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Abstract

This paper studies the impact of unconventional monetary policy on the economy and its interactions with bank supervisory rules. In particular, we look at the impact of liquidity injections (quantitative easing) and repurchases of impaired loans (qualitative easing) under increased capital requirements for banks. We show that quantitative easing is most effective in terms of reducing losses in GDP and consumption which occur after a financial shock but leads to high fluctuations in inflation and GDP. Qualitative easing, on the contrary, has only a small impact on GDP and consumption but does not increase the volatility of inflation and GDP as much as quantitative easing. When unconventional monetary policy is combined with stricter bank regulation, we find that qualitative easing becomes more effective in terms of reducing losses in GDP and consumption, whereas quantitative easing becomes less effective. Moreover, we show that stricter bank regulation helps to decrease the volatility of inflation and GDP caused by quantitative measures.

JEL classification: E02; E44; E52; G21; G28
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1 Introduction

The eruption of the financial crisis in 2007 and its extraordinary impact on markets, called for extraordinary measures. After lowering interest rates to the zero lower bound, central banks all over the world were urged to support the economy - and the financial sector in particular - with various unconventional measures. Amongst them were liquidity injections (quantitative easing), the repurchase of impaired loans (qualitative easing)[1], and direct lending to firms.

For the implementation of unconventional measures which aim to stabilize financial markets, it is crucial to understand how they transmit through the economy and how they interact with bank regulations. Unfortunately, theoretical models of monetary policy which would be suitable for such an analysis were rare at that time. There were certainly several papers on conventional monetary policy. For instance, Christiano, Eichenbaum, and Evans (2005) and Smets and Wouters (2007). These models, however, assume frictionless financial markets, thus missing possible spillovers from financial intermediaries on the real economy which were the reasons behind the unconventional interventions by central banks in first place.

On the other side, models which incorporate financial frictions, starting with Bernanke, Gertler, and Gilchrist (BGG, 1999), and later followed by Iacoviello (2005), fail to properly account for the cause of the financial crisis because they concentrate on the agency problem between banks and firms and also emphasize the role of firms' collateral value and not the possible default of banks. Recently, several papers established models with financial intermediaries and endogenous default probabilities to fill this gap in the literature. Gertler and Karadi (2009), Gertler and Kiyotaki (2010), for instance, add financial intermediaries to the model of Christiano, Eichenbaum, and Evans (2005) and to Smets and Wouters (2007) with a financial accelerator according to BGG, to quantitatively assess the effect of unconventional measures. Dib (2010) implements an interbank market and imposes regulatory requirements on banks into the model of BGG and investigates how liquidity injections and asset swaps affect the economy. Gerali et al. (2010) add a banking sector into a DSGE model with credit frictions and borrowing constrains according to Iacoviello (2005), to study the role of credit supply factors in business cycle fluctuations. Angeloni and Faia (2010) introduce banks, modeled as in Diamond and Rajan (2000, 2001) in a standard DSGE macro model and use this framework to understand monetary policy transmission and the interplay between monetary policy and bank capital regulation when banks are exposed to runs. de Walque et al. (2009) develop a DSGE model along the lines of Goodhart et al. (2005) and Goodhart et al. (2006) with a heterogeneous banking sector and endogenous default probabilities acting as financial accelerators to examine the relationship between the banking sector and the real economy as well the contribution of monetary policy and supervisory measures on restoring financial stability.

Our paper is related to the studies stated above but particularly draws on de Walque et al. (2009). To capture crucial trade-offs and transmission mechanisms which were at work during the financial crisis, we are introducing nominal rigidities á la Rotemberg into the model of de Walque et al. (2009). This is one contribution of our paper and enables us to take into account the behavior of inflation after unconventional measures are introduced. Moreover, we take into

[1] Quantitative easing is associated with creation of new money and expansion of banks' balance sheet whereas asset swaps of loans in exchange for government bonds alter the composition of banks' assets in the balance sheet but leave the balance sheet totals unchanged.

account the possibility of adjusting the supervisory environment of banks. To that end, we follow for calls for a new supervisory standards that have been demanded and discussed by public, researchers, and regulators in the aftermath of the crisis[2] by addressing two possible changes in the bank regulation. Firstly, we complement the standard capital requirement for banks with an additional one by introducing a leverage ratio besides the standard minimum capital ratio like in Basel III. Secondly, we consider a further modification to the minimum capital ratio for banks by relating it to indicators on macroeconomic activity in particular to the output gap. This allows us to mitigate procyclicality of the capital adequacy rules. Thirdly, we introduce an insurance scheme for banks as proposed, for instance, by Kashyap, Rajan, and Stein (2008), in which insurance payments provide banks with additional funds. This insurance kicks in after an occurrence of a systemic "event". We define this "event" as a substantial increase in the credit default rates of firms and banks.

Our framework is a DSGE model with a heterogeneous banking sector and nominal rigidities. Non-financial firms set prices á la Rotemberg, choose labor, capital, and loans. Households chose consumption, leisure time, and the amount of deposit they want to hold. They do not borrow. The banking sector consists of two types of banks: "deposit banks" and "lending banks" which face endogenous balance sheet decisions and are constrained by capital regulation rules. Deposit banks collect deposits from households and give loans to lending banks. Lending banks provide loans to non-financial firms and lend on the interbank market. Deposit banks are net creditors whereas lending banks are net debtors in the interbank market. Both lending banks and firms can default on their loans, but are subject to quadratic adjustment costs. These defaults have the effect of financial accelerators. Unconventional monetary policy is introduced according to Dib (2010) by assuming that banks can receive liquidity injections from the central bank or exchange a portion of their loans for a risk-free asset. Moreover, we allow for liquidity injections to non-financial firms as well, which is another contribution of our model.

Overall, the economy is subject to productivity shocks, monetary policy shock, unconventional monetary policy shocks, and financial stability shocks. Except for unconventional monetary policy shocks and financial stability shocks all other perturbations a rather standard in the literature and do not require further details. Unconventional monetary measures are exogenous and enter into the model through shocks to the budget constraint of banks and firms. Financial stability shocks, however, are modeled by a substantial increase in the default rate of banks and firms. In order to do so, we simulate a second model where default rates are exogenous. This enables us to change the rate of default by any amount we would like to simulate. We do this for two reasons. First, we want to replicate the environment of the financial crisis where we saw increased default rates for both banks and firms. Second, this allows us to evaluate the impact of the insurance scheme for banks which is triggered after a high increase in credit default rates.

Our results show that direct lending to firms and liquidity injections are most effective in terms of reducing losses in GDP and consumption which occur after a financial shock. However,

[2] See among many others "Annual Jackson Hole Economic Policy Symposium" in the year 2008 "Maintaining Stability in a Changing Financial System" or Basel Committee on Banking Supervision (2009a) and Basel Committee on Banking Supervision (2009b), for instance.

when we take volatilities into account, direct lending to firms leads to the highest fluctuation in inflation and second highest volatility in GDP. Liquidity injections also strongly increase the volatility of GDP and inflation. Asset swaps, on the contrary, have almost no impact, neither on GDP and consumption losses, nor on the volatility of inflation, GDP, and consumption. Stricter bank regulatory requirements reduce losses in GDP with almost no impact on volatilities. When unconventional monetary policy is combined with stricter bank regulation, we find that qualitative easing becomes more effective in terms of reducing losses in GDP and consumption, whereas quantitative easing becomes less effective. Interestingly, direct lending to firms becomes even more effective in mitigating losses in GDP and consumption when combined with a leverage ratio requirement like in Basel III.

The rest of this paper is organized as follows. The setup of the basic model is introduced in Section 1.2. In Section 1.3, we discuss the calibration of the model. Section 1.4, we conduct the impulse response analysis and discuss results. Section 1.5 concludes.

2 The Baseline Model

Our framework is a DSGE model with nominal rigidities. The economy is inhabited by households, banks, non-financial firms, and a central bank. Banking sector consists of deposit and lending banks which interact in an interbank market. Central bank conducts both conventional and unconventional monetary policy; as our model lacks any distinct fiscal or supervisory authorities, we assume that the central bank takes over those roles. In particular, it supervises banking sector through capital and leverage ratios.

Overall, the economy is subject to various perturbations: productivity, monetary policy, quantitative, and qualitative monetary easing shocks to banks and firms as well as financial stability shocks.

2.1 Households

Households allocate their resources to consumption C_t and investments and choose their leisure time $(1 - N_t)$. They provide labor N_t against wage w_t, place deposits D_t^h against an interest rate r_t^l with deposit banks and do not borrow. Following de Walque et al. (2009) we impose a target in deposits $\bar{D}^h$ via a quadratic disutility term[3]. This means that households dislike deviations of their deposits from the long-run optimal level. The households maximization program is given by:

$$\max_{C_t, N_t, D_t^h} \sum_{s=0}^{\infty} \beta^s E_t \left\{ \log\left(C_{t+s}\right) + \bar{m} \log\left(1 - N_{t+s}\right) - \frac{\chi}{2} \left(\frac{D_t^h}{1 + r_{t+s}^l} - \frac{\bar{D}^h}{1 + \bar{r}^l} \right)^2 \right\} \tag{1}$$

under the budget constraint:

$$C_t + \frac{D_t^h}{1 + r_t^l} = w_t N_t + \frac{D_{t-1}^h}{\pi_t} + \Pi_t^f + (1 - v_b)\,\Pi_t^b + (1 - v_l)\,\Pi_t^l \tag{2}$$

where $\pi_t = P_t / P_{t-1}$ is inflation and Π_t^f, Π_t^b, Π_t^l are profits of firms, lending banks, and deposit

[3]This term is necessary for technical reasons. For $\chi = 0$, first order conditions in (29) and (36) give the steady state for r_t^l leaving D_t^h undetermined. χ is kept very low so that the dynamics of the model are not altered significantly by its use.

banks, respectively. Households fully own firms and they receive a share of banks profits in line with retained earnings ratios v_b and v_l.

First order conditions of the households optimization problem are presented in the Appendix.

2.2 Non-financial Firms

Entrepreneurs choose price $P(i)_t$, labor $N(i)_t$, capital $K(i)_t$, loans $L(i)_t^f$ to rebuild capital stock and repayment rate on past borrowings $\alpha(i)_t$ from the profit maximization. They face price adjustment costs á la Rotemberg which introduce a nominal rigidity into the model.

$$\max_{P(i)_t, K(i)_t, N(i)_t, L(i)_t^f, \alpha(i)_t} \sum_{s=0}^{\infty} E_t \bar{\beta}_{t+s} \Pi(i)_{t+s}^f \tag{3}$$

where the profit is given by:

$$\begin{aligned} \Pi(i)_t^f &= \frac{P(i)_t}{P_t} Y(i)_t - w_t N(i)_t - \frac{\alpha(i)_t L(i)_{t-1}^f}{\pi_t} - \frac{M(i)_{t-1}^f}{\pi_t} \\ &\quad - \frac{\gamma}{2}\left[\left(1-\alpha(i)_{t-1}\right)\left(\frac{L(i)_{t-2}^f}{\pi_{t-1}} + d_f\right)\right]^2 - \frac{\psi}{2}\left(\frac{P(i)_t}{P(i)_{t-1}} - \pi^*\right)^2 Y_t \end{aligned} \tag{4}$$

π^* is the economy-wide inflation rate and the parameter ψ measures the degree of price stickiness. The higher ψ, the more sluggish is the adjustment of nominal prices; $\psi = 0$ implies flexible prices. In addition, non-financial firms bear quadratic costs of default on their loans[4]. At times of financial distress, when bank lending is scarce or difficult to obtain, central bank may step in and provide firms with additional liquidity $M(i)_t^f$ in order to help them to build up capital needed for production.

The production sector comprises of a continuum of monopolistically competitive firms each facing a downward-sloping demand curve for its differentiated product

$$Y(i)_t = \left(\frac{P(i)_t}{P_t}\right)^{-\theta} Y_t \tag{5}$$

where $P(i)_t$ is the profit-maximizing price consistent with production level $Y(i)_t$. Parameter θ is the elasticity of substitution between two differentiated goods. Both the aggregate price level P_t and aggregate output Y_t are beyond control of the individual firm. The aggregates for the economy are written as

$$Y_t = K_t^{\eta} \left(\exp(A_t) N_t\right)^{1-\eta} \tag{6}$$

[4]The expenses related to default consist of a variable part that relates to the notional of outstanding loans in the economy, $\left(1-\alpha(i)_{t-1}\right)\frac{L(i)_{t-2}^f}{\pi_{t-1}}$, and an additional fixed cost, $\left(1-\alpha(i)_{t-1}\right)d_f$. Linearity of cost would imply indeterminacy for (32); partition of cost is done in analogy to the setup of the maximization problem for lending banks, where this partitioning allows to reconcile (36), (39) and (41) when determining steady state values for r_t^b, r_t^l and i_t.

de Walque et al. (2009) solve this technicality by splitting the expenses related to default into non-pecuniary costs that affect utility and pecuniary costs that impact profits. However, as they acknowledge, this 'double cost' lacks pure micro foundations. In our opinion, segmentation of the pecuniary default costs into a fixed and variable portion is more appealing micro-economically.

$$K_t = (1-\tau) K_{t-1} + \frac{L_t^f}{1+r_t^b} + \frac{M_t^f}{1+r_t} \tag{7}$$

$$A_t = \rho_a A_{t-1} + \varepsilon_t^A \tag{8}$$

where firms produce output according to a Cobb-Douglas function with A_t functioning as an aggregate productivity shock. Equation (7) describes the law of motion for capital which depreciates at rate τ. Firms can obtain loans from lending banks L_t^f at interest rate r_t^b or receive liquidity from the central bank M_t^f at times of financial distress. Since firms are fully owned by households, their discount factor is given by:

$$\bar{\beta}_{t+s} = \beta^s \frac{C_t}{C_{t+s}} \tag{9}$$

First order conditions are solved assuming a symmetric equilibrium and are presented in the Appendix.

2.3 Banks

When modeling the banking sector we lean on de Walque et al. (2009) and Dib (2010) and introduce deposit banks and lending banks. Both types of banks are risk-averse.

Deposit Banks

Deposit banks collect deposits from households D_t^l and provide lending banks with loans D_t^{bs} on the interbank market. They also allocate their resources to a market book $\bar{B}^l$, which is assumed to be exogenous and to yield a return $\bar{\rho}$. In addition, deposit banks derive utility from holding own funds F_t^l above the capital requirement k and the leverage limit h - both imposed by the central bank - but they face opportunity costs $r_t F_t^l$ of maintaining these funds. We define leverage ratio as an inverse of the leverage multiple which is a ratio of total assets to equity. Contrary to the capital ratio, leverage ratio does not involve any riskiness weights of the assets and it serves as a primal measure of the sheer size of the balance sheet. In our basic setup we first assume that the central bank does not care about leverage ratio ($b_{F^l} = 0$); then, in Section 4, we present simulation results for the case when leverage ratio does become an instrument of financial regulation.

The maximization program of the deposit banks is:

$$\max_{D_t^l, D_t^{bs}} \sum_{s=0}^{\infty} E_t \bar{\beta}_{t+s} \left\{ \begin{array}{c} \log\left(\Pi_{t+s}^l\right) + d_{F^l}\left[F_{t+s}^l - k\left(w^l\left(D_{t+s}^{bs} - x_{t+s}^l\right) + \bar{w}\bar{B}^l\right)\right] \\ +b_{F^l}\left[F_{t+s}^l - h\left(D_{t+s}^{bs} + \bar{B}^l\right)\right] \end{array} \right\} \tag{10}$$

under the constraints:

$$\begin{aligned} \Pi_t^l \quad = \quad & \frac{\delta_t D_{t-1}^{bs}}{\pi_t} - \frac{D_t^{bs}}{1+r_t^i} + \frac{D_t^l}{1+r_t^l} - \frac{D_{t-1}^l}{\pi_t} + \zeta_l\left(1-\delta_{t-1}\right)\frac{D_{t-2}^{bs}}{\pi_{t-1}} + \frac{\bar{\rho}\bar{B}^l}{\pi_t} \\ & + x_t^l - \frac{x_t^l}{1+r_t} + \frac{M_t^l}{1+r_t} - \frac{M_{t-1}^l}{\pi_t} - r_t F_t^l \end{aligned} \tag{11}$$

$$F_t^l = (1 - \xi_l + \varpi_l) \frac{F_{t-1}^l}{\pi_t} + \upsilon_l \Pi_t^l \tag{12}$$

Loans on the interbank market are prone to lending banks' default rate $(1 - \delta_t)$. Deposit banks' own funds increase by a share of profits that are not redistributed to households $\upsilon_l \Pi_t^l$; a small proportion of funds ξ_l is put into an insurance scheme run by the central bank. A fraction ζ_l of the lending banks' defaulted amount is paid back from this insurance, decreasing the losses suffered from impaired loans on the interbank market. Another portion of the insurance payout, provided by the central bank, is aimed to increase equity of the deposit banks by ϖ_l. This insurance payout kicks in only if the solvency of the lending banks deteriorates notably.

Furthermore, deposit banks can exchange a portion of their lending for a risk-free asset x_t^l as a measure of so called qualitative easing policy conducted by the central bank. The quantitative policy actions, i.e. liquidity injections, operate through M_t^l. We assume that the portion of assets x_t^l under the swap agreement is impaired and would not pay any return otherwise.

First order conditions are presented in Appendix.

Lending Banks

Equivalently to deposit banks, lending banks derive additional utility from holding extra funds F_t^b (above the levels implied by the capital and leverage ratios) at the opportunity cost of $r_t F_t^b$. The maximization program of lending banks is given by:

$$\max_{D_t^{bd}, L_t^b, \delta_t} \sum_{s=0}^{\infty} E_t \bar{\beta}_{t+s} \left\{ \begin{array}{c} \log\left(\Pi_{t+s}^b\right) + d_{F^b}\left[F_{t+s}^b - k\left(w^b\left(L_{t+s}^b - x_{t+s}^b\right) + \bar{w}\bar{B}^b\right)\right] \\ + b_{F^b}\left[F_{t+s}^b - h\left(L_{t+s}^b + \bar{B}^b\right)\right] \end{array} \right\} \tag{13}$$

under the constraints:

$$\begin{aligned} \Pi_t^b \quad = \quad & \frac{\alpha_t L_{t-1}^b}{\pi_t} - \frac{L_t^b}{1 + r_t^b} + \frac{D_t^{bd}}{1 + i_t} - \frac{\delta_t D_{t-1}^{bd}}{\pi_t} - \frac{\omega}{2}\left[(1 - \delta_{t-1})\left(\frac{D_{t-2}^{bd}}{\pi_{t-1}} + d_\delta\right)\right]^2 \\ & + \zeta_b (1 - \alpha_{t-1}) \frac{L_{t-2}^b}{\pi_{t-1}} + \frac{\bar{\rho}\bar{B}^b}{\pi_t} + x_t^b - \frac{x_t^b}{1 + r_t} + \frac{M_t^b}{1 + r_t} - \frac{M_{t-1}^b}{\pi_t} - r_t F_t^b \end{aligned} \tag{14}$$

$$F_t^b = (1 - \xi_b + \varpi_b) \frac{F_{t-1}^b}{\pi_t} + \upsilon_b \Pi_t^b \tag{15}$$

Lending banks provide loans to the firms L_t^b, borrow from deposit banks D_t^{bd}, invest in an exogenous market book $\bar{B}^b$ at yield of $\bar{\rho}$, and choose their optimal repayment rate δ_t. In addition, lending banks can receive liquidity injections from the central bank M_t^b (quantitative easing) or swap a fraction of their loans against a risk-free asset x_t^b (qualitative easing). We assume that x_t^b is impaired in that it pays no return when retained in the loan portfolio. Lending banks face pecuniary costs of default represented by a quadratic cost function $\frac{\omega}{2}\left[(1 - \delta_{t-1})\left(\frac{D_{t-2}^{bd}}{\pi_{t-1}} + d_\delta\right)\right]^2$. Quadratic formulation prevents indeterminacy in the first order condition (41); d_δ stands for a fixed costs of default which are independent from the total amount of the defaulted interbank loans $(1 - \delta_{t-1}) \frac{D_{t-2}^{bd}}{\pi_{t-1}}$.

Similar to deposit banks, lending banks increase own funds by a share of profits that are not redistributed to households $\upsilon_b \Pi_t^b$; a small proportion of funds ξ_b is put into an insurance scheme, which is motivated by the fact that lending banks face losses on their loans to firms in accordance with firms' defaults ratio $(1-\alpha_t)$. A fraction ζ_b of the firms' defaulted amount is reimbursed by the insurance. In the case of a substantial increase in firms default rate, lending banks may be supported by equity capital ϖ_b provided by the central bank.

First order conditions are presented in the Appendix.

2.4 Central Bank

The monetary authority conducts its policy according to a Taylor-type policy rule:

$$(1+r_t) = (1+\bar{r})^{(1-\mu_r)} (1+r_{t-1})^{\mu_r} \left(\frac{\pi_t}{\pi^*}\right)^{Q_p} \left(\frac{Y_t}{Y_{t-1}}\right)^{Q_y} \exp\left(\varepsilon_t^r\right) \tag{16}$$

At times of financial distress it can use unconventional instruments: liquidity injections $M_t^{(\cdot)}$ (quantitative easing) or qualitative monetary easing $x_t^{(\cdot)}$ aimed at supporting both types of banks and firms. We model all unconventional monetary tools as $AR(1)$ processes:

$$x_t^l = \rho_x x_{t-1}^l + \varepsilon_t^{x^l} \tag{17}$$

$$x_t^b = \rho_x x_{t-1}^b + \varepsilon_t^{x^b} \tag{18}$$

$$M_t^l = \rho_M M_{t-1}^l + \varepsilon_t^{M^l} \tag{19}$$

$$M_t^b = \rho_M M_{t-1}^b + \varepsilon_t^{M^b} \tag{20}$$

$$M_t^f = \rho_M M_{t-1}^f + \varepsilon_t^{M^f} \tag{21}$$

It is assumed that the deposit, interbank, and commercial loan markets clear in the long run. However, in the short run the central bank may inject liquidity such that:

$$M_t^l = D_t^l - D_t^h \tag{22}$$

$$M_t^b = D_t^{bs} - D_t^{bd} \tag{23}$$

$$M_t^f = L_t^f - L_t^b \tag{24}$$

By assumption, the central bank finances liquidity injections, capital injections to banks, asset swaps, and payoffs from the insurance scheme by collecting contributions from banks.

3 Calibration

In the calibration we push our model towards a steady state with very low interest rates (around 0.5%) and yields on the market book (1%) in order to simulate an environment of low asset returns.

Real sector

We normalize employment to 0.2 and use Cobb-Douglas production function with labor share = 2/3. We utilize the assumption that capital stock is 10 times higher than production and set depreciation rate at 3%. This implies an investment ratio to output of 0.3 and allows us to avoid a negative search cost γ on the defaulted amount. ρ_a, the autoregression coefficient for the technology equation (8), is equal 0.95 which is a standard in the RBC literature.

We set the value for the default rate of firms equal to 5% (an therefore $\alpha_t = 0.95$ in steady state) which is inferred from the US courts and the Bureau of Labor Statistics quarterly pre-crisis data on business bankruptcies. The data are based on the number of non-financial corporations that go bankrupt. This enables us to deduct values for γ (firms default cost parameter) and $\bar{m}$ (households leisure utility parameter). Both firms fixed default cost parameter and the smoothing parameter for deposits are set close to 0 ($\chi = 0.01, d_f = 0.001$), in order to eschew any dynamic effects (positive χ enforces finding a steady state value for D_t^h). We also introduce a penalty parameter for setting prices above the economy-wide level of 50, which we obtain by comparing the elasticity of inflation to the real marginal cost in our model with the slope coefficient of the log-linear Phillips curve using a Calvo approach. Expressed as $\frac{(1-\delta)(1-\beta\delta)}{\delta}$, where δ is the probability of not resetting the price, this slope coefficient is found in the literature to be around 0.75 (see discussion of the frequency of price adjustment in Faia and Monacelli (2007), for instance).

Banking sector

In order to simulate the environment of low interest rates we set the deposit rate at $\bar{r}^l = 0.35\%$ and assume that the market book offers a mere $\rho = 1\%$, which lies below the average quarterly return of the Dow Jones Industrial Average Index from 1980Q1 to 2010Q3 (1.96%). However, this assumption may actually be somehow questionable due to possible assets bubbles when interest rates, i.e. borrowing costs are extremely low.

We set lending banks default rate $\delta = 0.98$ which is derived from the pre-crisis data provided by the Federal Deposit Insurance Corporation. These data encompasses the number of bank failures. Furthermore, when calibrating the model we impose D^l/L^b to be around 2, $D^{bd}/L^b = D^{bs}/L^b$around 0.5, which is in line with pre-crisis statistics of the Federal Reserve System. The market book for each bank equals firm loans: $\bar{B}^b = \bar{B}^l = L^b$.

The weights of bank assets are aligned to the Basel agreement: $w^b = 0.8$ and $w^l = 0.05$. Capital ratio is set at $k = 8\%$ and leverage ratio at $h = 4\%$. Banks are supposed to allocate half of their profits to own funds ($v_b = v_l = 0.5$) and the remaining 50% are distributed to the households. The insurance scheme is assumed to enable banks to recover 80% of bad loans; in exchange, banks must pay premia of around $6 - 7\%$ of their funds ($\xi_b = 0.06$ and $\xi_l = 0.07$, due to differences in default rates for firms and lending banks) in order to benefit from this provision. The parameter of fixed default costs for lending banks d_δ is equal to 0.001.

Other parameters - default cost parameter ω and own funds utility parameters for both bank types, d_{F^b} , d_{F^l} , b_{F^b} and b_{F^l} - are inferred from the restrictions mentioned above.

Central bank

Taylor-type monetary policy rule contains parameters that are set according to specifications used in the literature and satisfy the Taylor rule principle ($\mu_r = 0.7$, $Q_p = 1.2$, $Q_y = 0.05$). Regression parameters for all unconventional monetary tools ($\rho_{(\cdot)}$) are set to 0.85.

4 Quantitative Results

4.1 Impulse Responses

In this section we examine dynamic properties of our model by means of impulse response analysis. We investigate how shocks propagate through the system and affect the key macroeconomic variables. Our analysis starts with a short review of impulse responses to innovations in technology and monetary policy and then it passes on to inspection of shocks induced by unconventional monetary policy actions.

Standard analysis: Technology and monetary policy shocks

Figure 5 in the Appendix shows that a positive technology shock has positive effects on consumption, capital, output, and GDP. In the short run all interest rates and inflation increase, but after about 10 periods they all fall below their initial steady state levels. Interbank, deposit, and firms' lending rates react in a less pronounced way than the policy rate due to the adjustment costs of changing those rates.

Following the positive technology shock, demand for capital increases and is matched by a rising supply of loans to the firms. On the impact of the shock, profits of banks grow; however, firms' profits initially decline before returning to their pre-shock steady state level. This is due to rising capital costs caused by more expensive loans which also drives up the marginal cost. On the one hand, increases in the borrowing rate for capital reduces firms' profits. On the other hand, firms are subject to constraints set by price adjustment cost when trying to pass on the loan burden to consumers. Finally, positive technology shock leads to falling default rates for firms and lending banks; interest rates and inflation decrease in the long-run as a result of higher productivity and output.

When compared to Dib (2010) we observe responses to the technology shock in our model to be generally in line with his results. Notable exceptions are inflation and the policy rate where slightly different patterns of reaction can be observed. Dib (2010) finds that both fall immediately after the shock occurs and return gradually to their initial steady state levels thereafter. Yet, it seems to be reasonable that after a positive technology shock interest rates should increase. Two arguments speak in favor for this notion. First, central bank would increase its policy rate to close the output gap; second, higher demand for firm loans leads to an increase in interbank borrowing and thus to a rising demand for deposits. Consequently, the interest rates for these aggregates should increase.

As shown in Figure 6 in the Appendix, an expansionary monetary policy shock produces persistent moves in inflation and interest rates (except for the policy rate itself whose shock we model as an AR(1) process). After the monetary policy shock, consumption and capital increase; output stays almost unchanged; GDP grows, however, the effect on it seems to fade away relatively quickly. After the expansionary monetary policy shock banks' profits expand; in case of lending banks, this is due to rising demand for commercial loans and improving solvency within firms. In the case of deposit banks, this is causes by the fact that the interest rate for their liabilities is decreasing stronger than the interest rate for their assets. Reaction of inflation is somehow puzzling as we would expect it to rise after a decrease in the policy rate. This is presumably attributable to the model setup in which production sector simultaneously marks up its production. Falling interest rates throughout the economy contribute to the reduction in marginal cost for firms, i.e. reduction in capital costs weights out rising labor cost. However, firms' profits tend to decrease temporarily on the impact of the monetary policy shock as initially the build-up in capital is not matched by an increase in output.

Dib's (2010) analysis points to decreasing industrial loans and a short-run increase in the firms' borrowing rate after the expansionary monetary policy rate shock hits the economy. In our model, however, this shock leads to a fall in the borrowing rate along with an increased demand for firms' loans. We interpret our result as more intuitive since it reconfirms the expectation of falling interest rates throughout the whole economy after a cut in the policy rate.

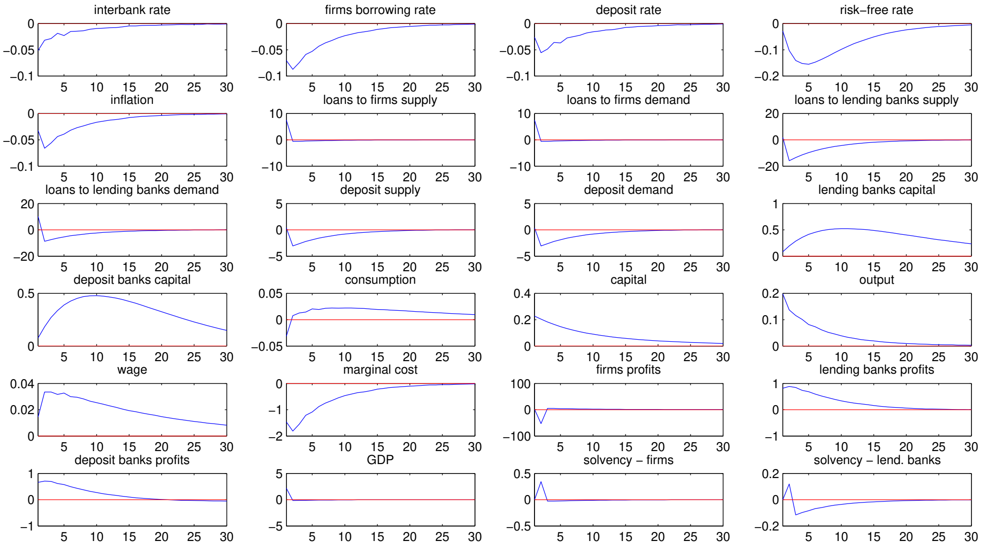
Unconventional monetary policy

Figure 1 displays impulse responses after a liquidity injection to lending banks. This shock tends to have only temporary effects on economic aggregates. It decreases the risk-free rate, inflation, firms' borrowing rate, deposit rate, and the interbank interest rate. Figure 1 shows that following a liquidity shock, output, and GDP rise, yet their reaction - like for most of the variables - is not persistent. This effect is due to the persistence of liquidity itself as it is an AR(1) process with lag parameter ρ_{M^b}. Since we assume that in the steady state the interbank market clears, liquidity injections are equal to zero in the long run. Imbalances in the interbank market after the liquidity shock are then quickly forced to equilibrium by the movement in the interbank interest rate and an adjustment in default rate of lending banks. Liquidity injection to lending banks seems to crowd out interbank loans and improve lending bank profits as they choose to default on a portion of their interbank borrowing given cheaper refinancing from the central bank. Deposit bank profits improve as well due to falling deposit rates.

Our results generally reconfirm the findings of Dib (2010). Output, consumption, inflation, policy rate, and other aggregates show the same pattern of behavior after the shock, however, they differ in persistence.

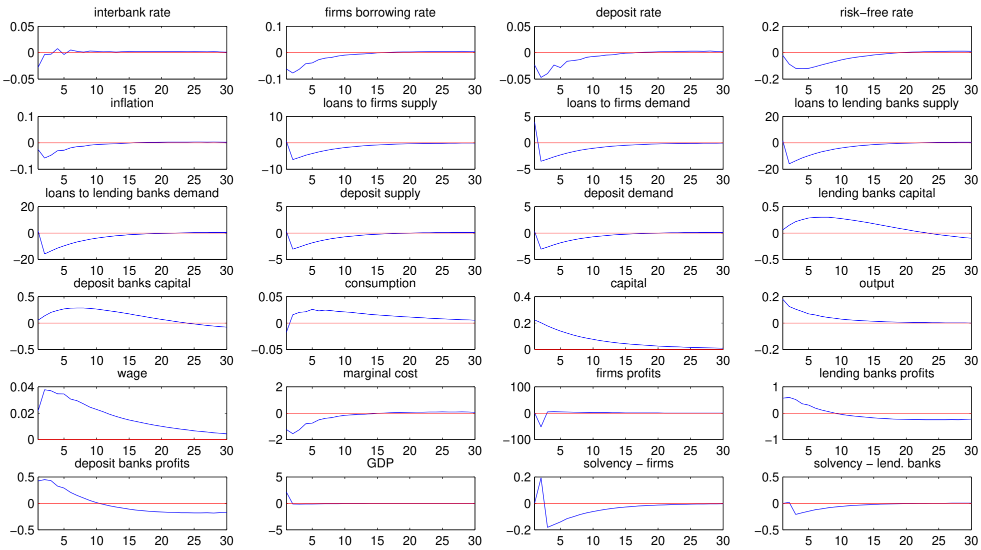
Liquidity injections to deposit banks serve as an instrument of supporting interbank market by strengthening the liquidity position of deposit banks (for instance, in case of significant deposit withdrawals). As shown in Figure 7 in the Appendix such liquidity injections to deposit banks

Figure 1: Figure 1.1: Impulse responses after a liquidity injection shock to lending banks



generate responses that are quite similar to those following a quantitative monetary easing shock to lending banks. Yet its impact on GDP, consumption, and in part on output tends to be of limited duration. Notable is also a non-negative effect on lending banks default rate. Even though M_t^l is injected at $r_t > r_t^l$ and thus above the initial refinancing cost, deposit bank profits rise and so does their capital, which by definition is partly cumulated from retained earnings. Lowering the price of this liquidity injection even further would, of course, have a positive influence on deposit bank profits, leaving its impact on other aggregates unchanged.

Figure 2: Figure 1.2: Impulse responses after a liquidity injection shock to firms

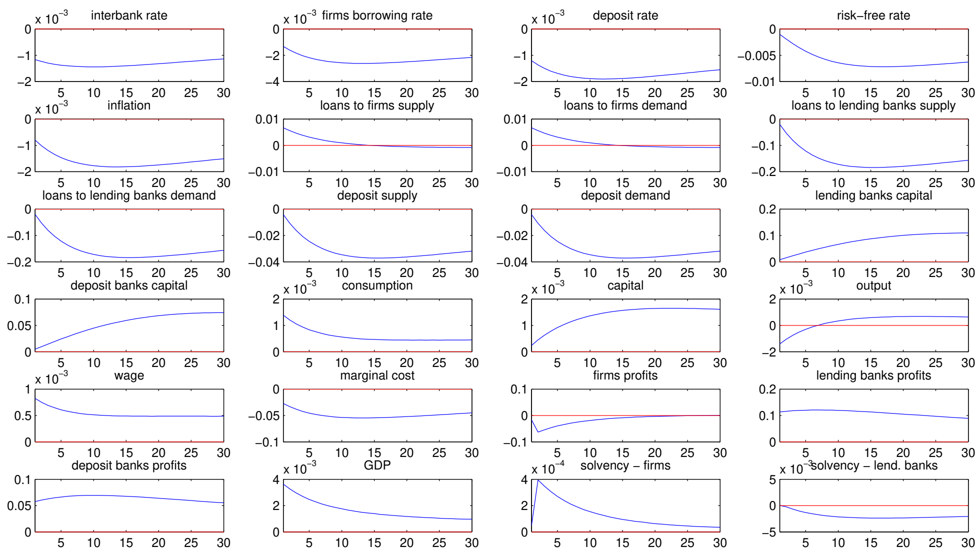


As illustrated in Figure 2, liquidity supply directed at firms improves output but has only a limited impact on GDP and consumption. When the central bank lends directly to firms, this action tends to crowd out bank loans to firms and to decrease lending on the interbank market. Motivated by cheaper financing, firms decide to default on some of its bank loans which in turn forces some of the lending banks to dishonor their debt. Altogether, impact to GDP is almost nil; only capital K_t and lending banks capital F_t^b increase but all other components fall.

Responses to a qualitative easing shock to banks are presented in Figure 3 and 8 in the Appendix. Contrary to quantitative easing, responses are mostly persistent. As a result of qualitative easing shock, policy rate and all other interest rates decrease, and inflation follows the same pattern of behavior.

The persistence of responses to the qualitative monetary easing shock in inflation, policy rate, and the deposit rate does not stand in line with Dib (2010). This is probably due, to the way how qualitative (and quantitative) monetary actions enter into his model: it happens through a Leontief loan production function, where lending banks either use interbank borrowing plus liquidity injections or bank capital plus liquidity received from asset swaps. While in our paper after a qualitative shock interest rates fall, loan supply increases, marginal cost decreases and thereby reduces inflationary pressure, Dib's (2010) findings show almost no increase in loan supply accompanied by rising interest rates and an increase in inflation.

Figure 3: Figure 1.3: Impulse responses after an asset swap shock to lending banks



In our setup, the effects of an assets swap tend to resemble the results for the traditional monetary policy shocks, with the same deflationary mechanism as before. As lending banks are relieved from impaired loans, they pick up on more lending causing the firms' borrowing rate to go down. As a result firms accumulate more capital, decide to default less on their lending, increase output (in the long run), and adjust their prices downwards in order to stimulate demand. Eventually, the risk-free rate falls due to the fact that the Taylor rule puts more weight on inflation changes than on the output fluctuations.

All variables, except for loans to lending banks, react similarly to the quantitative easing aimed at deposit banks as they did in case of this type of central bank action addressed at the lending banks (see Figure 8 in the Appendix). The possibility for deposit banks to swap their interbank loans has the same impact on the balance sheet of deposit bank as swaps of firm loans have on the balance sheet of lending banks: when the central bank absorbs impaired loans from banks' balance sheet (and thus improves deposit banks capital ratio), they instantly expand their lending on the interbank market at a lower price which, in turn, enhances solvency of lending banks.

When we compare the impulse responses for both types of banks, we observe that the solvency of firms, in both cases, increases remarkably in the short run and remains above its steady state in the medium to long run. However, the solvency of lending banks is decreasing when lending banks are allowed to swap their assets, but is strongly increasing in the short run and it remains above its steady state over the long horizon when deposit banks are the profiteers of the qualitative easing. This result indicates that qualitative monetary easing measures aimed at deposit banks can improve the stability of the financial system.

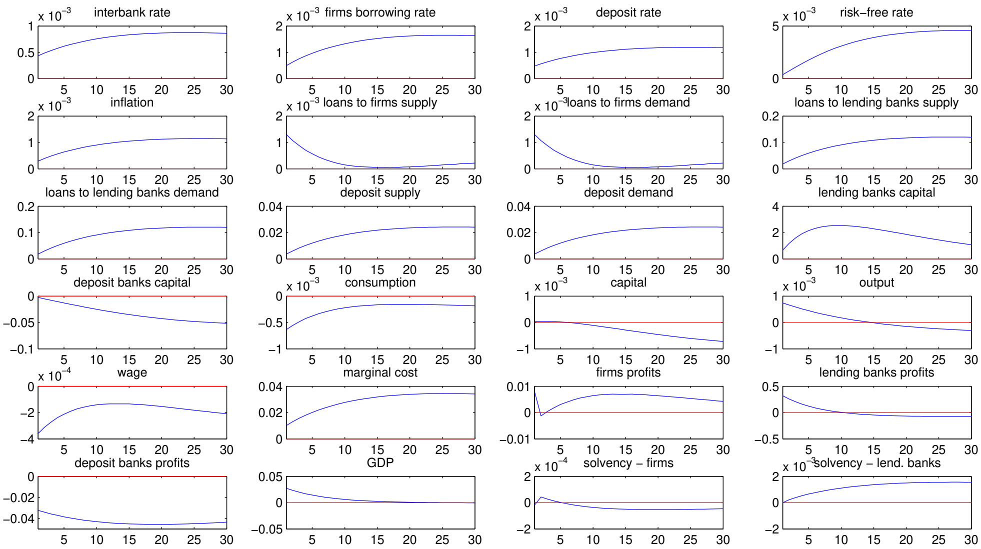
As Figure 4 shows, insurance payout to lending banks' improves their solvency and has a persistent effect on the economy. It also increases loans to firms, raises their production capital marginally and that in turn leads to a raise in output. Since the Taylor rule is driven by output and inflation, the growth of output results in an increase of the policy rate. The subsequent rising in interest rates have an ambiguous impact on economy: they increase the marginal cost of capital for firms which are now trying to substitute capital with labor; in addition, higher interest rates make consumption less desirable and therefore push households towards more labor supply resulting in lower wages. As marginal cost increases, firms mark up the prices letting policy interest rate to climb up even further. As commercial loan costs pick up, firms choose to default on some of their debt. Deposit and lending banks profits fall since in steady state their liabilities (deposits and interbank loans) outweigh their assets (interbank loans and loans to firms) in absolute terms, which leads to losses in the case of rising interest rates.

We observe in Figure 9 in the Appendix that a similar mechanism is at work in case of an increase in deposit banks' equity. Generally, the responses tend towards rising interest rates, inflation and marginal cost of production whereas consumption, wage, and production capital tend to fall. However, after an initial pick-up in credit supply to the economy, loans tend to fall in both real and financial sectors and as the level of interest rates raises, both firms and lending banks choose to default on more of their debt. The marginal increase in GDP seems to result from a small rise in the deposit banks' capital, as other components of GDP tend to fall.

4.2 Experiments

In this section we intend to simulate crisis conditions and then consider the role of central bank's instruments of unconventional monetary policy in moderating the crisis. We conduct experiments with two versions of our model: the basic one, where default rates are endogenously chosen by

Figure 4: Figure 1.4: Impulse responses after a capital injection shock to lending banks



firms and lending banks and another version in which default rates are exogenously given as $AR(1)$ processes:

$$\alpha_t = \rho_\alpha \alpha_{t-1} + \varepsilon_t^\alpha \tag{25}$$

$$\delta_t = \rho_\delta \delta_{t-1} + \varepsilon_t^\delta \tag{26}$$

The timeline looks as follows: in the 1st period a shock that introduces a downturn of the economy occurs. In the first scenario it is a two standard deviations negative productivity shock; in the second version of the model with exogenous default rates we let the firms' and lending banks' solvency ratios fall by 2.5% and 5% respectively. This is supposed to replicate the origin of the ongoing financial crisis. In the 2nd period the central bank steps in with its unconventional policy actions. We assume that in each case it commits 5% of GDP into its unconventional policy tools. We then evaluate the welfare effects simply by comparing present values of future consumption and GDP once central bank anti-crisis actions have been put in place. In particular, we take into account:

- liquidity injections to banks and firms,
- asset swaps to banks,
- switching the regulatory regime to the environment where capital ratio k is a function of output gap such that:

$$(1 + k_t) = (1 + k) \left(\frac{Y_t}{Y_{t-1}} \right)^{Q_k} \exp\left(\varepsilon_t^k\right) \tag{27}$$

- direct capital injections to lending and deposit banks,

- switching the regulatory regime to the environment with leverage ratio h.

We run the experiment in a deterministic context. We assume that agents have full foresight, they know when a shock is going to occur and how the central bank is going to react to it. Consequently, agents can specify in advance what actions they want to take in future given the shock and the central bank commitment to a particular monetary policy measure. In terms of computation, accounting for perfect foresight of monetary policy corresponds to running a single dynare file with economy entering a crisis in period one (either negative technology shock or a positive innovation in default rates of lending banks and firms) and a monetary policy action occurring at some time thereafter.

Table 1 presents results for our basic model with endogenous default rates. It reveals that all unconventional policy measures seem to be effective. With a notable exception of qualitative instruments, all policy actions mitigate adverse effects of a negative productivity shock on GDP and consumption[5]. Liquidity injections to firms seem to work best. The flipside of unconventional policy actions is the increased volatility of GDP and inflation, at least when quantitative monetary actions are considered. On the other hand, none of the unconventional policy measures tends to impact consumption volatility negatively.

Table 5 in the Appendix shows a summary for the version of our model with exogenous default rates. Here, we allow default rates for firms and lending banks to fall by 2.5 and 5 percent, respectively. Again, all central bank policy actions tend to reduce negative impact on GDP and consumption. Quantitative easing to banks contributes to the rising volatility of GDP and inflation whereas the same policy measure aimed at non-financial firms moderates both the downturn and the variability of GDP. In addition, making default rates exogenous seems to smooth GDP but it introduces slightly more variation into consumption and inflation. In the regulatory regime with leverage ratio, results stay broadly in line with those from the scenarios without limits on bank leverage (both in case of endogenous as well as of exogenous default rates). It is worth noticing, that increased requirements on bank capital tend to make recessions less severe and the GDP less volatile. When looking at inflation variability, liquidity injections tend to substantially increase the volatility of inflation whereas qualitative easing actions slightly reduce it. It seems that the central bank that is keen on using unconventional policy tools faces a difficult task of finding a proper mix of its policy instruments and it has to take into account the ability of those tools to reverse recession, their destabilizing impact on some of the macroeconomic aggregates and the horizon of the monetary policy.

Table 6 in the Appendix reports results for a model with endogenous solvency rates and a homogenous banking sector. We find that shutting down one part of the banking sector makes

[5]The impact of both the quantitative and qualitative monetary policy depends, of course, not only on the amount of money devoted to those measures but also on their price. In our model, we assume that the policy rate, r_t, defines the cost of liquidity injections and the return of asset swaps (both types of the unconventional monetary policy actions have different balance sheet effects, since liquidity injections affect liabilities whereas qualitative easing affects assets). If the central bank would use a higher markup, it would enhance the impact of the qualitative easing and dampen the effects of liquidity injections. Now, comparing how both instruments perform in our experiments, we conclude that the impact of qualitative easing is more sensitive to the height of the interest rate rather than to the amount of money that it supplies. It is apparent that for an economy facing a period of low interest rates liquidity injections are more desirable than asset swaps as long as the central bank deploys its policy instruments at market prices.

Table 1: Table 1.1: GDP and Consumption Losses for a Model with Endogenous Solvency Rates

	basis scenario	$M_t^b+M_t^l$	M_t^f	$x_t^b+x_t^l$	$k\,(Y)$	$\varpi_b F_t^b+\varpi_l F_t^l$
	regulatory regime without leverage ratio ($b_{F^b}=b_{F^l}=0$)					
$\frac{\sum_{t=1}^{T}\beta^t(gdp_t-gdp)}{gdp}$	-17.23%	-8.80%	-8.24%	-17.10%	-16.98%	-16.51%
$\left(\frac{\sum_{t=1}^{T}(gdp_t-gdp)^2}{T-1}\right)^{\frac{1}{2}}$	0.556%	1.237%	1.200%	0.555%	0.549%	0.533%
$\frac{\sum_{t=1}^{T}\beta^t(C_t-C)}{C}$	-10.95%	-7.98%	-7.43%	-10.90%	-10.89%	-10.98%
$\left(\frac{\sum_{t=1}^{T}(C_t-C)^2}{T-1}\right)^{\frac{1}{2}}$	0.180%	0.136%	0.141%	0.179%	0.179%	0.181%
$\left(\frac{\sum_{t=1}^{T}(\pi_t-\pi)^2}{T-1}\right)^{\frac{1}{2}}$	0.042%	0.723%	1.041%	0.041%	0.058%	0.043%
	regulatory regime with leverage ratio ($b_{F^b}=b_{F^l}=10$)					
$\frac{\sum_{t=1}^{T}\beta^t(gdp_t-gdp)}{gdp}$	-17.21%	-10.02%	-5.91%	-16.64%	-16.97%	-16.53%
$\left(\frac{\sum_{t=1}^{T}(gdp_t-gdp)^2}{T-1}\right)^{\frac{1}{2}}$	0.554%	1.213%	1.171%	0.544%	0.547%	0.531%
$\frac{\sum_{t=1}^{T}\beta^t(C_t-C)}{C}$	-10.94%	-8.51%	-6.81%	-10.73%	-10.88%	-10.98%
$\left(\frac{\sum_{t=1}^{T}(C_t-C)^2}{T-1}\right)^{\frac{1}{2}}$	0.180%	0.145%	0.152%	0.176%	0.179%	0.181%
$\left(\frac{\sum_{t=1}^{T}(\pi_t-\pi)^2}{T-1}\right)^{\frac{1}{2}}$	0.031%	0.339%	0.816%	0.031%	0.041%	0.032%

Note: This table shows present value of GDP and consumption loss as well as variation in GDP, consumption and inflation rate after positive shocks to default rates and subsequent central bank actions. First column shows results for a basis scenario consisting of a negative two standard deviations technology shock in a model with endogenous solvency rates. Subsequent columns present results of quantitative easing to banks, quantitative easing to firms, qualitative easing to banks, regime switch to output driven capital ratio and capital injection to banks, respectively, amounting to 5% of GDP each. T = 30.

recessions more severe in terms of GDP and consumption loss. Standard deviation of GDP and consumption rises whereas the variability of inflation decreases slightly. We conclude that having a heterogeneous banking sector enhances economy's resilience against economic downturns and moderates the variation in the most macroeconomic aggregates. In addition, the heterogeneity of banks also improves the effects of monetary policy actions.

Generally, results from Tables 1 and 5 suggest, that a central bank which puts more weight on targeting inflation should use more qualitative easing tools. On the other hand, a central bank which primarily focuses on GDP should apply quantitative easing instruments. Therefore, the inflation targeting central bank would observe a higher output gap when trying to manage inflation in the short run whereas central bank that stabilizes GDP in the long run would produce an excessive inflation variability[6].

5 Conclusion

The ongoing financial crisis revealed that standard DSGE models need to account for financial sectors of the economy. Recent research work[7] proposes models with heterogeneous banking sector that are able to capture financial frictions and their transmission mechanism in the economy. We follow this approach and extend a relatively simple model of de Walque et al. (2009) by introducing a nominal dimension, several monetary shocks, and changes in the rules of the financial supervision. In particular, this setup enables us to study impacts of unconventional monetary policy actions at times of low interest rates when various capital adequacy requirements are in force.

We show that in this framework qualitative monetary easing impulses tend to produce more persistent changes in aggregates and their impact on GDP and consumption, though limited in magnitude, is similar to the expansionary monetary policy. Quantitative monetary easing shock, on the other hand, is more effective in the short run (in terms of changes in output and GDP) but does not seem to affect variables in the long run. Equity injections to banks achieve rather modest results in mitigating losses from financial frictions, yet they are able to substantially improve the solvency rates in the financial sector. In terms of consumption and GDP losses, direct credit to firms outperforms the unconventional actions aimed at banks. A direct capital payout to financial institutions diminishes consumption, raises inflationary pressure and results in small and persistent positive responses of GDP.

Our experiments in Section 4 also support the general result that the quantitative monetary policy actions are superior to other tools. In addition, we conclude that in cases when capital ratio is tied to the output gap or when banks receive equity injections GDP fluctuations get smaller. In general, we observe that if financial institutions are supposed to meet additional capital adequacy requirements, GDP volatility is smaller and recessions are less extreme.

Future work could consist of introducing other fiscal policy tools into the model. It would also be of interest to model richer financial markets with other financial intermediaries, like brokers and

[6]See discussion on the policy horizon in Smets (2003).
[7]Dib (2010) and Gerali et al. (2010).

so called shadow banks[8]. Recent research suggests that the analysis of their balance sheets could be used for prediction of economic activity and inflation dynamics[9].

[8]We refer to ABS issuers, finance companies, and funding corporations as "shadow banks".
[9]See Adrian, Moench, and Shin (2010).

6 Appendix

6.1 First Order Conditions

Note: for $(t+s)$-terms expectation operator is omitted for notational convenience.

Households

$$w_t = \bar{m}\frac{C_t}{(1-N_t)} \tag{28}$$

$$\frac{1-T_t}{C_t\left(1+r_t^l\right)} = \beta\frac{1}{C_{t+1}\pi_{t+1}} - \chi\left(\frac{D_t^h}{1+r_t^l} - \frac{\bar{D}^h}{1+\bar{r}^l}\right)\frac{1}{1+r_t^l} \tag{29}$$

Non-financial Firms

$$Y_N = w_t \tag{30}$$

$$Y_K = \lambda_t - \bar{\beta}_{t+1}\left(1-\tau\right)\lambda_{t+1} \tag{31}$$

$$\frac{\lambda_t}{1+r_t^b} = \bar{\beta}_{t+1}\frac{\alpha_{t+1}}{\pi_{t+1}} + \bar{\beta}_{t+2}\gamma\frac{\left(1-\alpha_{t+1}\right)^2}{\pi_{t+1}}\left(\frac{L_t^f}{\pi_{t+1}} + d_f\right) \tag{32}$$

$$\frac{L_{t-1}^f}{\pi_t} = \bar{\beta}_{t+1}\gamma\left(1-\alpha_t\right)\left(\frac{L_{t-1}^f}{\pi_t} + d_f\right)^2 \tag{33}$$

$$\theta\left(1-mc_t\right) = 1 - \psi\left(\pi_t - \pi^*\right)\pi_t - \bar{\beta}_{t+1}\psi\left(\pi_{t+1} - \pi^*\right)\pi_{t+1}\frac{Y_{t+1}}{Y_t} \tag{34}$$

$$mc_t = \exp\left(A_t\right)^{\eta-1}\left(r_t^b\frac{\left(1+r_t^b\right)}{\eta}\right)^{\eta}\left(\frac{w_t}{1-\eta}\right)^{1-\eta} \tag{35}$$

Deposit Banks

$$\frac{\lambda_t^l}{1+r_t^l} = \bar{\beta}_{t+1}\frac{\lambda_{t+1}^l}{\pi_{t+1}} \tag{36}$$

$$\frac{\lambda_t^l}{1+i_t} = \bar{\beta}_{t+1}\frac{\delta_{t+1}\lambda_{t+1}^l}{\pi_{t+1}} + \bar{\beta}_{t+2}\zeta_l\left(1-\delta_{t+1}\right)\frac{\lambda_{t+2}^l}{\pi_{t+1}} - d_{F^l}kw^l - b_{F^l}h \tag{37}$$

$$d_{F^l}v_l = \left(\lambda_t^l\left(1+v_l r_t\right) - \frac{1}{\Pi_t^l}\right) - \bar{\beta}_{t+1}\left(1-\xi_l+\varpi_l\right)\left(\lambda_{t+1}^l - \frac{1}{\Pi_{t+1}^l}\right)\frac{1}{\pi_{t+1}} \tag{38}$$

Lending Banks

$$\frac{\lambda_t^b}{1+i_t} = \bar{\beta}_{t+1}\frac{\lambda_{t+1}^b\delta_{t+1}}{\pi_{t+1}} + \bar{\beta}_{t+2}\lambda_{t+2}^b\omega\frac{\left(1-\delta_{t+1}\right)^2}{\pi_{t+1}}\left(\frac{D_t^{bd}}{\pi_{t+1}} + d_\delta\right) \tag{39}$$

$$\frac{\lambda_t^b}{1+r_t^b} = \bar{\beta}_{t+1}\frac{\alpha_{t+1}\lambda_{t+1}^b}{\pi_{t+1}} + \bar{\beta}_{t+2}\zeta_b\left(1-\alpha_{t+1}\right)\frac{\lambda_{t+2}^b}{\pi_{t+1}} - d_{F^b}kw^b - b_{F^b}h \tag{40}$$

$$\frac{\lambda_t^b D_{t-1}^{bd}}{\pi_t} = \bar{\beta}_{t+1}\lambda_{t+1}^b\omega\left(1-\delta_t\right)\left(\frac{D_{t-1}^{bd}}{\pi_t} + d_\delta\right)^2 \tag{41}$$

$$d_{F^b}v_b = \left(\lambda_t^b\left(1+v_b r_t\right) - \frac{1}{\Pi_t^b}\right) - \bar{\beta}_{t+1}\left(1-\xi_b+\varpi_b\right)\left(\lambda_{t+1}^b - \frac{1}{\Pi_{t+1}^b}\right)\frac{1}{\pi_{t+1}} \tag{42}$$

6.2 Tables

Table 2: Table 1.2: Calibrated Parameters

households		firms		banks				monetary policy	
$\bar{r}^l$	0.0035	θ	4.24	k	0.08	ω	367	Q_p	1.2
χ	0.01	ψ	50	h	0.04	d_δ	0.02	Q_y	0.05
$\bar{D}^l$	0.39	ρ_a	0.95			$\bar{\rho}$	0.01	$\bar{r}$	0.0015
β	0.9965	η	0.333	$\bar{B}^l$	0.19	$\bar{B}^b$	0.19	μ_r	0.7
$\bar{m}$	3.72	τ	0.03	d_{F^l}	53.4	d_{F^b}	6.71	π^*	1
		γ	103.5	ζ_l	0.8	ζ_b	0.8	Q_k	0.5
		d_f	0.001	ξ_l	0.07	ξ_b	0.06		
				v_l	0.5	v_b	0.5		
				w^l	0.05	w^b	0.8		
				$\rho_{M^{(\cdot)}}$	0.85	$\rho_{x^{(\cdot)}}$	0.85		
				b_{F^l}	10	b_{F^b}	10		

Table 3: Table 1.3: Steady State Values

Variable	Definition	Value			
		endogenous default rates		exogenous default rates	
	steady state values	$b_{F^{(\cdot)}} = 0$	$b_{F^{(\cdot)}} = 10$	$b_{F^{(\cdot)}} = 0$	$b_{F^{(\cdot)}} = 10$
π	inflation	1.0009	1.0034	1.0003	1.0031
r	central bank interest rate	0.0050	0.0154	0.0028	0.0138
r^l	deposit interest rate	0.0044	0.0070	0.0038	0.0066
i	interbank interest rate	0.0091	0.0122	0.0081	0.0111
r^b	firms' borrowing interest rate	0.0161	0.0201	0.0154	0.0195
α	solvency rate: firms	0.9490	0.9490	0.9500	0.9500
δ	solvency rate: lending banks	0.9774	0.9766	0.9800	0.9800
mc	marginal cost of production	0.7848	0.8454	0.7720	0.8362
w	wage	2.0895	2.0880	2.0907	2.0893
	steady state ratios				
C/Y	consumption to output	0.7138	0.7138	0.7136	0.7135
K/Y	capital stock to output	9.8231	9.8098	9.8347	9.8220
Π^f/Y	firms' profits to output	0.0418	0.0418	0.0415	0.0415
Π^b/Y	lending banks' profits to output	0.0051	0.0051	0.0052	0.0051
Π^l/Y	deposit banks' profits to output	0.0013	0.0012	0.0013	0.0013
F^b/Y	lending banks' own funds to output	0.0422	0.0403	0.0427	0.0403
F^l/Y	deposit banks' own funds to output	0.0088	0.0080	0.0095	0.0087
D^l/gdp	deposits to GDP	0.6134	0.6157	0.6125	0.6148
D^{bs}/gdp	interbank lending to GDP	0.1192	0.1121	0.1383	0.1358
L^b/gdp	firms' borrowing to GDP	0.2960	0.2969	0.2961	0.2970

Table 4: Table 1.4: Second Moments (Model with Endogenous Default Rates and No Leverage Ratio)

Variable	σ
π	0.00106
K	0.21568
N	0.00264
Y	0.02222
C	0.01102
w	0.05478
gdp	0.02221

Table 5: Table 1.5: GDP and Consumption Losses for a Model with Exogenous Solvency Rates

	basis scenario	$M_t^b + M_t^l$	M_t^f	$x_t^b + x_t^l$	$k\,(Y)$	$\varpi_b F_t^b + \varpi_l F_t^l$
regulatory regime without leverage ratio ($b_{F^b} = b_{F^l} = 0$)						
$\frac{\sum_{t=1}^{T} \beta^t (gdp_t - gdp)}{gdp}$	-9.15%	-2.70%	5.64%	-8.45%	-9.13%	-8.52%
$\left(\frac{\sum_{t=1}^{T} (gdp_t - gdp)^2}{T-1}\right)^{\frac{1}{2}}$	0.471%	0.880%	0.838%	0.464%	0.470%	0.458%
$\frac{\sum_{t=1}^{T} \beta^t (C_t - C)}{C}$	-2.72%	-0.51%	1.00%	-2.51%	-2.72%	-2.76%
$\left(\frac{\sum_{t=1}^{T} (C_t - C)^2}{T-1}\right)^{\frac{1}{2}}$	0.240%	0.351%	0.251%	0.241%	0.240%	0.240%
$\left(\frac{\sum_{t=1}^{T} (\pi_t - \pi)^2}{T-1}\right)^{\frac{1}{2}}$	0.231%	0.681%	0.859%	0.224%	0.236%	0.234%
regulatory regime with leverage ratio ($b_{F^b} = b_{F^l} = 10$)						
$\frac{\sum_{t=1}^{T} \beta^t (gdp_t - gdp)}{gdp}$	-8.74%	-1.50%	5.69%	-7.67%	-8.70%	-8.15%
$\left(\frac{\sum_{t=1}^{T} (gdp_t - gdp)^2}{T-1}\right)^{\frac{1}{2}}$	0.458%	0.905%	0.843%	0.449%	0.456%	0.446%
$\frac{\sum_{t=1}^{T} \beta^t (C_t - C)}{C}$	-2.58%	0.11%	1.12%	-2.27%	-2.58%	-2.63%
$\left(\frac{\sum_{t=1}^{T} (C_t - C)^2}{T-1}\right)^{\frac{1}{2}}$	0.236%	0.353%	0.252%	0.236%	0.235%	0.236%
$\left(\frac{\sum_{t=1}^{T} (\pi_t - \pi)^2}{T-1}\right)^{\frac{1}{2}}$	0.178%	0.657%	0.719%	0.175%	0.179%	0.179%

Note:

This table shows present value of GDP and consumption loss as well as variation in GDP, consumption and inflation rate after positive shocks to default rates and subsequent central bank actions. First column shows results for a basis scenario consisting of a positive 2,5% and 5% shocks to firm and lending banks default rates, respectively, in a model with exogenous solvency rates. Subsequent columns present results of quantitative easing to banks, quantitative easing to firms, qualitative easing to banks, regime switch to output driven capital ratio and capital injection to banks, respectively, amounting to 5% of GDP each. T = 30.

Table 6: Table 1.6: GDP and Consumption Losses for a Model with no Interbank Market

	basis scenario	M_t^l	M_t^f	x_t^l	$k\,(Y)$	$\varpi_l F_t^l$
	regulatory regime without leverage ratio ($b_{F^l} = 0$)					
$\frac{\sum_{t=1}^{T}\beta^t(gdp_t - gdp)}{gdp}$	-17.84%	-14.24%	-16.75%	-17.23%	-17.17%	-17.46%
$\left(\frac{\sum_{t=1}^{T}(gdp_t - gdp)^2}{T-1}\right)^{\frac{1}{2}}$	0.581%	1.280%	1.294%	0.566%	0.561%	0.569%
$\frac{\sum_{t=1}^{T}\beta^t(C_t - C)}{C}$	-11.18%	-9.87%	-10.46%	-10.75%	-11.04%	-11.26%
$\left(\frac{\sum_{t=1}^{T}(C_t - C)^2}{T-1}\right)^{\frac{1}{2}}$	0.185%	0.167%	0.182%	0.178%	0.182%	0.186%
$\left(\frac{\sum_{t=1}^{T}(\pi_t - \pi)^2}{T-1}\right)^{\frac{1}{2}}$	0.011%	0.102%	0.123%	0.014%	0.017%	0.010%
	regulatory regime with leverage ratio ($b_{F^l} = 10$)					
$\frac{\sum_{t=1}^{T}\beta^t(gdp_t - gdp)}{gdp}$	-17.84%	-14.29%	-16.82%	-17.17%	-17.13%	-17.45%
$\left(\frac{\sum_{t=1}^{T}(gdp_t - gdp)^2}{T-1}\right)^{\frac{1}{2}}$	0.581%	1.279%	1.292%	0.564%	0.560%	0.568%
$\frac{\sum_{t=1}^{T}\beta^t(C_t - C)}{C}$	-11.18%	-9.92%	-10.52%	-10.69%	-11.03%	-11.27%
$\left(\frac{\sum_{t=1}^{T}(C_t - C)^2}{T-1}\right)^{\frac{1}{2}}$	0.185%	0.167%	0.182%	0.177%	0.182%	0.186%
$\left(\frac{\sum_{t=1}^{T}(\pi_t - \pi)^2}{T-1}\right)^{\frac{1}{2}}$	0.011%	0.099%	0.118%	0.015%	0.016%	0.010%

Note: This table shows present value of GDP and consumption loss as well as variation in GDP, consumption and inflation rate after positive shocks to default rates and subsequent central bank actions. First column shows results for a basis scenario consisting of a negative two standard deviations technology shock; subsequent columns present results of quantitative easing to banks, quantitative easing to firms, qualitative easing to banks, regime switch to output driven capital ratio and capital injection to banks, respectively, amounting to 5% of GDP each. T = 30. Model with endogenous solvency rate for firms and homogenous banking sector which offers deposits to households, lends to firms and is not subject to default.

6.3 Figures

Figure 5: Figure 1.5: Impulse responses after a positive technology shock

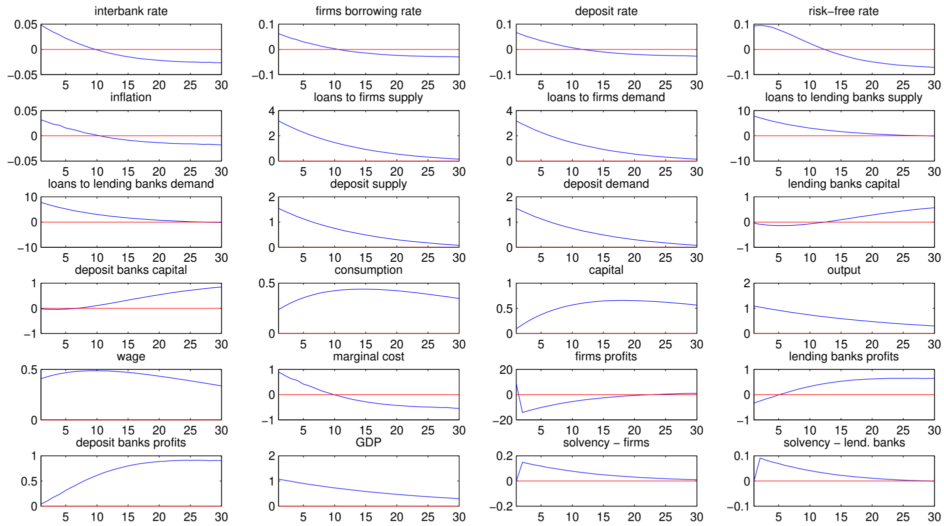


Figure 6: Figure 1.6: Impulse responses after an expansionary monetary policy shock

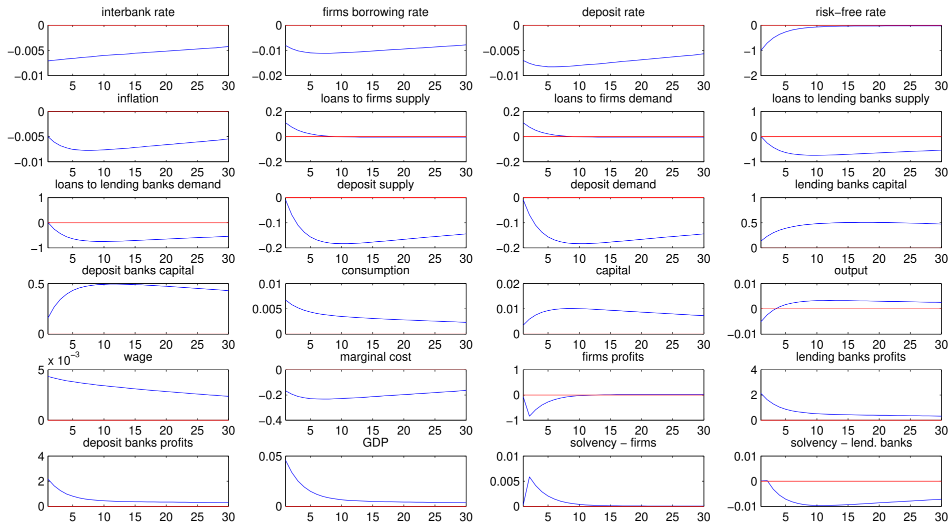


Figure 7: Figure 1.7: Impulse responses after a liquidity injection shock to deposit banks

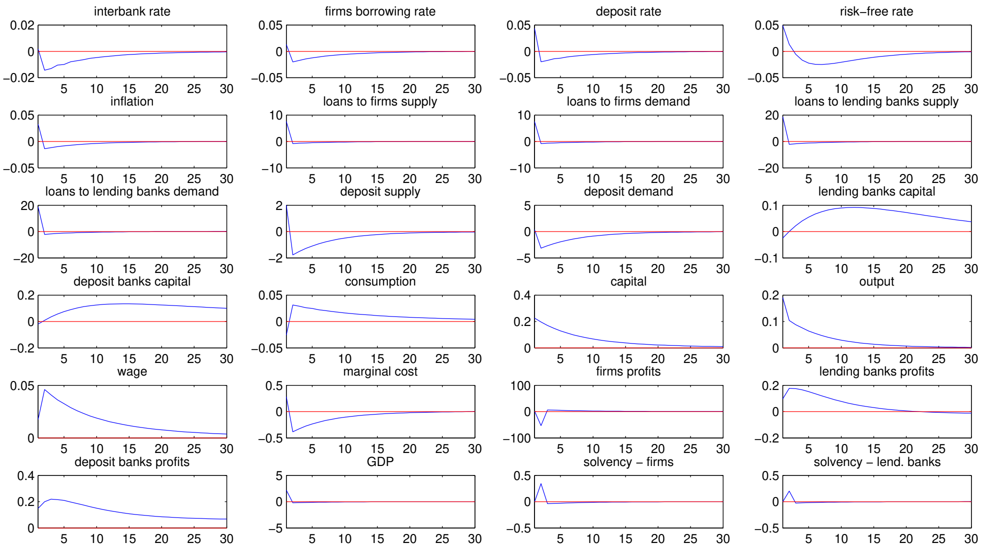


Figure 8: Figure 1.8: Impulse responses after an asset swap shock to deposit banks

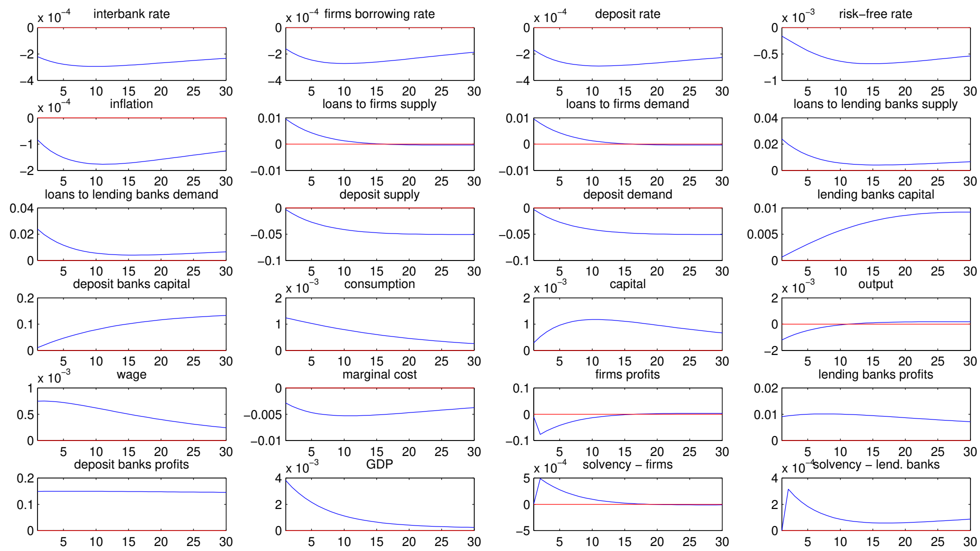
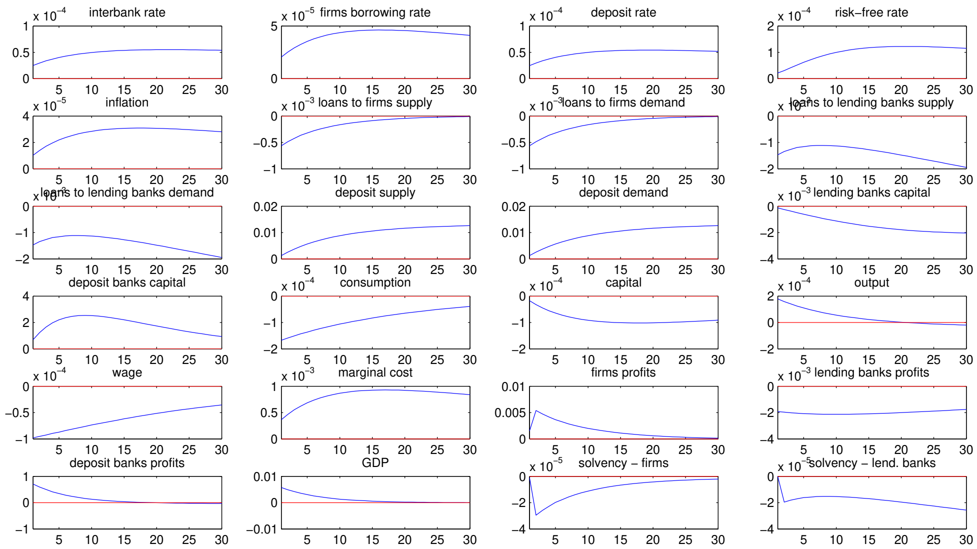


Figure 9: Figure 1.9: Impulse responses after a capital injection shock to deposit banks



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