,$
$y_t, b_t, g_t, n_t^g, \tilde{n}_t^g, \tau_t, \tau_t^n, \tilde{\tau}_t^n, r_t^n, r_t^{n,cb}, \Gamma_t^{cb}, \theta_t, \Pi_t^{cb}, z_t, \xi_t$ such that:

(i) Households optimize taking prices as given: (89) - (92).

(ii) Financial intermediaries optimize taking prices as given: (93) - (103).

(iii) Capital producers optimize taking prices as given: (111) - (112).

(iv) Intermediate goods producers optimize taking prices as given: (109) - (110)

(v) Retail goods producers that are allowed to change prices optimize taking input prices m_t as given: (104) - (108).

(vi) Final goods producers optimize taking prices as given: (113).

(vii) Asset markets clear: (129) - (131).

(viii) The goods market clears: (132).

(ix) The fiscal variables evolve according to: (114) - (121).

(x) The monetary variables evolve according to: (122) - (128).

(xi) Productivity and capital quality evolve according to: (133) and (134).

E Robustness checks

To check whether my results are robust, I conduct a robustness check. I will perform this check along two dimensions. First, I will change some of the key parameters of the model. A second line of robustness checks is along the dimension of model specification. I perform these checks to make sure that my model results do not depend on some arbitrary parameter choice or a particular model specification.

E.1 Parameters

Since the substitution of private loans for government bonds is driving the results of the unconventional monetary policy operation, I change parameters that are related to government bond holdings, or the willingness to hold government bonds. I start by adjusting the household's portfolio adjustment costs for government bond holdings $\kappa_{s_{b,h}}$, since this parameter determines the elasticity with which households are willing to buy and sell government bonds when the demand for government bonds by commercial banks changes in response to the unconventional central bank lending. Because the initial calibration shows a rather conservative increase in the recourse to low-interest-rate central bank funding, I decrease $\kappa_{s_{b,h}}$ from 0.0025 to 0.0010 in Figure 11.

Second I investigate the relative diversion rate λ_b/λ_k. An increase in λ_b/λ_k increases the steady state spread between bonds and deposits, and makes it harder for commercial banks to expand the balance sheet through an increase in bond holdings, since bankers can divert a larger fraction of bondholdings. I investigate both an decrease in λ_b/λ_k from 0.5 to 0.25 (Figure 12), as well as the case where $\lambda_b/\lambda_k = 0.75$ (Figure 13).

Third, I investigate the impact of changing the fraction of government debt on banks' balance sheets $\bar{q}_b\bar{b}$ by reducing the steady state level of government liabilities from 100% of annual GDP to 80% of annual GDP, see Figure 14.

Fourth, I change the steady state fraction of government bonds financed by the household from 75% to 90% in Figure 15.

Fifth, a parameter that influences the volatility of net worth, and hence of the tightness of bank balance sheet constraints, is the bankers' survival rate σ. I look at both a decrease in the average survival period from 20 to 16 quarters (Figure **??**), as well as an increase from 20 to 24 quarters (Figure **??**).

E.2 Model specification

A second line of robustness checks is along the dimension of model specification. One obvious robustness check is to allow households to intermediate private loans. Another specification allows for commercial banks to use private loans for collateral purposes in addition to government bonds. I also allow for an adjusted collateral constraint, which still only features government bonds, but is adjusted to make sure that the central bank can seize the bondholdings that were pledged to the central bank under the central bank's lending operations. The last specification is the implementation of the zero lower bound (ZLB).

E.2.1 Household financing of private loans

Commercial banks are in reality not the only financiers of private loans to non-financial corporations. I abstain, however, from introducing household intermediation of private loans in the main part of the paper for two reasons. First, bank financing of credit to non-financial corporations accounts for approximately 80% in the Eurozone. Second, I construct a model that includes household financing of private loans, and find that the results are not significantly affected by the introduction of household intermediation of private loans. But to check whether the inclusion of household intermediation of private loans changes the results qualitatively, I introduce the possibility for households to finance private loans

Private loans yield a return r_t^k on their holdings $q_{t-1}^k s_{t-1}^{k,h}$, where $s_{t-1}^{k,h}$ is the number of private loans purchased in period $t-1$. Households are less efficient in financial intermediation than commercial banks, hence they incur financial intermediation costs, which is quadratic in the deviation from the number of private loans $\hat{s}_{k,h}$. The household's problem changes into:

$$\max_{\left\{c_{t+i},h_{t+i},a_{t+i},s_{t+i}^{k,h},s_{t+i}^{b,h}\right\}} E_t \quad \left[\sum_{i=0}^{\infty} \beta^i \left\{ \log\left(c_{t+i} - \upsilon c_{t-1+i}\right) - \Psi \frac{h_t^{1+\varphi}}{1+\varphi} \right\}\right]$$

s.t.

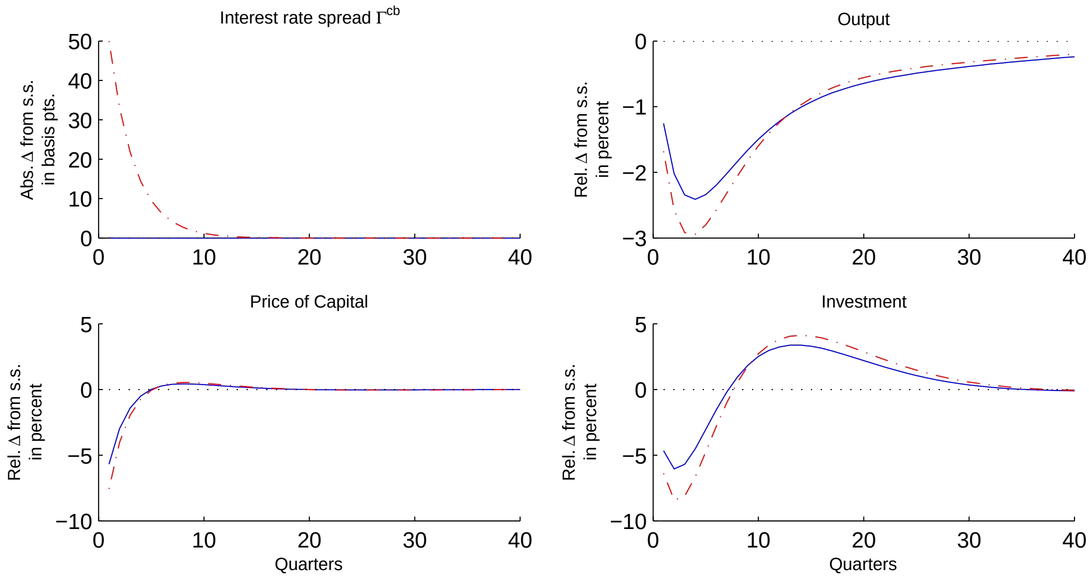
$$\begin{aligned} c_t + \tau_t + a_t + q_t^k s_t^{k,h} + q_t^b s_t^{b,h} + \frac{\kappa_{s_{k,h}}}{2}\left(s_t^{k,h} - \hat{s}_{k,h}\right)^2 &+ \frac{\kappa_{s_{b,h}}}{2}\left(s_t^{b,h} - \hat{s}_{b,h}\right)^2 = w_t h_t + \left(1 + r_t^d\right) a_{t-1} \\ &+ \left(1 + r_t^k\right) q_{t-1}^k s_{t-1}^{k,h} + \left(1 + r_t^b\right) q_{t-1}^b s_{t-1}^{b,h} + \Pi_t, \end{aligned}$$

which give rise to an additional first order condition for private loans $s_t^{k,h}$, next to the first order conditions from the main text:

$$s_t^{k,h} \quad : \quad E_t \left[\beta \frac{\lambda_{t+1}}{\lambda_t} \left(\frac{\left(1 + r_{t+1}^k\right) q_t^k}{q_t^k + \kappa_{s_{k,h}} \left(s_t^{k,h} - \hat{s}_{k,h}\right)} \right)\right] = 1. \qquad (135)$$

This introduces a new parameter, namely $\kappa_{s_{k,h}}$, into the model. It is reasonable to assume that transaction costs for households are larger for private credit intermediation than for sovereign debt intermediation. We therefore set $\kappa_{s_{k,h}} = 0.1$, which is four times larger than $\kappa_{s_{b,h}}$. The

Financial crisis impact, no additional policy vs. unconventional monetary policy for $\kappa_{s_{b,h}} = 0.0010$.



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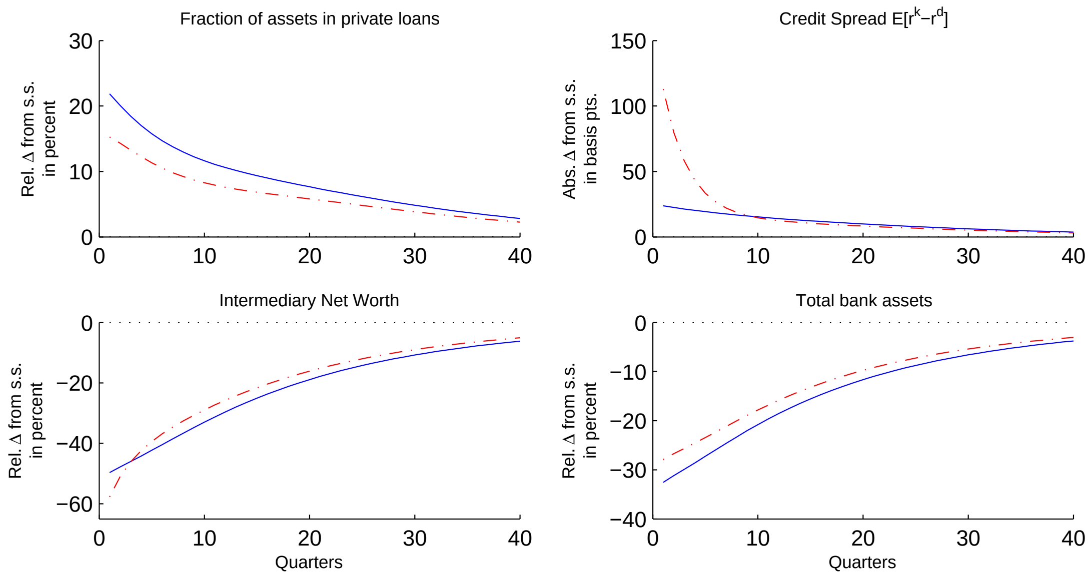

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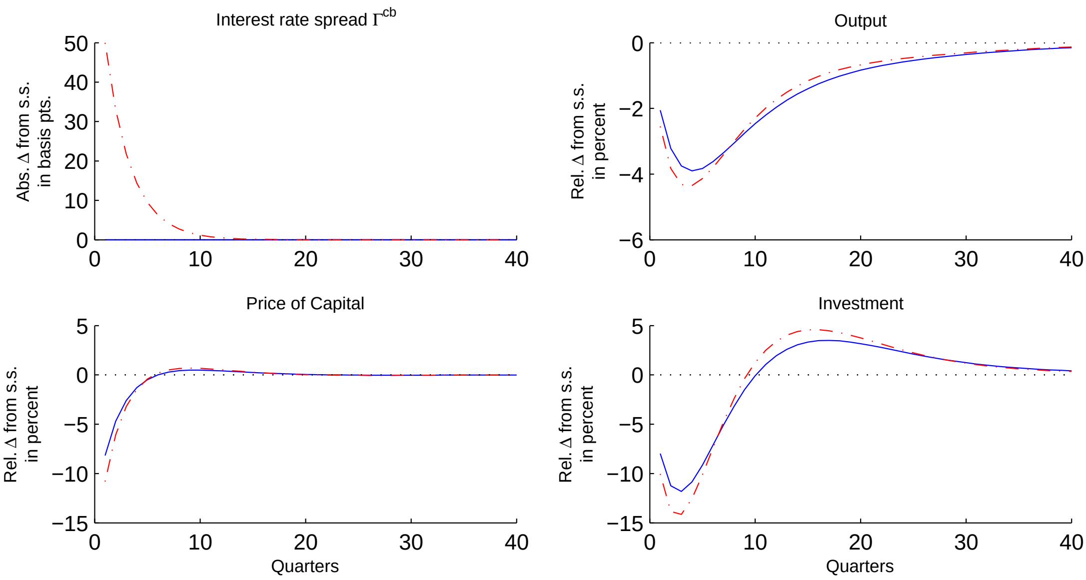
Figure 11: Impulse response functions for the case from section 5.1 with no additional policy (blue, solid) vs. the LTRO, represented by a decrease in the nominal interest rate on central bank lending facilities of 50 basis points on impact with respect to the nominal interest rate on regular deposit funding (red, slotted). The financial crisis is initiated through a negative capital quality shock of 5 percent relative to the steady state.

Financial crisis impact, no additional policy vs. unconventional monetary policy for $\lambda_b/\lambda_k = 0.25$.



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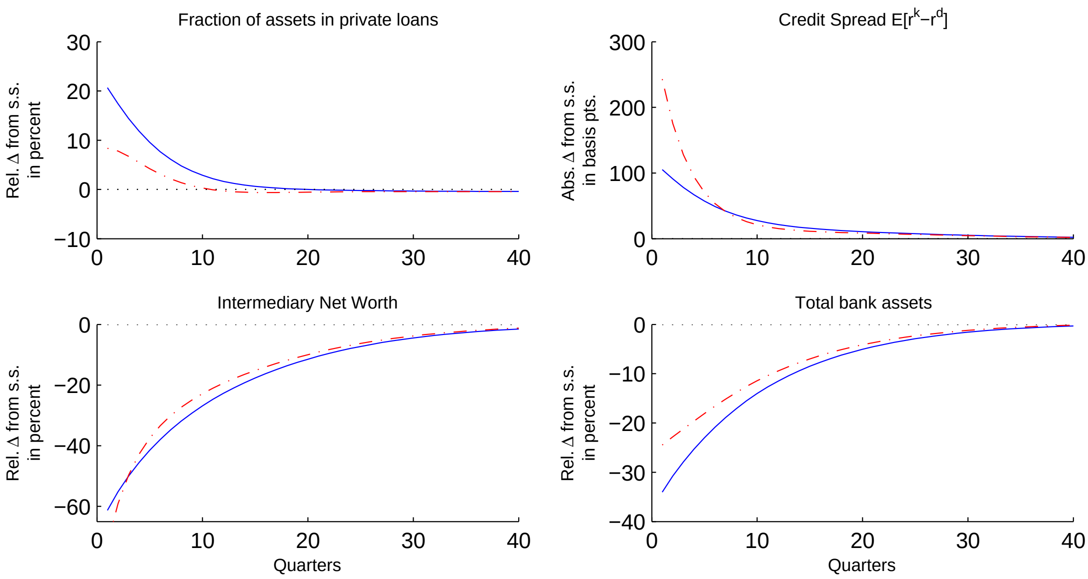

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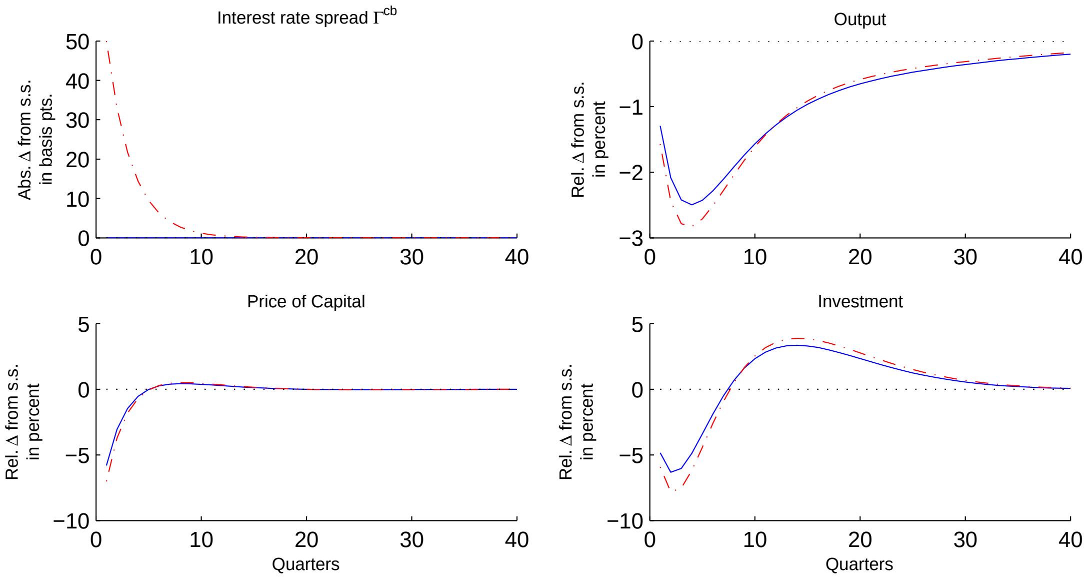
Figure 12: Impulse response functions for the case from section 5.1 with no additional policy (blue, solid) vs. the LTRO, represented by a decrease in the nominal interest rate on central bank lending facilities of 50 basis points on impact with respect to the nominal interest rate on regular deposit funding (red, slotted). The financial crisis is initiated through a negative capital quality shock of 5 percent relative to the steady state.

Financial crisis impact, no additional policy vs. unconventional monetary policy for $\lambda_b/\lambda_k = 0.75$.



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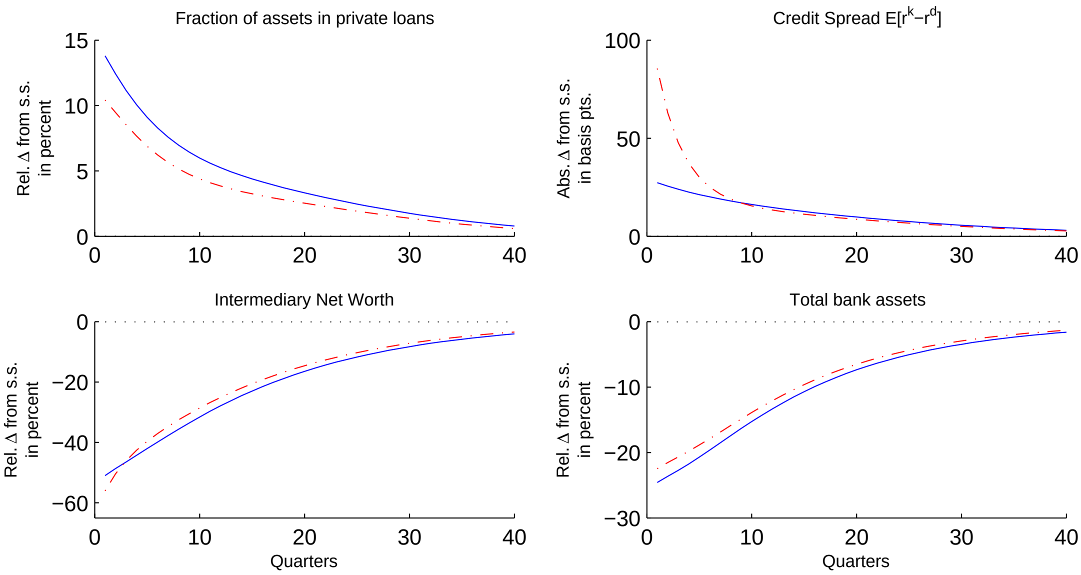

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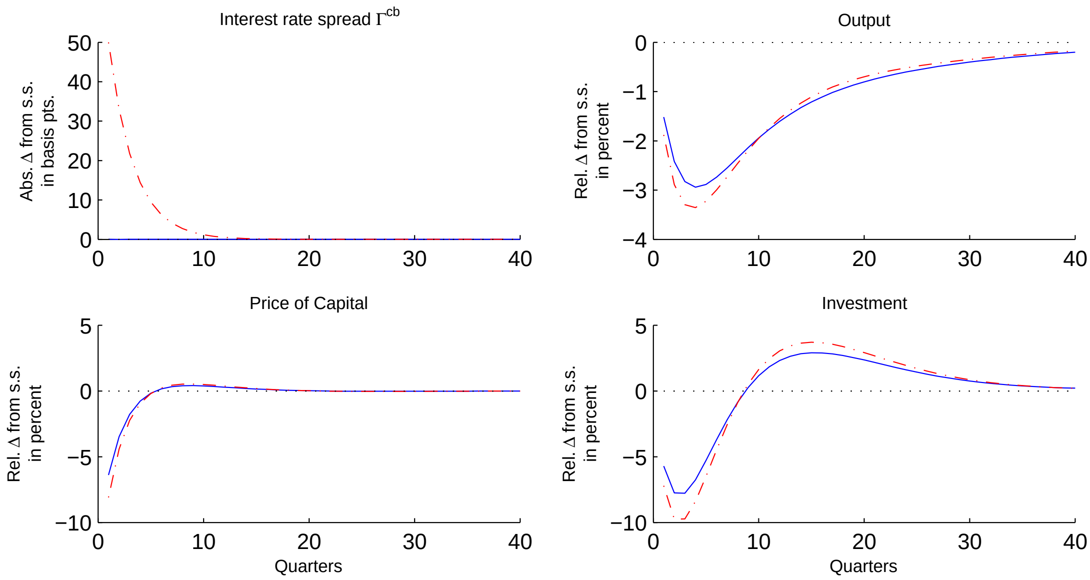
Figure 13: Impulse response functions for the case from section 5.1 with no additional policy (blue, solid) vs. the LTRO, represented by a decrease in the nominal interest rate on central bank lending facilities of 50 basis points on impact with respect to the nominal interest rate on regular deposit funding (red, slotted). The financial crisis is initiated through a negative capital quality shock of 5 percent relative to the steady state.

Financial crisis impact, no additional policy vs. unconventional monetary policy for steady state gov't debt at 80% of annual GDP.



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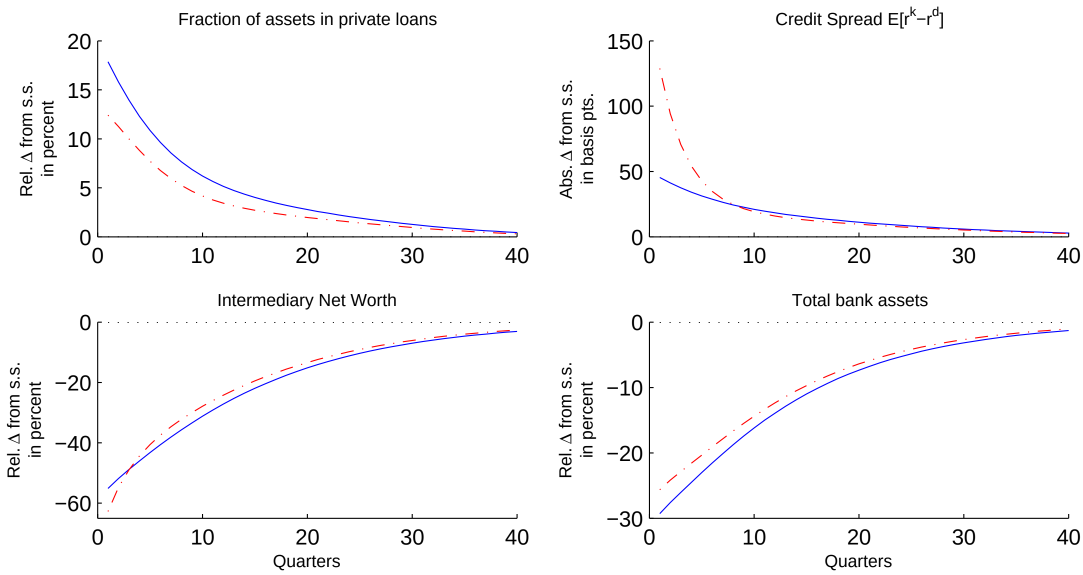

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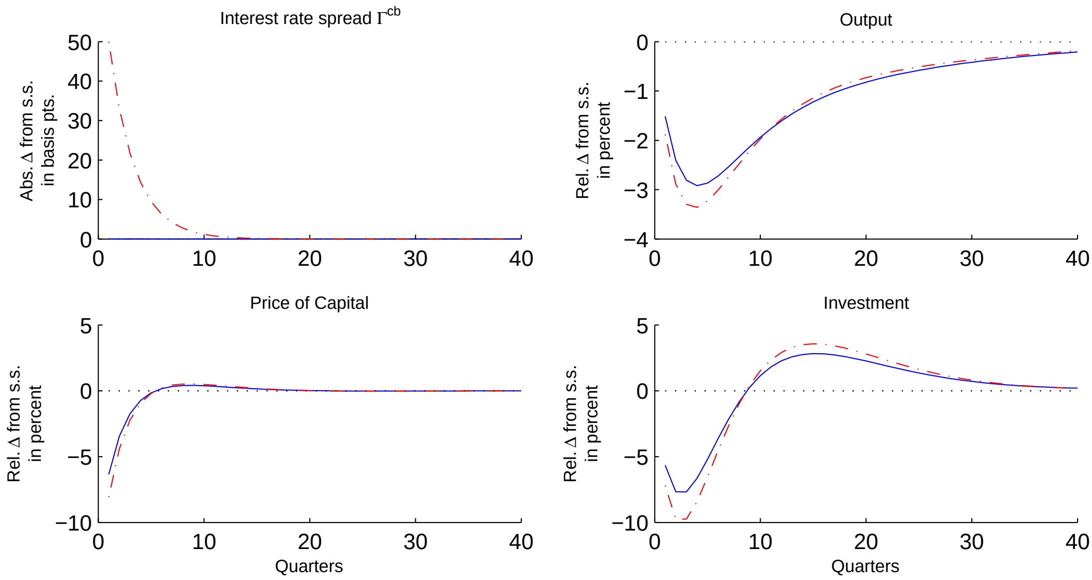
Figure 14: Impulse response functions for the case from section 5.1 with no additional policy (blue, solid) vs. the LTRO, represented by a decrease in the nominal interest rate on central bank lending facilities of 50 basis points on impact with respect to the nominal interest rate on regular deposit funding (red, slotted). The financial crisis is initiated through a negative capital quality shock of 5 percent relative to the steady state.

Financial crisis impact, no additional policy vs. unconventional monetary policy for households financing 90% of sovereign debt in steady state.



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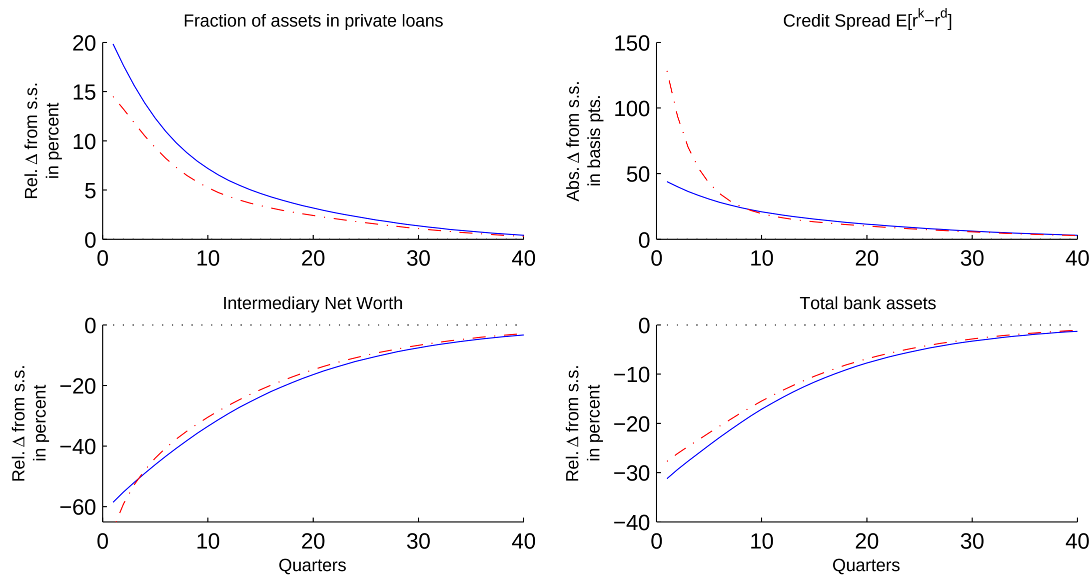

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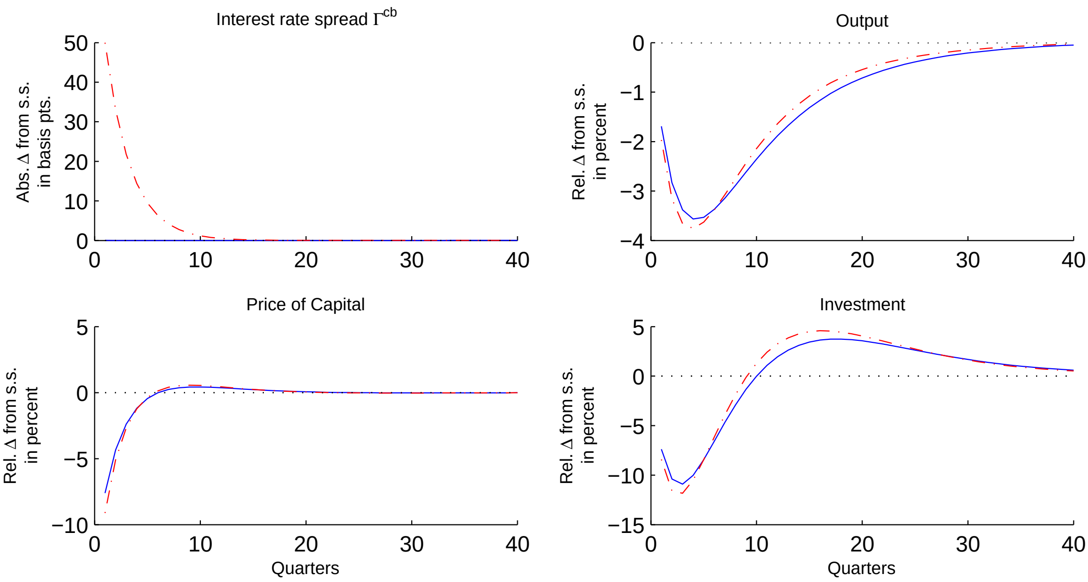
Figure 15: Impulse response functions for the case from section 5.1 with no additional policy (blue, solid) vs. the LTRO, represented by a decrease in the nominal interest rate on central bank lending facilities of 50 basis points on impact with respect to the nominal interest rate on regular deposit funding (red, slotted). The financial crisis is initiated through a negative capital quality shock of 5 percent relative to the steady state.

Financial crisis impact, no additional policy vs. unconventional monetary policy for average survival time bankers 8 quarters.



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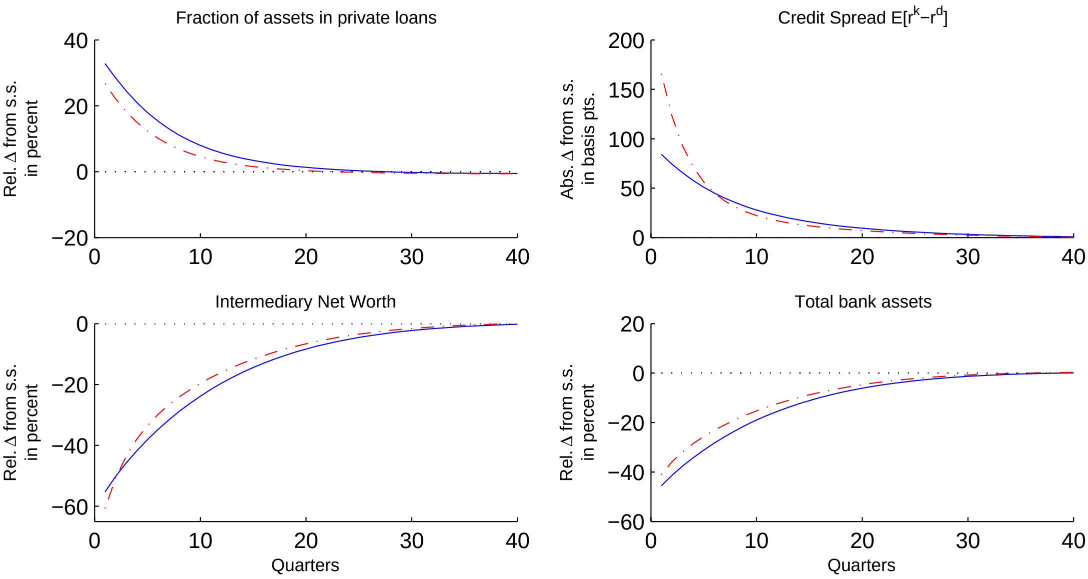

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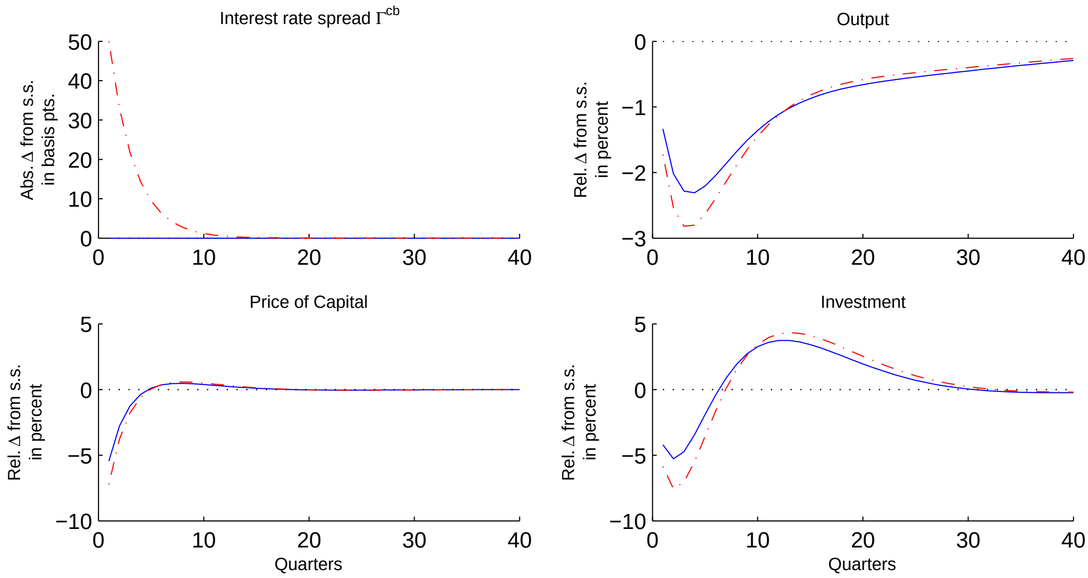
Figure 16: Impulse response functions for the case from section 5.1 with no additional policy (blue, solid) vs. the LTRO, represented by a decrease in the nominal interest rate on central bank lending facilities of 50 basis points on impact with respect to the nominal interest rate on regular deposit funding (red, slotted). The financial crisis is initiated through a negative capital quality shock of 5 percent relative to the steady state.

Financial crisis impact, no additional policy vs. unconventional monetary policy for average survival time bankers 28 quarters.



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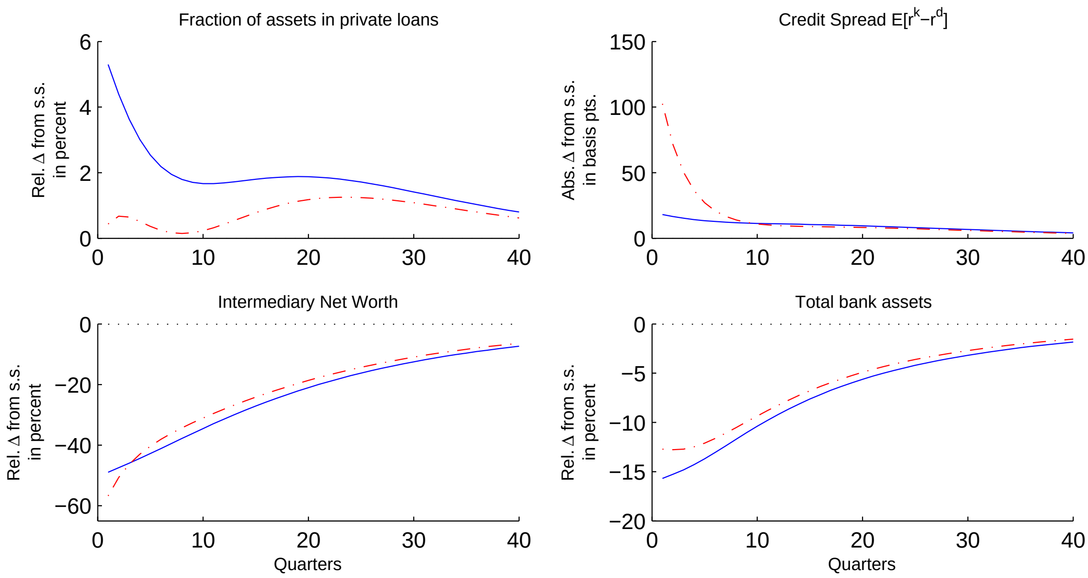

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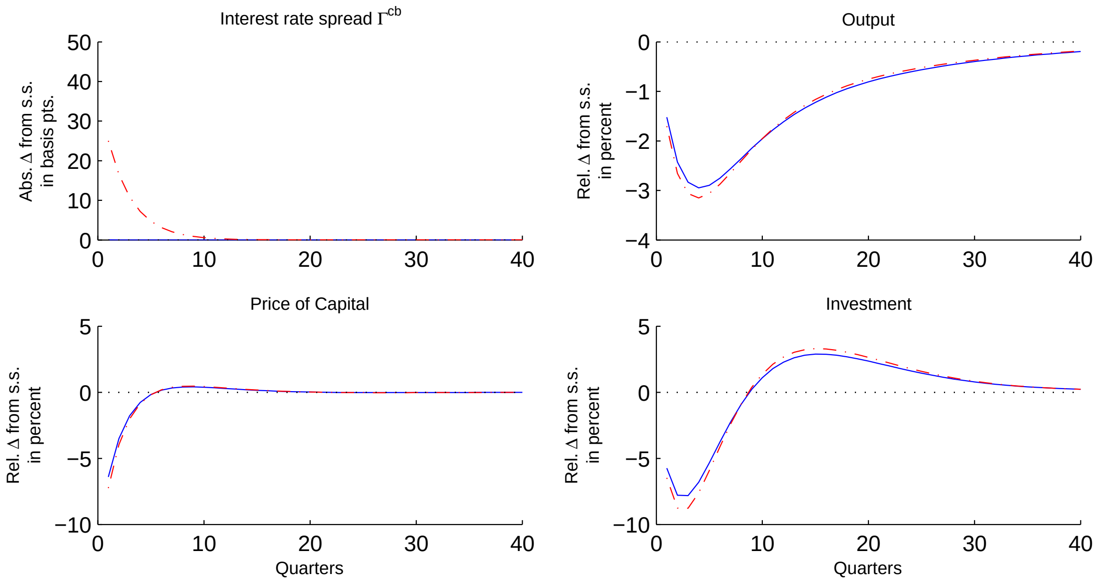
Figure 17: Impulse response functions for the case from section 5.1 with no additional policy (blue, solid) vs. the LTRO, represented by a decrease in the nominal interest rate on central bank lending facilities of 50 basis points on impact with respect to the nominal interest rate on regular deposit funding (red, slotted). The financial crisis is initiated through a negative capital quality shock of 5 percent relative to the steady state.

Financial crisis impact, no additional policy vs. unconventional monetary policy for $\Gamma_t^{cb} = 25$ basis points on impact.



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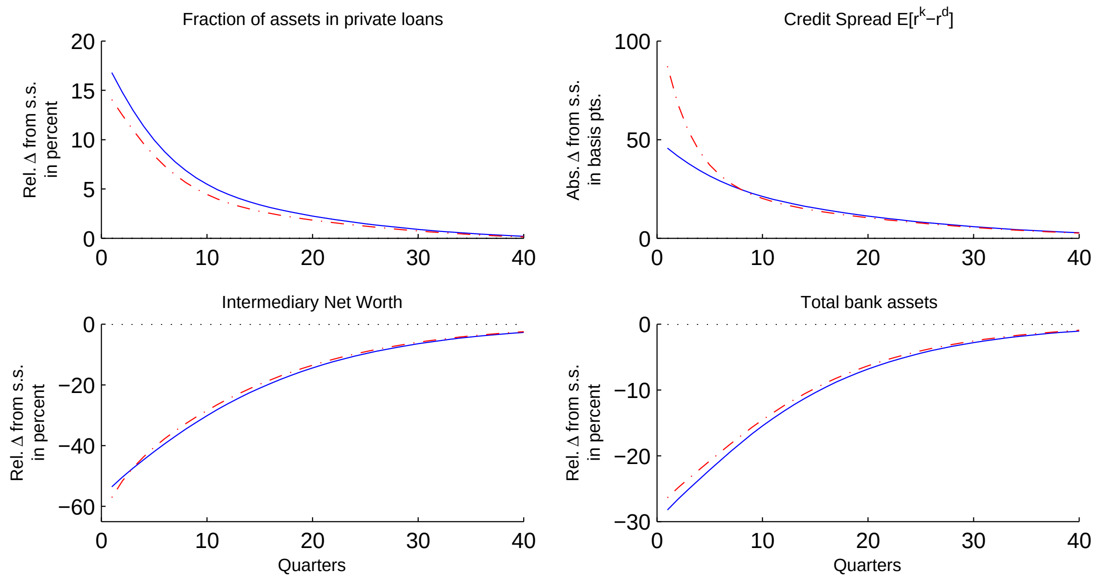

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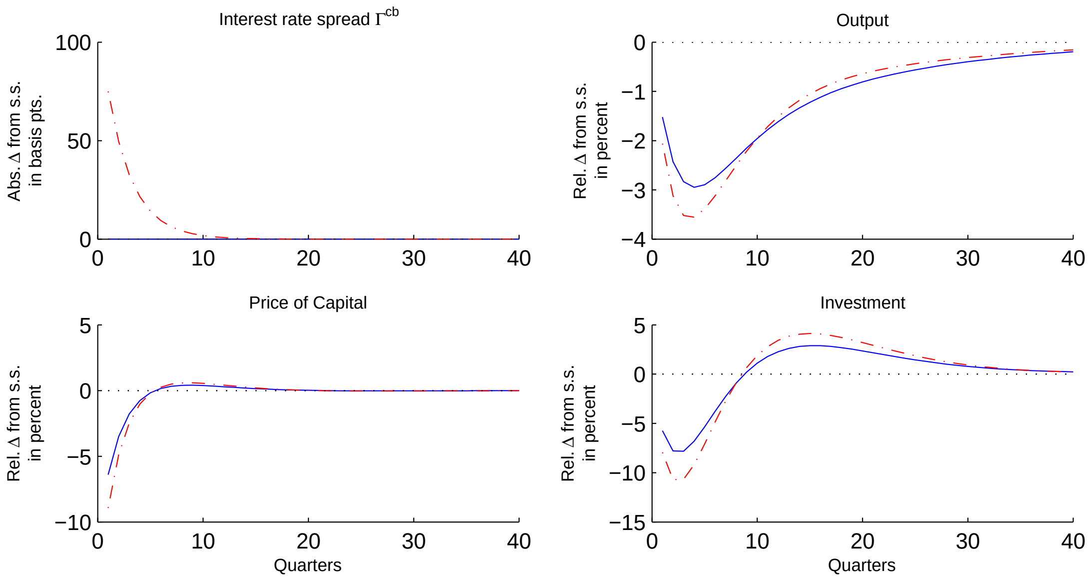
Figure 18: Impulse response functions for the case from section 5.1 with no additional policy (blue, solid) vs. the LTRO, represented by a decrease in the nominal interest rate on central bank lending facilities of 25 basis points on impact with respect to the nominal interest rate on regular deposit funding (red, slotted). The financial crisis is initiated through a negative capital quality shock of 5 percent relative to the steady state.

Financial crisis impact, no additional policy vs. unconventional monetary policy for $\Gamma_t^{cb} = 75$ basis points on impact.



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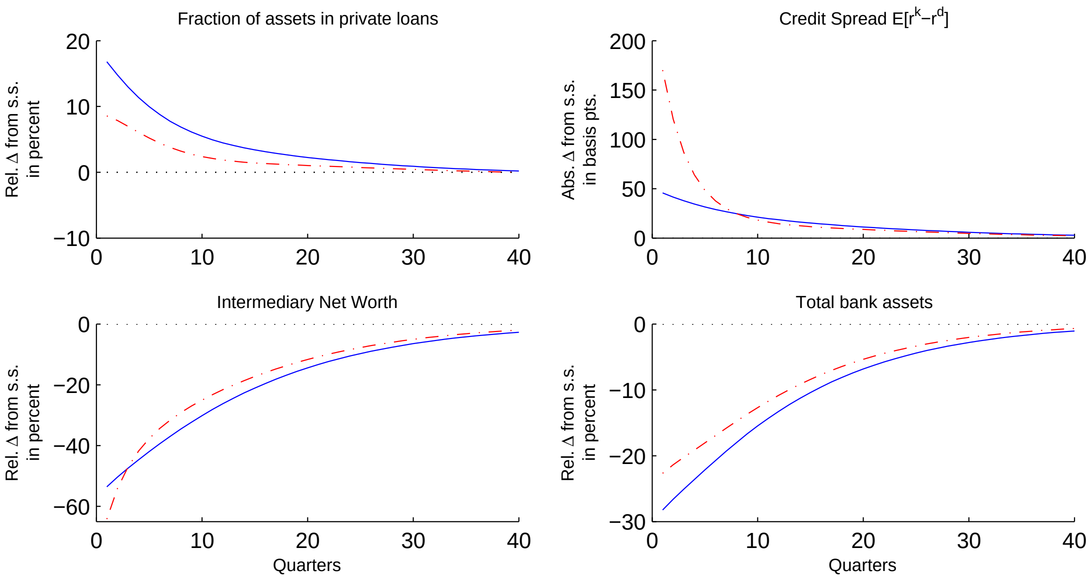

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Figure 19: Impulse response functions for the case from section 5.1 with no additional policy (blue, solid) vs. the LTRO, represented by a decrease in the nominal interest rate on central bank lending facilities of 75 basis points on impact with respect to the nominal interest rate on regular deposit funding (red, slotted). The financial crisis is initiated through a negative capital quality shock of 5 percent relative to the steady state.

market clearing condition (27) for private loans changes into:

$$k_t = s_t^{k,p} + s_t^{k,h}, \tag{136}$$

while the aggregate resource constraint (29) changes into:

$$y_t = c_t + i_t + g_t + \frac{1}{2}\kappa_{s_{k,h}}\left(s_t^{k,h} - \hat{s}_{k,h}\right)^2 + \frac{1}{2}\kappa_{s_{b,h}}\left(s_t^{b,h} - \hat{s}_{b,h}\right)^2. \tag{137}$$

The qualitative results of the unconventional central bank lending operations do not change upon introduction of household intermediation of private loans, see Figure 20.

E.2.2 Private loans under the collateral constraint

In reality, government bonds are not the only security that can be pledged as collateral in refinancing operations at the ECB. Alternative collateral classes include covered and uncovered bank bonds, asset-backed securities (ABS), corporate bonds and some other securities. Private loans to non-financial corporations and households are usually hard to collateralize, and most of these loans are therefore not used in refinancing operations with the ECB. To test whether the inclusion of private credit under the collateral constraint affects my result, I change the collateral constraint into:

$$d_{j,t}^{cb} \leq \theta_t^k q_t^k s_{j,t}^{k,p} + \theta_t^b q_t^b s_{j,t}^{b,p}, \tag{138}$$

where θ_t^k, respectively θ_t^b denote the haircut parameter on private loans, respectively government bonds. In line with actual ECB policy, I take θ_t^k to be smaller than θ_t^b, i.e. the ECB applies a larger haircut on private loans, which are considered to be more risky than government bonds.

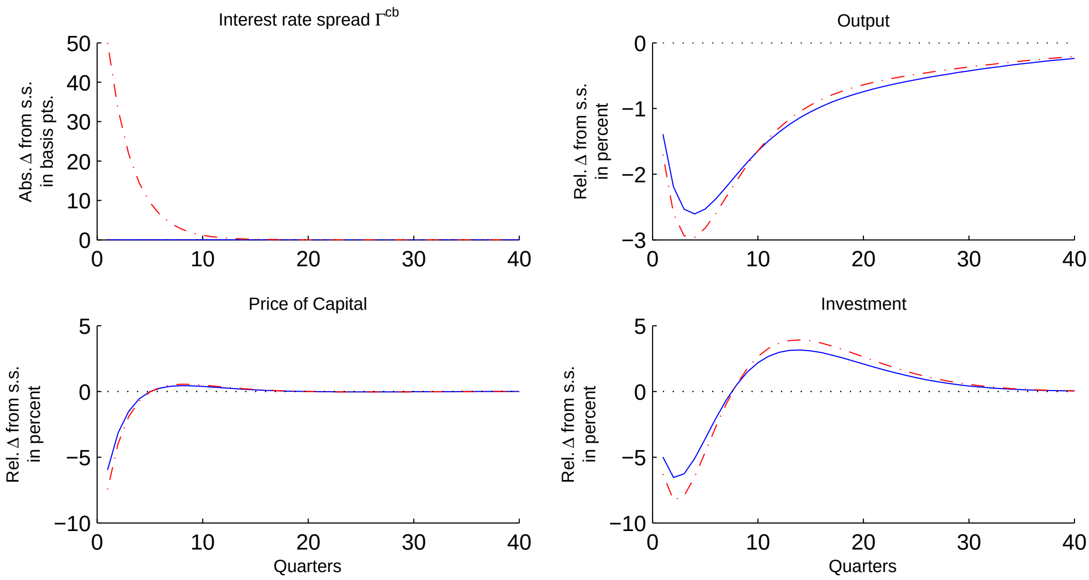
The first order conditions for the portfolio choice between private loans and government bonds, as well as the first order condition for private loans, are adjusted:

$$\frac{\lambda_b}{\lambda_k} E_t \left[\Omega_{t,t+1}\left(r_{t+1}^k - r_{t+1}^d\right)\right] = E_t \left[\Omega_{t,t+1}\left(r_{t+1}^b - r_{t+1}^d\right)\right] + \left(\theta_t^b - \theta_t^k \left(\frac{\lambda_b}{\lambda_k}\right)\right)\left(\frac{\psi_t}{1+\mu_t}\right), \tag{139}$$

$$\lambda_k \left(\frac{\mu_t}{1+\mu_t}\right) = E_t \left[\Omega_{t,t+1}\left(r_{t+1}^k - r_{t+1}^d\right)\right] + \theta_t^k \left(\frac{\psi_t}{1+\mu_t}\right), \tag{140}$$

Just as in the previous section, I include household intermediation of private loans under this specification. We immediately see that the inclusion of private credit under the collateral constraint is not capable to offset the effect of the collateral requirement on the portfolio decision of the commercial banks. There are two reasons for this: first, government bonds usually carry a smaller haircut than private loans, i.e. $\theta_t^b > \theta_t^k$. Hence a commercial bank obtains more central bank funding for a euro of government bonds than for a euro of private loans. Hence government bonds are more attractive collateral than private loans. At the same, the balance sheet constraint is more binding for private loans than for government bonds, as reflected by the fact that $\lambda_k > \lambda_b$. Hence it is harder to expand the balance sheet by a unit of private loans to obtain more funding from the central bank than by buying a government bond. This is a second reason why buying government bonds is more attractive when commercial banks want to obtain more central bank funding. Offsetting the distortion in the portfolio decision induced by the central bank requires $\theta_t^b = (\lambda_b/\lambda_k)\,\theta_t^k$. This requires $\lambda_b > \lambda_k$ if $\theta_t^b > \theta_t^k$, which implies that it is easier to expand the balance sheet by buying private loans than by buying government bonds, which is clearly not realistic. If $\lambda_k > \lambda_b$, we need $\theta_t^k > \theta_t^b$, i.e. a smaller haircut for private loans than for government bonds, which is in sharp contrast with current central bank policies at the ECB and the Fed. When we take the realistic case where $\lambda_k > \lambda_b$ and $\theta_t^b > \theta_t^k$, we see that

Financial crisis impact, no additional policy vs. unconventional monetary policy with household intermediation of private loans.



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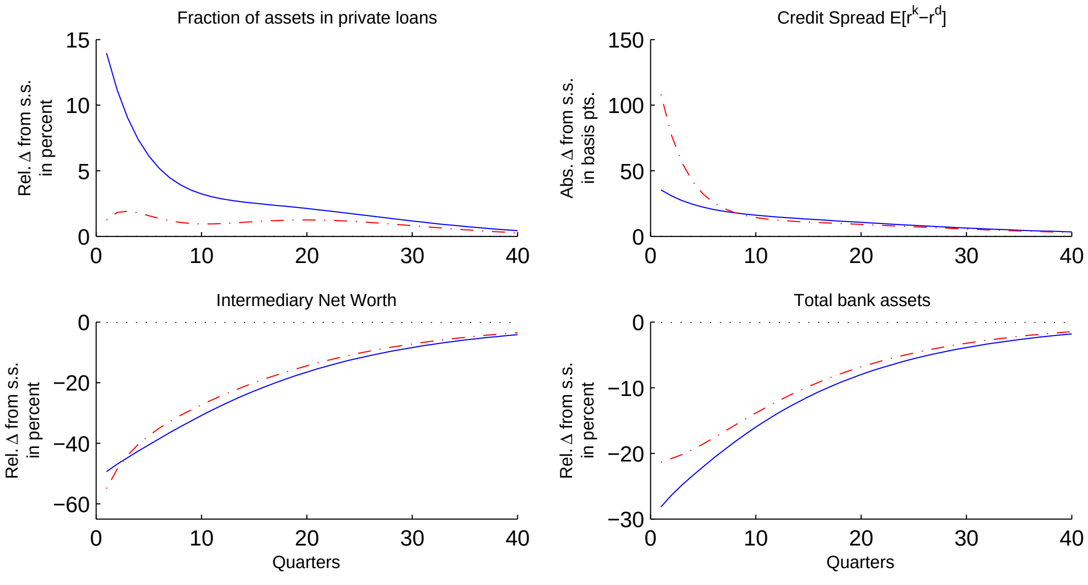


(b)

Figure 20: Impulse response functions for the case from section 5.1 with no additional policy (blue, solid) vs. the LTRO, represented by a decrease in the nominal interest rate on central bank lending facilities of 50 basis points on impact with respect to the nominal interest rate on regular deposit funding (red, slotted). The financial crisis is initiated through a negative capital quality shock of 5 percent relative to the steady state.

$\theta_t^b - (\lambda_b/\lambda_k)\,\theta_t^k > 0$. Hence including private loans under the collateral constraint still induces commercial banks to shift out of private loans and into government bonds, although the effect will be muted with the case where private loans can not be pledged as collateral, i.e. $\theta_t^k = 0$.

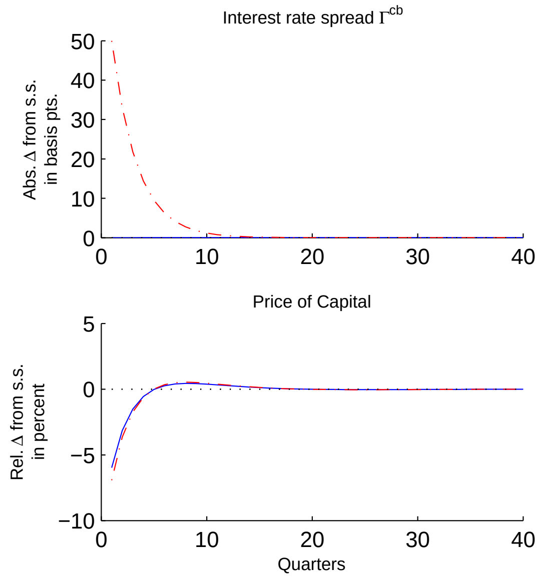
To summarize, there are two reasons why government bonds remain more attractive as collateral. First it is easier to expand the balance sheet by one unit of government bonds than by one unit of private loans, as the balance sheet constraint is less binding for government bonds than for private loans, since $\lambda_b < \lambda_k$. Second, the haircut on government bonds is smaller than on private loans, i.e. $\theta_t^b > \theta_t^k$. Hence more central bank funding is obtained for a unit of government bonds as collateral than for a unit of private loans as collateral.

Figure 21 shows the result from a simulation where the haircut on private loans is 50%, i.e. $\theta_t^k = 0.50$, and the elasticity of household demand for private loans $\kappa_{s_{k,h}}$ is equal to 0.1, as in the version with household intermediation of private loans, but no private loans under the collateral constraint. Ofcourse the shift out of private loans and into government bonds is reduced when compared with the case where private loans are not eligible for collateral purposes, but the short term contractionary effect remains.

E.2.3 Zero Lower Bound

In this section I implement the zero lower bound by setting the interest rate smoothing parameter at $\rho_r = 0.999$ in Figure 22. This is strictly speaking not the same as the zero lower bound, but captures the fact that endogenous changes in output and inflation do not cause an adjustment in the nominal interest rate.

Financial crisis impact, no additional policy vs. unconventional monetary policy with private loans as collateral.



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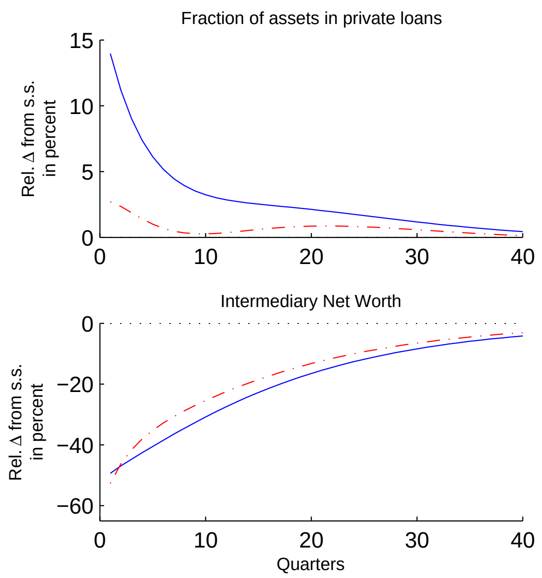

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Figure 21: Impulse response functions for the case from section 5.1 with no additional policy (blue, solid) vs. the LTRO, represented by a decrease in the nominal interest rate on central bank lending facilities of 50 basis points on impact with respect to the nominal interest rate on regular deposit funding (red, slotted). The financial crisis is initiated through a negative capital quality shock of 5 percent relative to the steady state.

Variation in haircut parameter θ_t at zero lower bound.

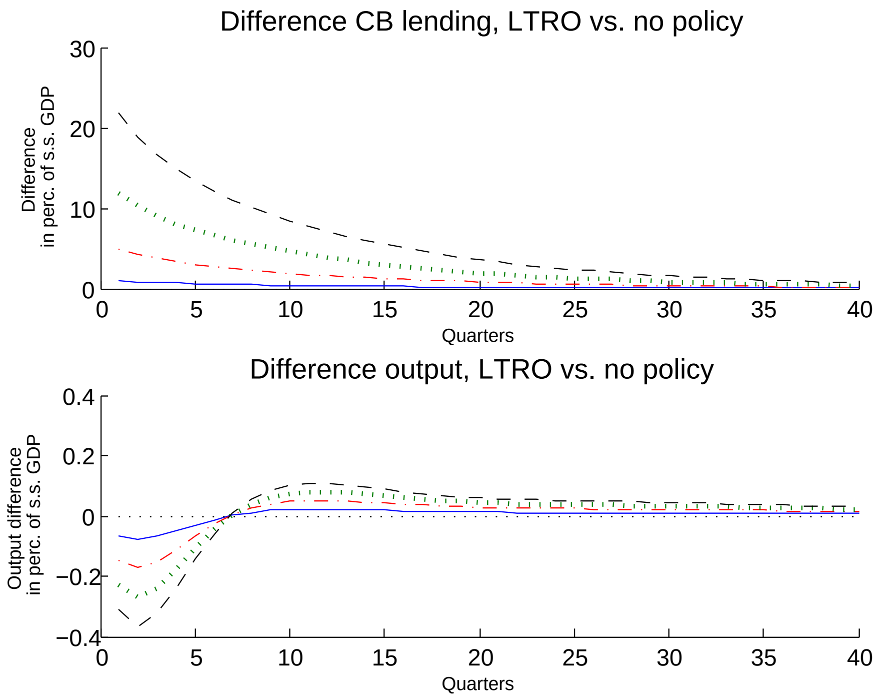

Figure 22: Both panels display the difference between the case where the nominal interest rate on central bank lending facilities is lowered by 50 basis points with respect to the nominal interest rate on regular deposit funding on impact (LTRO) and the no intervention case for different steady state values of the haircut parameter θ_t. The blue solid line refers to $\theta_t = 0.20$, the red slotted line to $\theta_t = 0.45$, the green dotted line to $\theta_t = 0.70$, and the black dashed line to $\theta_t = 0.95$. The upper panel displays the difference in central bank (CB) lending, while the lower panel displays the difference in output.The zero lower bound is implemented by setting $\rho_r = 0.999$

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