# Accepted Manuscript


Title: Interbank Market Failure and Macro-prudential Policies

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PII: S1572-3089(16)30129-2
DOI: http://dx.doi.org/doi:10.1016/j.jfs.2016.10.007
Reference: JFS 492

To appear in: *Journal of Financial Stability*

Received date: 4-8-2015
Revised date: 27-3-2016
Accepted date: 26-10-2016

# Interbank Market Failure and Macro-prudential Policies

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October 15, 2016



**Abstract**

This paper analyses the effects of several macro-prudential policy measures on the banking sector and its linkages to the macroeconomy. We employ a dynamic general equilibrium model with sticky prices, in which banks trade excess funds in the interbank lending market. We find that an increase in the liquidity requirement effectively reduces the impact of an interbank shock on the real and financial sector, while an increased capital requirement propagates only through nominal variables as inflation and interest rates. We conclude that stricter liquidity measures which limit inside money creation, dampen the severity of a breakdown in interbank lending. Targeting interbank financing directly through liquidity measures along with a moderate capital requirement generates lower welfare losses. We thereby provide a comprehensive rationale in favor of the regulatory measures in Basel III.

**JEL Classification:** E40, E51, E58, G28

**Keywords:** Macro-prudential Policies, Interbank Market, Liquidity Ratio, Capital Ratio

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**Acknowledgements**:

We would like to thank Iftekar Hasan, an anonymous referee, discussants and participants in seminars at ASSET 2014, INFINITI 2015, the 27th Mondragone International Economic Seminar, Society of Computational Economics CEF 2016, EEA-ESEM 2016, and at the internal seminar at University of Rome for helpful comments. Tobias Schuler thanks EIEF, Rome for their hospitality and financial support. Any errors are ours.

# 1 Introduction

This paper analyses the effect of several regulatory measures on mitigating the severity of banking crises. The recent financial crisis has revealed several regulatory shortcomings, in particular low reserve liquidity and insufficient capital in the banking system. The breakdown of the interbank market and the subsequent credit crunch has resulted in large welfare losses and required massive Central Bank intervention. Financial authorities have responded to these developments by introducing regulation regarding bank liquidity and by tightening capital adequacy requirements. Two liquidity measures within the Basel III regulatory framework are directed at the interbank exposure, i.e. the Liquidity Coverage Ratio (LCR), which increases hoarded reserve against liquidity shocks from interbank loans, and the Net Stable Funding Ratio (NSFR) which restricts short-refinancing through the interbank market. This paper is the first study to evaluate these measures in a single framework and thus allows to assess implications on welfare. We focus on the analysis of systemic risks which materialize through the interbank lending relationships. We derive a Dynamic Stochastic General Equilibrium (DSGE) model with financial frictions in order to introduce vulnerabilities in the financial sector, giving a structural role to the interbank lending market. Through a "money in advance"constraint shocks to liquidity provision in the financial sector transmit to the household's budget constraint and optimality conditions. We simulate a banking crisis by introducing an abrupt change in the trust between banks which increases the cost of interbank lending. The wedge between the risk-free interest rate targeted by the Central Bank and the interbank rate, which in turn depends on bank's risk perceptions, induces a failure in the interbank lending market that adversely affects the supply of loans. As a consequence, economic activity and inflation contract, and interest rates decline. We study the effects of macro-prudential policies to the banking system under this shock scenario and use the calibrated model to evaluate the macroeconomic effects on credit growth and leverage. We compare how the above liquidity measures, LCR and NSFR, as well as changes in the Capital Requirement Ratio (CRR) affect interest rate spreads and the stability in the interbank market. We find that higher liquidity and capital requirements dampen the boom-bust effect on loan creation, albeit with the following caveats: i) the LCR and FSFR effectively reduce the macro impact of an interbank shock, and ii) the CRR only affects financial variables during an interbank shock. The main difference between these measures is that the capital requirement relies on private sector funding, while liquidity measures on public sector funding. The model shows how macro-prudential policy tools can mitigate the severity of a breakdown in interbank lending, thereby providing a rationale for the newly-introduced regulatory measures in Basel III which are described in Table 1.

Table 1: Macro-prudential Measures in Basel III

| **Liquidity** | | **Capital** | |
|---|---|---|---|
| LCR | Withstand liquidity outflow during a stress scenario | Capital | Equity standard 7% +0-2.5% Capital buffer +1%-2.5% for SIBs |
| NSFR | Address liquidity mismatches with stable funding sources | Leverage | Contain leverage through a non-risk based leverage ratio |

*Source:* Basel Committee on Banking Supervision reforms - Basel III (BIS (2010))
SIBs: systemically important banks

Macro-prudential policy tools are policy tools which try to influence the supply of credit taking a system-wide approach. In the absence of macro-prudential policy the monetary authority reacts to an adverse change to financial conditions. The primary instrument is the Central Bank's policy rate as it affects refinancing conditions of financial intermediaries (Blinder *et al.* (2008), Carlstrom and Fuerst (1997)). Chadha and Corrado (2012) find that paying interest on Central Bank reserves can play a stabilizing role in the business cycle. In extreme situations, as when the Central Bank operates at the zero lower bound, interest rate policy may be complemented by unconventional tools (Bernanke and Reinhard (2004), Gertler and Karadi (2011), Curdia and Woodford (2010)). Woodford (2012) and Svensson (2012) analyse the effectiveness of macro-prudential policy along with an interest rate policy. While Woodford finds a complementary role of both, Svensson argues in favor of a clear assignment to financial stability and price stability, respectively.

Most of macro-prudential tools discussed in the literature are targeted at the bank's regulatory capital. The capital requirement and the loan-to-value ratio (LTV) address potential vulnerabilities on the demand side of credit.[1] Studies which raise the importance of supply side features identify short term debt refinancing of banks as a major source of vulnerability.

[1]Eminent examples for models with limited borrowing capacity of households are Bernanke, Gertler and Gilchrist (1999) and Kiyotaki and Moore (1997)

Justiniano *et al.* (2014), Gertler and Karadi (2011) and Gertler and Kiyotaki (2010) focus on the role endogeneous leverage constraints for banks to trigger credit supply disruptions.[2] Stein (2010) shows in a theoretical model that money creation through short-term refinancing can lead to externalities which, in turn, increase the probability of a financial crisis. Ideosyncratic risks propagate through interbank linkages and can generate a systemic crisis, as shown in Rochet and Tirole (1996). Taylor and Williams (2009) point to the role of the spike in the unsecured interbank rate as a special feature of the 2008/09 financial crisis and Gorton (2010) underlines how the run on interbank lending can induce the breakdown of parts of the banking system. Bianchi and Bigio (2015) model a run on interbank lending through an increase in the mismatch between lending and borrowing banks. While the vulnerabilites in the interbank market have been clearly identified, the interbank transactions have not yet been a focal point in the macro-prudential literature. The present paper is thus the first study which addresses both capital requirements and liquidity related measures in one single framework.

The paper is structured as follows. Section 2 presents stylized facts on the interbank market during the financial crisis to motivate the analysis empirically. Section 3 presents the model. In Section 4 we show the calibration while section 5 discusses the quantitative results for the interbank shock and its implications for macro-prudential and monetary policies. Section 6 presents simulation results and welfare implications. Section 7 concludes.

## 2 Stylized facts

In order to underpin our approach giving a structural role to the interbank market we provide several stylized facts.[3] We perform a VAR analysis with quarterly U.S. data from the St. Louis Fed economic database (FRED) for 2000Q1to 2014Q4 (See Figure 1). For the Interbank spread (interbank) we employ the spread between the 3-month Libor in USD and the Fed Funds Overnight Rate. For the Loan Spread (loan_spread) we consider the spread between the Quarterly Prime Loan Rate and the Fed Funds Overnight Rate. For the policy rate we consider the Fed Funds Overnight Rate (fedfunds). For inflation we employ the quarterly CPI and for

[2]The combination of leverage limits and transfers to mitigate deleveraging shock are discussed in Korinek and Simsek (2014). They find that it is possible to reach an optimal allocation when a financial shock is anticipated, thus averting a liquidity trap.

[3]Further tables and charts for this section can be found in the Supplementary Material available on request.

output we consider the seasonally adjusted GDP in Millions of Dollars.

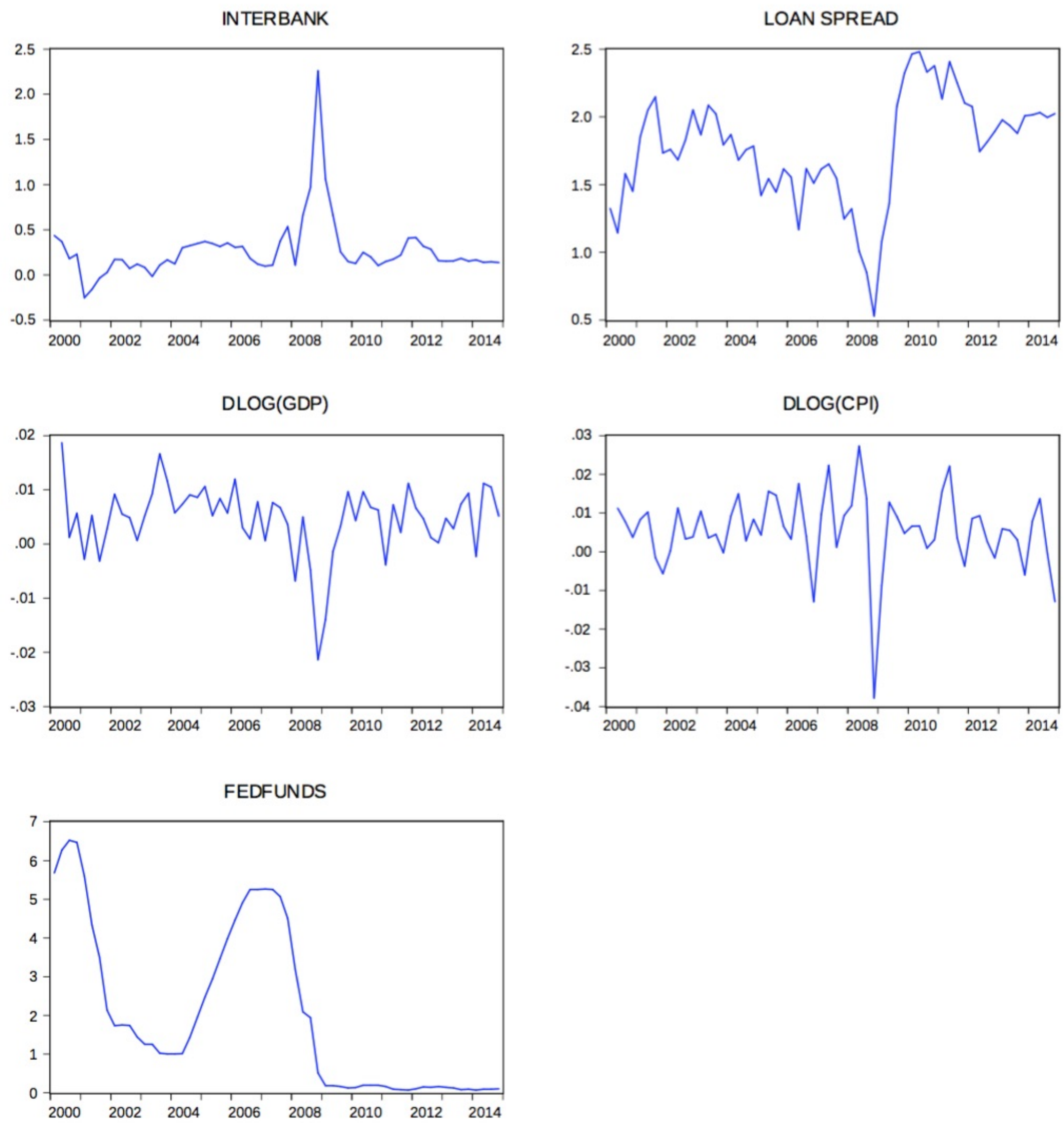


Figure 1: Variables used in the VAR 2000Q1 to 2014Q4.
*Note:* The chart shows the interbank spread, the loan spread, (log) changes in CPI and GPD, and the fed funds rate for the U.S. economy.

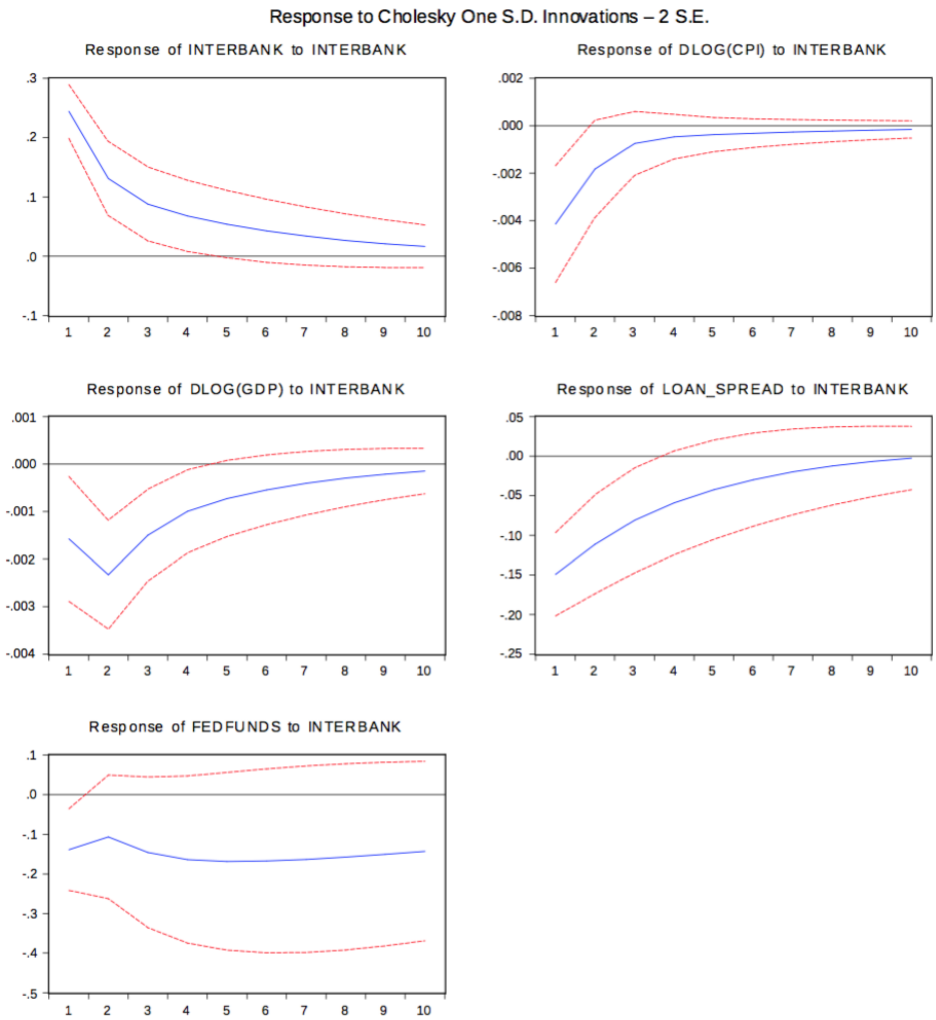


Figure 2: Impulse response function 2000Q1 to 2014Q4.
*Note:* The chart shows the impulse response function from the VAR including interbank spread, (log) changes in CPI and GPD, the fed funds rate, and the loan spread.

Figure 2 shows that a one S.D. innovation to the interbank spread affects negatively inflation, the loan rate spread and GDP. The variance decomposition analysis (FEVD) in Figure 3 reports the relative importance of each random innovation on the variables considered at various forecast horizons. Variation in the current and future values of the innovations to each endogenous variable in the VAR is the source of this forecast error.[4]

[4]Column two of Table 1 in the Supplementary Material shows the forecast error of the variable at the given forecast horizon. Columns three to five show the percentage of the forecast variance due to each innovation such that every row adds up to 100.

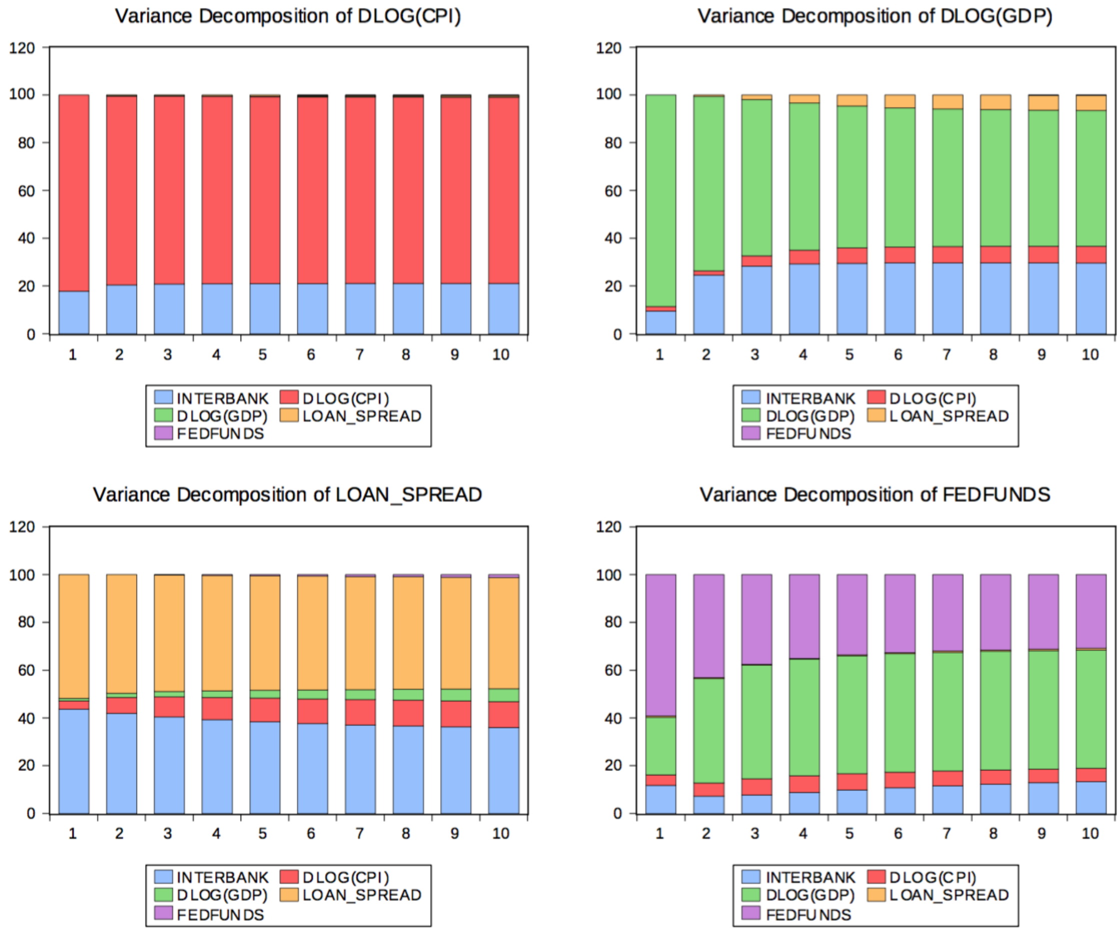


Figure 3: Forecast Error Variance Decomposition.
*Note:* The chart shows the forecast error variance decomposition from the VAR including interbank spread, (log) changes in CPI and GPD, the fed funds rate, and the loan spread.

For the evaluation we concentrate on the explained fluctuations after 3 quarters (short run) and after 10 quarters (long run). Figure 3 shows that a shock to the interbank spread has a stronger impact on GDP, CPI and the loan spread both in the short run and in the long run. Three quarters ahead an interbank spread shock explains 20% of the variance in CPI, 28% of the variance in GDP, 40% of the variance in the loan rate spread. The impact is still strong 10 quarters ahead as the interbank shock explains 21% of the variance in CPI, 29% of the variance in GDP and 36% of the variance in the variance in the loan rate spread. A shock to the interbank spread has some explanatory power in the long-run fluctuations also on the Fed funds rate (13%).

## 3 Model

We extend the DSGE model based on Goodfriend and McCallum (2007). We include interbank transactions between commercial banks as a means for refinancing. In addition, the model comprises households, intermediate good-producing and retail firms, and the government including the Central Bank, the Treasury and a regulatory authority. This approach employs some realistic features of the money creation process in modern economies to model a banking system (see McLeay et al. (2014)), a point also stressed by Jakab and Kumhof (2015).

Table 2: Balance sheets

| Households | | Treasury | |
|---|---|---|---|
| *Assets* | *Liabilities* | *Assets* | *Liabilities* |
| Deposits $D$<br>Bonds (1-$\gamma$)$B$<br>Bank equity $e$ | Loans $L$<br>$\sum_{t=0}^{\infty} tax_t$ | $\sum_{t=0}^{\infty} tax_t$ | Bonds $B$ |
| **Commercial banks** | | **Central Bank** | |
| *Assets* | *Liabilities* | *Assets* | *Liabilities* |
| Loans $L$<br>Interbank loans $L^{IB}$<br>Reserves $Res$ | Deposits $D$<br>Interbank loans $L^{IB}$<br>Bank equity $e$ | Bonds $\gamma B$ | Reserves $Res$ |

Table 2 shows the balance sheets of the agents in the model. The accounting identities reflect an economy with money creation by banks. Households use money in form of deposits as a transaction means to acquire consumption goods. Households receive deposits for transactions by taking a liability in form of loans. They save in government bonds and are the owners of bank equity. Commercial banks create deposits as a liability by handing out loans as a claim on their customers. They are required to hold bank equity capital against their loan portfolio and reserves against their deposits. Banks also engage in interbank transactions in which banks with excess refinancing from deposits exchange funds with banks with excess loan opportunities. Thus interbank loans serve as a means to clear mismatches between loan demand and financing among banks. In the consolidated view of the balance sheet of commercial banks interbank loans appear both as assets and liabilities as they form an accounting identity. The Treasury issues bonds against the tax liability on households. The Central Bank provides reserves to the commercial banks against a share of government bonds as collateral.

### 3.1 Households

There is a continuum of mass 1 of identical households. Let $c_t$ be consumption, $l_t^s$ the time household members devote to work in production firms and $m_t^s$ the time household members work as bankers, with $0 \leq l_t^s + m_t^s \leq 1$ as time constraint for total working time. Preferences are represented by the utility function of the form:

$$max E_0 \sum_{t=0}^{\infty} \beta^t [log(c_t) + \phi log(1 - l_t^s - m_t^s)], \tag{1}$$

where $0 < \beta < 1$ is the household discount factor of future utility. The household acquires consumption goods through money, i.e. deposits $D_t$. We assume as in Goodfriend and McCallum (2007) that the "money in advance"constraint always binds[5] and consequently require that

$$c_t = v \frac{D_t}{P_t}, \tag{2}$$

where $v$ stands for the velocity of money.[6] The household's resource constraint is given by

$$\begin{aligned} c_t + \frac{B_{t+1}}{P_t} + \frac{D_{t+1}}{P_t} - \frac{L_{t+1}}{P_t} + \frac{e_{t+1}}{P_t} \leq w_t(l_t^s + m_t^s) + (1 + R_t^B)\frac{B_t}{P_t} + (1 + R_t^D)\frac{D_t}{P_t} \\ - (1 + R_t^L)\frac{L_t}{P_t} + (1 + R_t^e)\frac{e_t}{P_t} + \Pi_t - tax_t \end{aligned} \tag{3}$$

In this inequality, $B_{t+1}$ are the holdings of a riskless bond by the household paying the nominal interest $R_t^B$.[7] $\Pi_t$ are the net payouts from non-financial firms and financial firms. $tax_t$ are lump-sum tax transfers, and $e_t$ are household bank equity holdings paying the return $R_t^e$.[8]

The household has two bank accounts: the savings account where bond savings $B_t$ are kept and the giro account for transaction deposits $D_t$. Bonds and deposits are not perfect substitutes, as bonds cannot be used for consumption spending. When the household demands a loan $L_t$ from a bank it receives money in form of deposits $D_t$. This implies that changes in loan

[5]This is for tractability reasons. The assumption can be motivated by costs arising from holding money. We can show that in equilibrium the cost results in a marginally lower rate on deposits $R_t^D$ than the rate on government bonds $R_t^B$. Freeman and Huffman (1991) analyze the size of transaction versus interest payments to motivate the use of non-interest bearing money.

[6]The parameter $v$ is employed in the calibration of the model.

[7]Households hold the dominant share of the bonds $(1\text{-}\gamma)B_t$ and effectively price the bonds as given in the Euler equation.

[8]We assume later that the return on bank equity, $R_t^e$, will bear an additional risk premium $\Delta_e$. See Castelnuovo and Nisticò (2010).

vs. deposit holdings move in parallel, i.e. $\Delta D_{t+1}/P_t = \Delta L_{t+1}/P_t$, with $\Delta$ as the first-difference operator.

Households maximize their utility (1) subject to the "money in advance"constraint (2) and their budget condition (3). The Lagrangian multiplier on the budget constraint is denoted by $\lambda_t$. A standard no-Ponzi scheme condition limits borrowing.

This allows for a direct substitution for $c_t$ into the utility function. Solving for optimal consumption yields[9]

$$\frac{(1-\alpha)}{m_t}\left(\frac{1}{\lambda_t} - c_t - \frac{L_t}{P_t}\left(R_t^L - R_t^D\right)\right) = 0. \tag{4}$$

Optimal supply of production labor, $l_t^s$, and monitoring work, $m_t^s$, requires

$$\lambda_t w_t = \frac{\phi}{1 - l_t^s - m_t^s}, \tag{5}$$

and optimal household holdings of government bonds, $B_{t+1}$, are determined by the following consumption Euler equation,

$$E_t \Lambda_{t,t+1}(1 + R_{t+1}^B) = 1, \tag{6}$$

with

$$\Lambda_{t,t+1} \equiv E_t \beta \left\{\frac{\lambda_{t+1} P_t}{\lambda_t P_{t+1}}\right\}. \tag{7}$$

The Euler equation (6) gives the inter-temporal condition for households, while (4) and (5) determine the intra-temporal optimal allocation of consumption and labor for the households.[10]

## 3.2 Non-Financial Firms

Monopolistically competitive intermediate good firms hire workers to produce inputs for the final consumption good provided by perfectly competitive retail firms.

**Intermediate good firms.** The intermediate good producing firm $i$'s objective is to

[9] This relationship derives from the substitution of the "money in advance"condition into the household's optimizing problem.

[10] Money holdings $D_t$ are thus determined for each period separately, while savings are in bonds $B_t$.

maximize real profits given by

$$\Pi_t^F(i) = y_t(i) - w_t l_t(i) \tag{8}$$

where $y_t(i)$ is a single firm's output, $w_t$ the real wage for the labor employed $l_t(i)$. Maximization is subject to a decreasing returns to scale technology,

$$y_t(i) = A1_t l_t(i)^{1-\eta} \tag{9}$$

with (1-$\eta$) reflecting the curvature of the production function, and $A1_t$ the level of total factor productivity (TFP) similar to the real business cycle literature, which can be represented by the following stochastic process in log form $a1_t = \rho_1 \; a1_{t-1} + \epsilon_t^{(1)}$.

The marginal cost for an individual intermediate goods firm $i$ is given by

$$MC_t(i) = \frac{w_t}{(1-\eta)A1_t l_t(i)^{-\eta}} \tag{10}$$

Optimal aggregate labor demand $l_t$ is given by:

$$w_t = A1_t(1-\eta)l_t^{-\eta}. \tag{11}$$

Each intermediate firm resets its price with probability ($1$-$\theta$) in each period (see Calvo (1983)). The first-order condition for the intermediate firm's problem is:[11]

$$\sum_{k=0}^{\infty} \theta^k E_t\{\Lambda_{t,t+k} y_{t+k|t} (\frac{P_t^*}{P_{t-1}} - \mathcal{M} \; MC_{t+k} \varrho_{t-1,t+k})\} = 0, \tag{12}$$

where $\theta$ is the probability that an intermediate firm keeps its price from the previous period, $E_t\{\Lambda_{t,t+k}\}$ is the expected discount factor from the consumption Euler equation (6), $y_{t+k|} \; t$ the expected production of a firm adjusting prices in period $t$, and $\mathcal{M}$=$\frac{\epsilon}{1-\epsilon}$ represents the markup of the price over the marginal cost.

**Retailers.** A representative retail firm maximizes profits taking the retail price $P_t$ as given and the intermediate goods prices $P_t(i)$ for $i \in$[0,1]. The retail good has a constant elasticity

[11] The index $i$ can be left out as all firms resetting the price at time $t$ choose the same optimal price $P_t^*$.

of substitution (CES) representation

$$y_t = \left( \int_0^1 y_t(i)^{1-\epsilon} di \right)^{\frac{1}{1-\epsilon}} \tag{13}$$

with inputs $y_t(i)$ with an elasticity of substitution of $\epsilon>1$. This yields the set of demand functions,

$$y_t(i) = \left( \frac{P_t(i)}{P_t} \right)^{-\epsilon} y_t, \tag{14}$$

and the price index

$$P_t = \left( \int_0^1 P_t(i)^{1-\epsilon} di \right)^{\frac{1}{1-\epsilon}}. \tag{15}$$

By invoking the Weak Law of Large Numbers, the evolution of the price level is

$$P_t = \left[ (1-\theta) P_T^* + \theta P_{t-1}^{1-\epsilon} \right]^{\frac{1}{1-\epsilon}}. \tag{16}$$

As only a fraction of intermediate firms adjusts prices each period, the price index for the retail good and thus inflation do not immediately adjust to changes in real or financial conditions. Credit supply conditions, along with monetary policy changes, can thus have real effects.

### 3.3 Commercial Banks

Commercial banks lend to the non-financial sector, which in this setup are households, in a bank-client relationship, or to other banks, through the interbank market. Each bank either belongs to a group of banks with excess funding, denoted as interbank-lender, with probability $\frac{1}{2}$, or with excess lending opportunities with probability $\frac{1}{2}$, which we call interbank-borrowers. Banks face constraints in obtaining funds from households and the interbank market depends on the type of bank. Commercial banks' period profits are given by

$$\Pi_t^B = (R_t^L - R_t^f) \frac{L_t}{P_t} - w_t m_t + V_t, \tag{17}$$

with $L_t$ as loans to non-financial sector for which they receive the spread of the loan rate $R_t^L$ over the financing costs $R_t^f$ and hire loan managers $m_t$ at the real wage $w_t$. As Figure 4 shows, at the beginning of each period banks determine their loan rate $R_t^L$ taking into account their financing cost from depositors $R_t^D$ and their financing costs or refinancing profits from interbank lending $R_t^{IB}$ given their type which is revealed at the end of each period. Bank profits depend on lending or borrowing positions in the interbank market at the end of each period $t$,

$$V_t = \frac{1}{2}V_t^I + \frac{1}{2}V_t^{II}, \tag{18}$$

where $V_t^I$ is the continuation profit for lending banks and $V_t^{II}$ is the continuation profit for borrowing banks. Financing costs $R_t^f$ are determined by the interest rate paid to depositors $R_t^D$ and by regulatory requirements. The liquidity requirement takes the form of a ratio of reserves to deposits, i.e. $Res_t{=}rrD_t$, with $rr$ denoting the reserve requirement ratio (LCR). Capital regulation requires banks to hold a minimum level of equity in relation to their loan portfolio, i.e. $e_t \geq \kappa L_t$, where $\kappa$ is the capital requirement ratio (CRR). To obtain reserves $Res_t$, banks sell bonds $\gamma\ B_t$ to the Central Bank. For the sake of tractability of open-market operations, we assume that banks pay the policy rate $R_t^P$ on the amount of reserve holdings coming from the refinancing operations from the Central Bank.[12] Refinancing costs can be affected by the interbank market, denoted as interbank financing premium (*IFP*).[13] The funding cost of banks are thus given by

$$R_t^f = R_t^D + (rr + \kappa\zeta)R_t^P + (\Delta_s IFP_s)_t \tag{19}$$

which includes $R_t^e$, in turn, given by

$$R_t^e = \zeta R_t^P \tag{20}$$

[12]The liquidity requirement is applicable to the amount of reserve liquidity and highly-liquid risk free government bonds. In this stylized setting without explicit open-market operations in their economic meaning both are equivalent, and can be used interchangably. Thus the approach would cover also central banks without a reserve requirement, as e.g. the Bank of England.

[13]The concept of *IFP* will be explained in the below.

We restrict the parameter $\zeta$ to values greater than 1, thereby generating $\Delta_e$, the equity risk premium (ERP). Thus the return on equity, $R_t^e$ includes the ERP over the policy rate.[14] As equity is more costly than other sources of funding, the equity will be held by banks to fulfill exactly the capital requirement, i.e. $e_t = \kappa L_t$.[15]

Banks need to employ monitoring work for a given efficiency in loan management represented by the parameter $Q$:

$$\frac{L_t}{P_t} = Q m_t^{1-\alpha}. \tag{21}$$

The optimal loan provision depends then on the spread of the loan rate over the marginal costs of loan provision:

$$R_t^L - R_t^f = \frac{v w_t m_t}{(1-\alpha)c_t}. \tag{22}$$

The spread gives the external finance premium resulting from recovering the cost of monitoring.

Figure 4 shows how transactions take place with decisions made sequentially by households and intermediaries. At the beginning of each period banks determine their loan rate $R_t^L$ taking into account their financing costs from depositors $R_t^D$ and their expectation for financing costs or refinancing profits from interbank lending $R_t^{IB}$ given their type which is revealed at the end of each period. Firms receive deposits from households in exchange for goods and hold them at banks in different proportions than household loans creating a mismatch between loans and deposits at the two types of banks. This mismatch is cleared through interbank transactions - excess deposits of one bank type are transferred through interbank loans $L_t^{IB}$ to the other bank type.

The optimization problem for the lending bank $V^I$ and the borrowing bank $V^{II}$ is given below. Interbank loans $L_t^{IB}$ require monitoring which we denote by $m_t^{IB}$

$$\frac{L_t^{IB,S}}{P_t} = (m_t^{IB})^{1-\alpha} \tag{23}$$

[14]See the seminal study by Mehra and Prescott (1968), and for DSGE models with equity Meh and Moran (2010), and Gust and Lopez-Salido (2009). In this formulation lowering the policy rate leads to a fall in the equity premium in line with evidence provided by Bernanke and Kuttner (2005).

[15]Along Smets and Wouters (2003) for financial shocks.

Banks decide $R_t^L$ given $R_t^D$, and $Res_t$. Bank types and trust between banks ($\Phi$) realize. Households demand loans $L_t$.

Households exchange funds $D_t$ for goods $c_t$. Mismatch of loans and funds at the bank.

Banks determine $R_t^{IB}$ and $L_t^{IB}$ in interbank market. Re-channeling of funds.

Figure 4: Timeline of events in each period $t$

analogous to equation (21), albeit weighted by (1-Φ). We define Φ as the trust between banks, which reflects the ease with which banks can refinance excess loan demand through the interbank lending market.[16] Rearranging above equation yields

$$m_t^{IB} = \left( \frac{L_t^{IB,S}}{P_t} \right)^{\frac{1}{1-\alpha}} \tag{24}$$

In the case of $\Phi$=1 there is no cost arising from granting an interbank loan. Therefore, as will be shown in Figure 5, this gives a corner solution (vertical line) where interbank loans completely correspond to excess funds.

For the interbank-lender and the interbank-borrower the continuation values of bank profits are the following:

*Interbank-lender*

$$V_t^I = (R_t^{IB} - R_t^f)\frac{L_t^{IB,D}}{P_t} - (1-\Phi) w_t m_t^{IB} \tag{25}$$

The real supply for interbank loans, $\frac{L_t^{IB,S}}{P_t}$, is then

$$\frac{L_t^{IB,S}}{P_t} = \left[ \frac{(1-\alpha)(R_t^{IB} - R_t^p)}{(1-\Phi_t) w_t} \right]^{\frac{1-\alpha}{\alpha}}. \tag{26}$$

Hence interbank loan supply depends on the net revenue, $(R_t^{IB} - R_t^p)$, of the interbank loan, $L_t^{IB}$, and in case of distrust, $\Phi$<1, on the extra cost of monitoring in the interbank market.

*Interbank-borrower*

$$V_t^{II} = (R_t^L - R_t^{IB})\frac{L_t^{IB,D}}{P_t} - w_t m_t^{II} \tag{27}$$

[16]The approach links a standard "cash in advance "technology (see Clower (1967)) with elements of monetary economy with market trading structures (see Kiyotaki and Wright (1989); Lagos and Wright (2005)).

The interbank-borrower earns the net revenue $(R_t^L - R_t^{IB})$ and faces the (additional) loan monitoring cost $w_t m_t^{II}$, since the interbank-borrower uses the interbank loan to lend to households. We assume that borrowing banks do not need to hold reserves or capital against interbank balances. The demand for interbank loans $\frac{L_t^{IB,D}}{P_t}$ is given by

$$\frac{L_t^{IB,D}}{P_t} = \left[\frac{(1-\alpha)(R_t^L - R_t^{IB})}{w_t}\right]^{\frac{1-\alpha}{\alpha}} \tag{28}$$

The market equilibrium for the optimal loan from the interbank-lender to the interbank-borrower is

$$\frac{L_t^{IB}}{P_t} = \left[\frac{(1-\alpha)(R_t^L - R_t^p)}{(2-\Phi)w_t}\right]^{\frac{1-\alpha}{\alpha}} \tag{29}$$

By solving the interbank problem the condition on the interbank rate is

$$R_t^{IB} = R_t^P + \frac{1-\Phi}{2-\Phi}(R_t^L - R_t^p). \tag{30}$$

**Proposition 1** (Interbank lending shock)**.** *(a) In the absence of peer monitoring cost (*$\Phi$*=1), the interbank rate* $R_t^{IB}$ *equals the policy rate* $R_t^P$*. (b) A negative shock to* $\Phi$ *from an initial level of* $\Phi$*=1 creates, ceteris paribus, a spike in the interbank rate* $R_t^{IB}$ *versus the policy rate.*

The first result stems from the no arbitrage condition which equalizes different sources of funds of commercial banks taking into account that there are no liquidity and capital requirements for interbank loans. The second result follows immediately from equation (30) and affects adversely the volume of interbank loans $L_t^{IB}$.

Figure 5 shows the mechanisms in the interbank market. Demand by the borrowing bank $L_t^{IB,d}$ is downward sloping, while supply $L_t^{IB,s}$ upward sloping in $R_t^{IB}$. In the case of favorable conditions in the interbank market, i.e. $\Phi$=*1*, all supply clears ${L_t}^{IB}(\Phi{=}1)$ at ${R_t}^{IB}(\Phi{=}1)$. The supply curve for interbank loans $L_t^{IB,s}$ becomes vertical (or inelastic) at the point where all excess deposits are re-channeled. This is different under a shock scenario. As soon as the interbank lending shock pushes $\Phi$=1 to $\Phi$<1, inducing higher monitoring needs, the supply curve slopes upward more steeply. The interbank rate jumps ${R_t}^{IB}(\Phi{<}1)$[17] and the interbank

[17]Credit rationing as in Stiglitz and Weiss (1981) could further aggravate the cutback in interbank lending

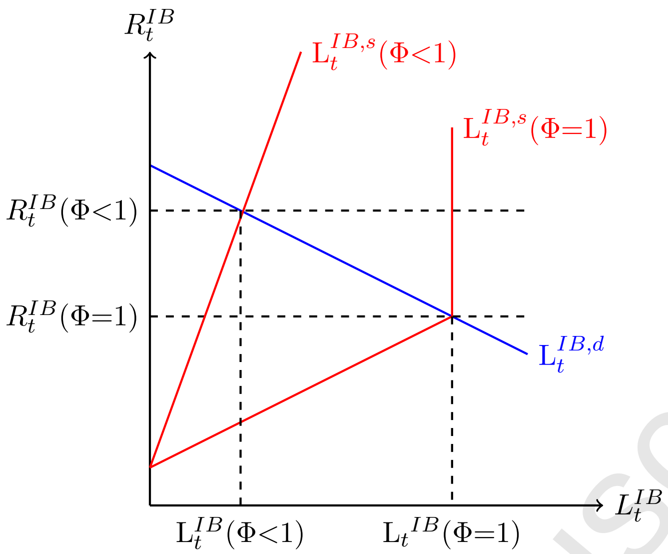


Figure 5: Impact of interbank lending shock

*Note:* $\Phi$=1 and $\Phi < 1$ denote the ease of refinancing in the interbank market, reflected by a low or high degree of interbank monitoring.

loans collapse $L_t^{IB}(\Phi<1)$.[18]

The spike in the interbank rate, $R_t^{IB}$, creates a wedge in comparison to the policy rate $R_t^P$. We now specify $A2_t$ as a shock to the interbank market. We assume that the shock $A2_t$ reflects a spike in the interbank rate given a lower trust level in the interbank market captured by a shift in the trust parameter from $\Phi$=1 to $\Phi$<1, weighted by the size of the interbank loans, which we denote by interbank finance premium ($IFP$).

$$A2_t = (\Delta_s IFP_s)_t \tag{31}$$

$s$ refers to the overnight transactions in which otherwise endogenous variables are constant. This implies for the funding costs of banks

$$R_t^f = R_t^D + (rr + \kappa\zeta)R_t^P + A2_t \tag{32}$$

The decline in loans following the disruptions in the interbank market is linked, through the

leading to a complete market freeze.

[18] Taylor and Williams (2009) and Gorton (2010) refer to the Libor-OIS spread to describe the breakdown of the US repo market in 2008, described in section 2. The equivalent measure for the Eurozone, the Euribor-EONIA spread reacted similarly in 2007-2008 and again in 2012, see Schuler (2014).

"money in advance"constraint, to the household optimality condition (equation 4), which gives after several substitutions and transformations

$$w_t = \frac{(1-\alpha)}{m_t}\left(\frac{1}{\lambda_t} - c_t - R_t^P\left(\frac{Res_t}{P_t} + \frac{\zeta e_t}{P_t}\right) - \frac{L_t}{P_t}A2_t\right). \tag{33}$$

A shock to the need for monitoring, which reduces the amount of refinancing in the interbank market, affects the external finance premium unfavorably.

**Proposition 2** (Decline in loans and EFP)**.** *An interbank lending shock propagates through a sharp reduction in interbank lending $L_t^{IB}$ followed by reduction in lending to households $L_t$. The external financing premium $R_t^L - R_t^f = \frac{vw_t m_t}{(1-\alpha)c_t}$ also falls.*

The total loans are reduced from the supply side

$$\frac{L_t}{P_t} = \frac{(L + \Delta_s L_s^{IB})_t}{P_t} \tag{34}$$

with $\Delta_s L_s^{IB}$ being the change in the size of interbank loans in the overnight market which gives

$$\frac{(L + \Delta_s L_s^{IB})_t}{P_t} = Q m_t^{1-\alpha} \tag{35}$$

or by substituting the term referring to the shock

$$\frac{L_t}{P_t} = Q m_t^{1-\alpha} + \frac{A2_t}{\epsilon_{IB}} \tag{36}$$

with $\epsilon_{IB}$ being the elasticity of the reaction of interbank loans after a spike in the interbank rate.[19] The external finance premium,

$$R_t^L - R_t^f = \frac{vw_t m_t}{(1-\alpha)c_t}, \tag{37}$$

falls with a rising refinancing rate $(R^f + \Delta_s IFP_s)_t$ for the spread (lhs) resulting in a reduction in overall monitoring work $m_t$ on the marginal cost side (rhs) in line with falling loans $L_t$.[20]

[19]This elasticity is assumed to be a constant value.

[20]This pattern reflects the empirical development of the loan spread as shown in Fig. 1.

### 3.4 Government

The government consists of the Treasury, the Central Bank and a regulatory authority.

**Treasury.** The fiscal authority follows a balanced budget rule. $B_t$ arises from past deficits. The Treasury takes a passive stance on the economy by solely collecting taxes for interest payments on outstanding bonds in each period.

$$tax_t - R_t^B B_t = 0 \tag{38}$$

Households purchase in $t$ and redeem in $t+1$ a share of government bonds, $(1-\gamma)B_t$. The remaining part, $\gamma B_t$, is used by commercial banks as a pure collateral in exchange for Central Bank liquidity.

**Central Bank.** The Central Bank provides reserves, $Res_t$, via refinancing operations to commercial banks against collateral, $\gamma B_t$, charging the policy rate $R_t^P$. The limit to Central Bank refinancing comes from the amount of marketable securities held by banks. In setting the policy rate, $R_t^P$, the Central Bank acts according to a Taylor (1993) rule targeting the inflation rate of $\pi$=0 and the stabilization of output changes $\hat{y}_t$.[21]

$$\hat{R}_t^P = (1-\rho)(\phi_\pi \pi_t + \phi_y \hat{y}_t) + \rho \hat{R}_{t-1}^P + a3_t, \tag{39}$$

where $\phi_\pi$ and $\phi_y$ are the weights assigned to inflation and to output, respectively, and $a3_t$ represents the exogenous shock to the interest rate which follows an autoregressive process given by $a3_t = \rho_3 \; a3_{t-1} + \epsilon_t^{(3)}$ with $|\rho_3| < 1$. The term $\rho \; \hat{R}_{t-1}^P$ refers to the interest rate smoothing of the policy rule.[22]

**Regulatory Authority.** The regulatory authority sets the liquidity requirement ratio, $rr$, a proxy for the LCR and NSFR, and the capital requirement ratio, $\kappa$, a proxy for the CRR. We demonstrate below how these instruments can potentially have strong effects on credit growth.

[21] We do not consider the inclusion of the output gap since, as also stressed by Galí (2008), this implicitly assumes observability of the latter variable. That assumption is unrealistic because determination of the output gap and its movements requires an exact knowledge of (i) the economy 'true model', (ii) the values taken by all its parameters, and (iii) the realized value (observed in real time) of all the real and financial shocks impinging on the economy.

[22] Taylor rule interest smoothing is assumed here. Micro-founded approaches which justify this as an optimal rule are based on money in utility function.

### 3.5 The Equilibrium

We consider rational expectations equilibria without aggregate uncertainty. By imposing market clearing in the labor and goods markets, the model can be solved for the equilibrium solution.

**Proposition 3** (Equilibrium)**.** *Households maximize their utility by choosing the sequences* { $c_t$, $l_t^s$, $m_t^s$, $B_t$, $L_t$ *. The intermediate firm i chooses optimal* $P_t^*$*, given its cost function with labor input* $\{l_t(i)\}$*. The retail firm provides* $\{y_t\}$ *through a cost-minimal combination of intermediate goods* $y_t(i)$*. Commercial banks maximize profits by lending to households* $\{L_t\}$*, by receiving funds in the form of deposits* $\{D_t\}$*, and trade excess funds in the interbank market* $\{L_t^{IB}\}$*. Markets clear in each period t, i.e. for output* $y_t$=$c_t$*, bond holdings of the households and the Central Bank sum to total government bonds* $\gamma$ $B_t$*+(1-*$\gamma$*)*$B_t$*=*$B_t$*, and labor markets clear, i.e.* $l_t^s$=$l_t$*,* $m_t^s$=$m_t$*.*

Upon log-linearizing and combining the relevant equilibrium conditions, we obtain a system of equations which characterize the dynamics of the economy in the neighborhood of the efficient, non-stochastic steady state. There are four forcing variables: productivity shocks $a1_t$, interbank lending shocks $a2_t$, and monetary shocks $a3_t$. We list below the main approximate equilibrium conditions, the remaining ones are relegated to Appendix D.

*Output and Monitoring demand*

$\hat{y}_t$= (1-$\eta$)$_t$ + $a1_t$

$\hat{c}_t$ = (1-$\alpha$)$\hat{m}_t$+ $a2_t$

*Factor prices and quantities.*

$\hat{\lambda}_t+\hat{w}_t=\frac{l}{1-l-m}\hat{l}_t + \frac{m}{1-l-m}\hat{m}_t$

$\hat{w}_t$=-$\eta_t$+ a$1_t$

$\hat{w}_t+\hat{m}_t$ - (1-$\alpha$)($c_t$ +$\frac{1}{\lambda}$ $\hat{\lambda}_t$ +$R^P$Res($\hat{R}_t^P+\widehat{Res}_t$)+$\zeta$ $R^P$e($\hat{R}_t^P+\hat{e}_t$)+L $a2_t$=0

*Price inflation.*

$$\hat{\pi}_t = \beta E_t\{\hat{\pi}_{t+1}\} + \vartheta\widehat{mc_t}$$

with $\vartheta = \frac{(1-\theta)(1-\beta\theta)}{\theta}\frac{1-\eta}{1-\eta+\eta\epsilon}$

*Monetary policy rule.*

$$\hat{R}^P_t = (1\text{-}\rho)(\phi_\pi\hat{\pi}_t + \phi_y\hat{y}_t) + \rho\hat{R}^P_{t-1} + a3_t$$

*Return on equity.*

$$\hat{R}^e_t = \zeta\hat{R}^P_t$$

*Refinancing costs.*

$$\hat{R}^f_t = \hat{R}^D_t + (rr + \kappa\zeta)\hat{R}^P_t + a2_t$$

## 4 Calibration

The model is calibrated to quarterly frequencies matching endogenous aggregates and interest rates to observable data. We assume zero average inflation. The household discount factor $\beta$ is set to 0.99 implying an annual real rate of interest of 4% for the riskless bond rate $R^B$. The share of intermediate firms which cannot reset their price in a given period is $\theta$=0.77. The Dixit-Stiglitz parameter $\epsilon$ is set to 6 generating a mark-up of 20%.

Table 3: Benchmark calibration.

| **Calibrated Parameter** | | |
|---|---|---|
| $\beta$ | discount factor | 0.99 |
| $\eta$ | concavity in production | 0.35 |
| $\alpha$ | concavity in loan management | 0.65 |
| $\phi$ | weight of leisure in utility | 0.65 |
| $\epsilon$ | Dixit-Stiglitz parameter | 6 |
| $rr$ | reserve ratio | 0.1 |
| $\kappa$ | equity requirement | 0.08 |
| $Q$ | bank loan management quality | 20 |
| $v$ | velocity of money | 0.25 |
| $\theta$ | share of firms without price reset | 0.77 |
| $\phi_\pi$ | weight of inflation in policy function | 1.62 |
| $\phi_y$ | weight of output in policy function | 0.96 |
| $\phi_{R^{IB}_t - R^P_t}$ | weight of interbank spread in policy function | 0.5 |
| $\rho$ | smoothing in policy function | 0.25 |
| $\Phi$ | trust in between banks | 1 |

*Note:* The deep parameters are described in section 4.

The liquidity ratio is set to $rr$=10% measured as total bank reserves to total deposits from

Table 4: Implied Steady States.

| **Implied Steady State** | | |
|---|---|---|
| $l$ | steady state labor | 0.49 |
| $m$ | steady state monitoring | 0.01 |
| $w$ | steady state wage | 0.83 |
| $c$ | steady state consumption | 1.5 |
| $\lambda$ | steady state Lagrange multiplier | 1.96 |
| $Res$ | steady state reserves | 0.6 |
| $L$ | steady state loans | 5.4 |
| $D$ | steady state deposits | 5.6 |
| $B$ | steady state bonds | 3.6 |
| $e$ | steady state equity | 0.4 |
| **Interest Rate** | | |
| $R^P$ | policy rate | 1.00 % |
| $R^L$ | loan rate | 1.60 % |
| $R^D$ | deposit rate | 0.97 % |
| $R^B$ | bond rate | 1.00 % |
| $R^e$ | return on equity | 3.50 % |
| $EFP$ | external finance premium | 0.60 % |

*Note: The steady-states have been derived by solving the set of simultaneous equations.*

2000-2005 and the velocity of money $v$ is set to 0.25 on the basis of average GDP to M3 for the same period. The capital requirement ratio $\kappa$ is set to 8%. For further experimentation we change $rr$ to 20% and $\kappa$ to 15%.

We assume a coefficient of $\eta$ equal to 0.35 for the concavity of the production function of the intermediate product; for loan management we choose a coefficient of $\alpha$ equal to 0.65. We set total labor supplied in steady state to 1/2 of hours, similar to Goodfriend and McCallum (2007).

Table 5: Calibration of exogenous shocks.

| **Description of shock** | | Persistence | Volatility |
|---|---|---|---|
| a1 | productivity | $\rho_1 = 0.95$ | $\sigma_1 = 0.72\%$ |
| a2 | monetary policy | $\rho_2 = 0.3$ | $\sigma_2 = 0.82\%$ |
| a3 | interbank lending | $\rho_3 = 0.9$ | $\sigma_3 = 0.90\%$ |

*Note: See Chadha and Corrado (2012) for productivity and monetary shock. The parameters for the interbank lending shock are own specifications.*

The share of working time devoted to banking services is 2%. This implies that a share of 49% of total time is in the production sector and 1% in the banking sector.

Following Gerali *et al.* (2010) we calibrate the banking parameters to replicate data averages for commercial bank interest rates and spreads. We choose an average annual spread between the rate on retail deposits, $R^D$, and the overnight rate, $R^P$, of 125 basis points. The external finance premium (EFP) represents the loan rate markup over the policy rate which is 0.6%. Return on bank equity $R^e$ is set to 3.5% quarterly rate, in line with empirical averages.

The technology shocks are assumed to be quite persistent, with a standard deviation of $\sigma_1=$ 0.72% and an autoregressive parameter of $\rho_1 = 0.95$. The shock to the policy rate has a standard deviation $\sigma_2= 0.82\%, andanautoregressiveparameterof \rho_2 = 0.3$, and for the interbank shock we assume $\sigma_3= 0.9\% and \rho_3 = 0.9$, respectively. Shocks to the TFP have a relatively prolonged effect on macroeconomic variables, while a monetary policy shock rapidly dies out and the economy reaches again the steady state. The interbank shock is modeled as being somewhat persistent due to its effects on loan creation. Monetary policy coefficients on inflation and the output are 1.62 and 0.96, respectively as in Soederlind *et al.* (2002). The coefficient on the spread between the interbank and the policy rate is set to 0.5. The rest of the parameters, implied steady states and interest rates used in the calibration are given in Tables 3-5.[23]

## 5 Quantitative Results

In this section we perform a quantitative simulation for the model with a bank lending channel and a forward looking pricing equation in a linearized setup. We study the impulse response functions under an interbank lending shock.[24] The interbank lending shock increases overall refinancing cost lowering the external finance premium which detrimentally affects loan supply. Inflation falls, hence inducing a reduction in interest rates. Lower availability of transaction money, $D_t$, subsequently leads to a decline in consumption. In this scenario we perform four policy experiments: 1) raising the liquidity requirement for banks and 2) raising the capital adequacy requirement, as well as introducing an augmented Taylor rule into 3) a setup with a liquidity requirement only and 4) a specification with an additional capital adequacy requirement.



[23]For the full solution for the steady state values please refer to the Appendix C.
[24]The quantitative exercise is performed with the King and Watson (1998) solution algorithm.

### 5.1 Liquidity Requirement

We first perform the analysis of the effects of a change in the liquidity requirement under the interbank shock scenario. In order to introduce the impulse response for the interbank shock we briefly describe the mechanics for the liquidity ratio of 10% (black IRFs) in Figure 6. The interbank shock adversely affects loans, monitoring work and the EFP, which is equivalent to the loan spread described in section 2. Mainly due to a fall in deposits, inflation is pushed down and, as a result of lower consumption, labor and real wages contract. The Central Bank acts according the Taylor rule and lowers the policy rate, which in turn pushes the loan rate and the bond rate down.

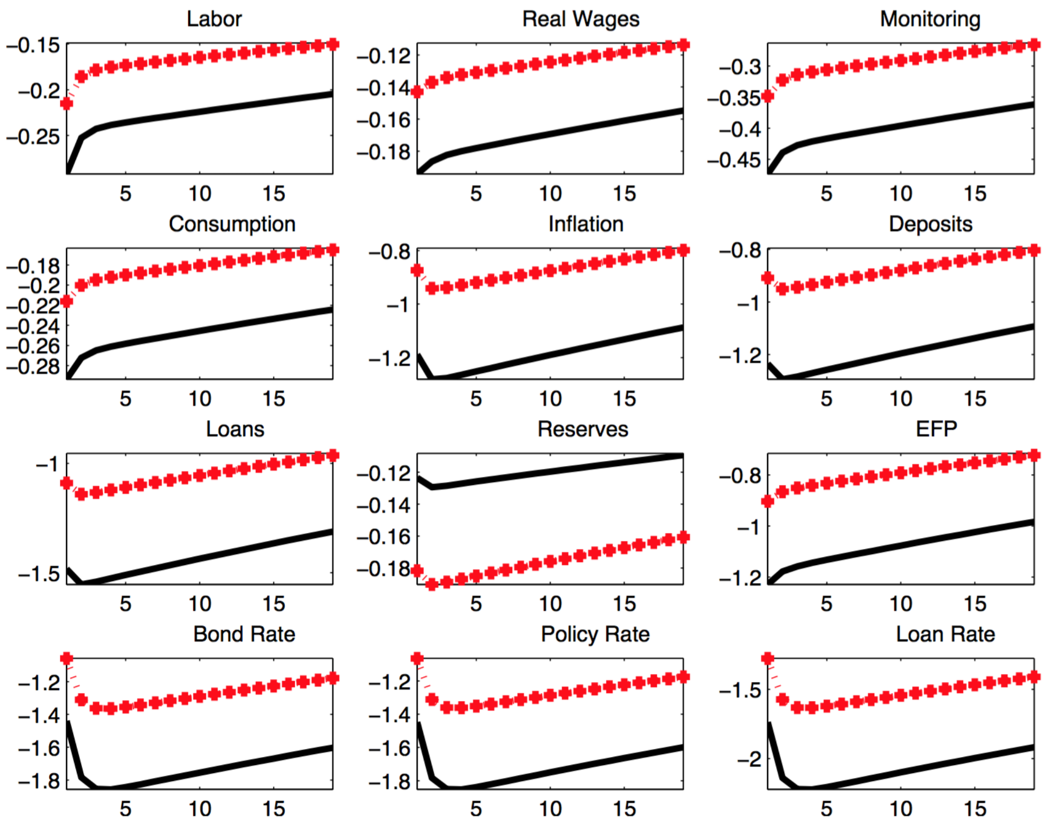


Figure 6: Impulse response from 1% shock to interbank rate under 10% (black) and 20% (red) liquidity ratio.
*Note:* All interest rates are shown as absolute deviations from the steady state, expressed in percentage points. All other variables are percentage points deviations from the implied steady state value.

We now compare the impulse response for a ratio of 10% (black) of reserves in relation to deposits with a ratio of 20% (red). The change in the liquidity requirement is a stylized way to model the Liquidity Coverage Ratio and the Net Stable Funding Ratio from the regulatory framework Basel III. We see in the impulse response that both financial and real variables are affected by an increase in the liquidity ratio from 10% to 20%. The impact of the interbank lending shock is reduced significantly by raising the liquidity held in the commercial banks' balance sheets.

## 5.2 Capital Adequacy Requirement

Secondly, we study the effects of a change in the capital adequacy ratio under the interbank shock scenario. As shown in Figure 7, we start with a value of 8% bank equity in relation to the commercial loan portfolio (red), and compare it to the impulse response under 15% (black).

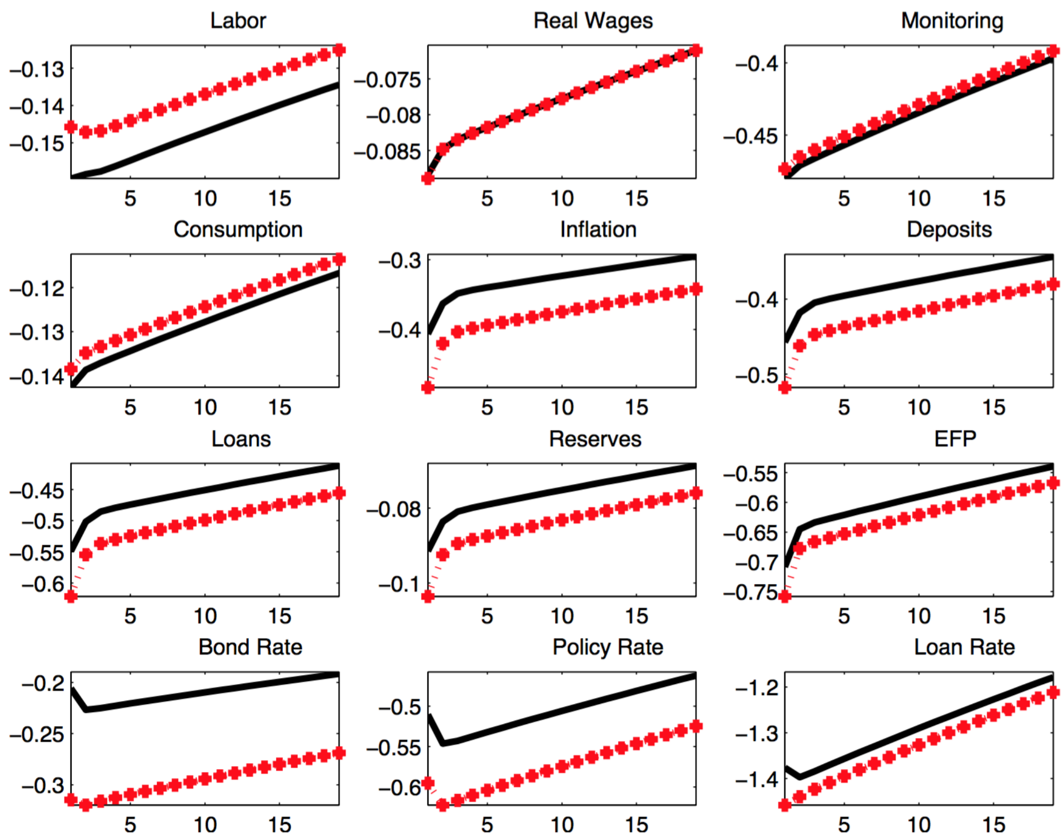


Figure 7: Impulse response from 1% shock to interbank rate under 20% liquidity ratio for 8% (red) and 15% (black) equity ratio.
*Note:* All interest rates are shown as absolute deviations from the steady state, expressed in percentage points. All other variables are percentage points deviations from the implied steady state value.

First, we notice that introducing capital requirements into the setup has a general dampening effect on the reactions of the simulated macroeconomic variables. Bank capital acts as a shock absorber via falling interest rates for the return on equity, as this rate follows the declining pattern of the policy rate. We find that the effects on the financial variables, especially on interest rates, are comparable to the reaction after a change in the liquidity ratio. The required reaction of the Central Bank is less severe, indicating that a higher CRR is a buffer against a scenario in which the Central Bank hits the zero lower bound.

However, we see barely any effects on real variables from increasing the capital requirement: consumption, labor and wages are only marginally affected by a variation in the equity requirement for banks. This leads us to conclude that while equity requirements improve financial stability, there is little effect of a higher CRR on the general economy.

### 5.3 Taylor rule reacting to an Interbank Shock

Spread-adjusted Taylor rules reflect the idea that the policy rate should be lowered when credit spreads increase, so as to prevent dampening effect of these spreads on the economy. We essentially follow the proposal of McCulley and Toloui (2008) and Taylor (2008), except that we consider the possible advantages of a spread adjustment that is less than the size of the increase in credit spreads i.e. $\phi_{R^{IB}-R^{P}}$ less than one as in Curdia and Woodford (2010). We show how a spread-adjusted Taylor rule and canonical Taylor rule perform under different macro-prudential policy scenarios.

A Taylor rule reacting to the interbank spread would induce a stronger reaction in the interest rate policy implement by the Central Bank. We use an augmented rule which takes the following form:

$$R_t^P = \phi_\pi \pi_t + \phi_y \hat{y}_t - \phi_{R^{IB}-R^{P}}(R_t^{IB} - R_t^P).$$

We analyze how the Central Bank reacts after an interbank shock. We assign a feedback parameter on the interbank spread in the policy rule of $\phi_{R^{IB}-R^{P}}$=0.5.

Figure 8 shows the impulse response from a 1% shock to the interbank rate under a 10% liquidity ratio. We consider no direct policy reaction to the interbank spread (black) and a policy reaction to the interbank spread (red). We see that with an augmented policy reaction function the policy rate drops by 1.1 percentage points (as in the case of liquidity requirement of 10%). The effects on real variables are also dampened. We can argue that during an interbank shock the policy rate should be used more aggressively as an instrument. However, the real effects of the policy rate are stronger under higher liquidity buffers. By imposing a higher liquidity requirement the Central Bank obtains more room to maneuver to implement a rule reacting to spread. This would be important when the policy rate reaches the zero lower bound.

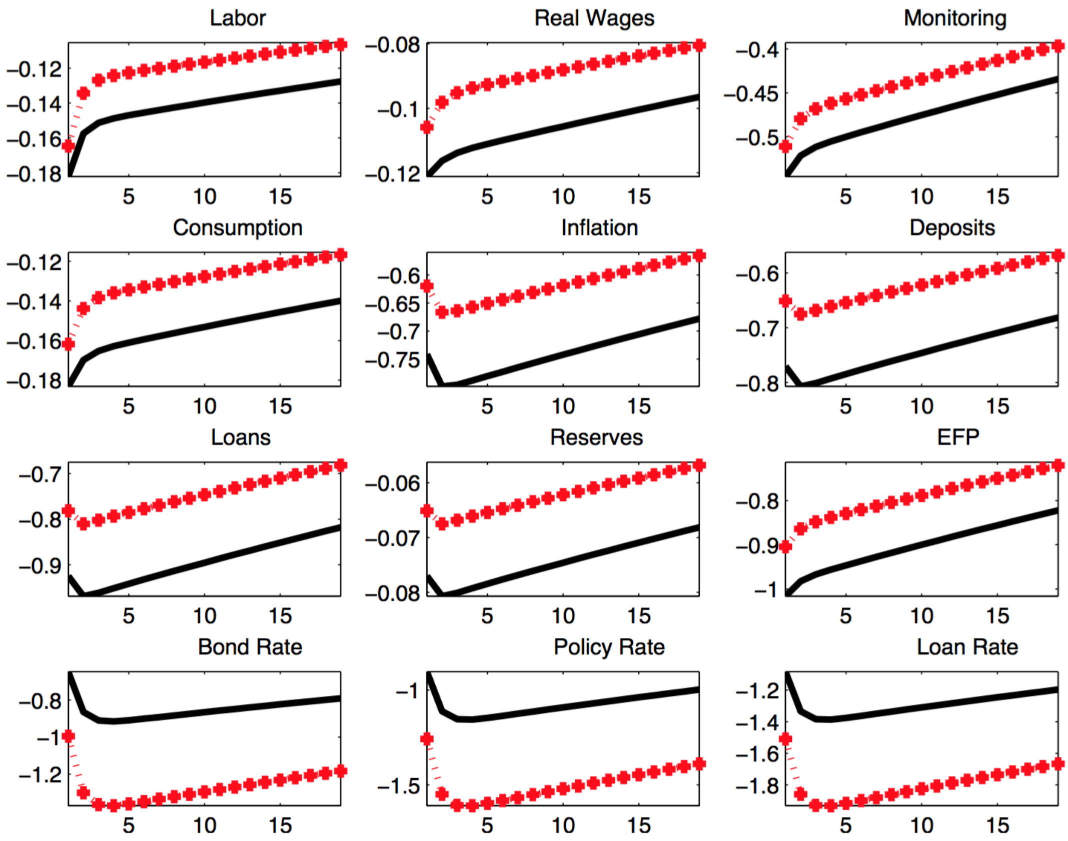


Figure 8: Impulse response from 1% shock to interbank rate under 10% liquidity ratio with 1) no direct policy reaction to the interbank spread (black) and 2) policy reaction to the interbank spread (red).
*Note:* All interest rates are shown as absolute deviations from the steady state, expressed in percentage points. All other variables are percentage points deviations from the implied steady state value.

Finally, the impulse response with the combination of the CRR and the Taylor rule reacting to the interbank shock is shown in Figure 9. Following an interbank shock the policy instrument reacts more pronouncedly with the augmented rule (black) than in the case of the canonical rule (red, corresponding to the red IRFs in Figure 7). We see that the augmented rule has stronger effects by, to a large extent, preventing the shock in the interbank market to spill over to loan provision, the loan rate and EFP.

The effects on the non-financial sectors are different as well. Firms' marginal costs rise given the reduction in consumption and a dampened reduction of real wages. This pushes inflation back to zero. Together with the, albeit smaller, decrease in transaction deposits this leads to minor improvements in the consumption response.

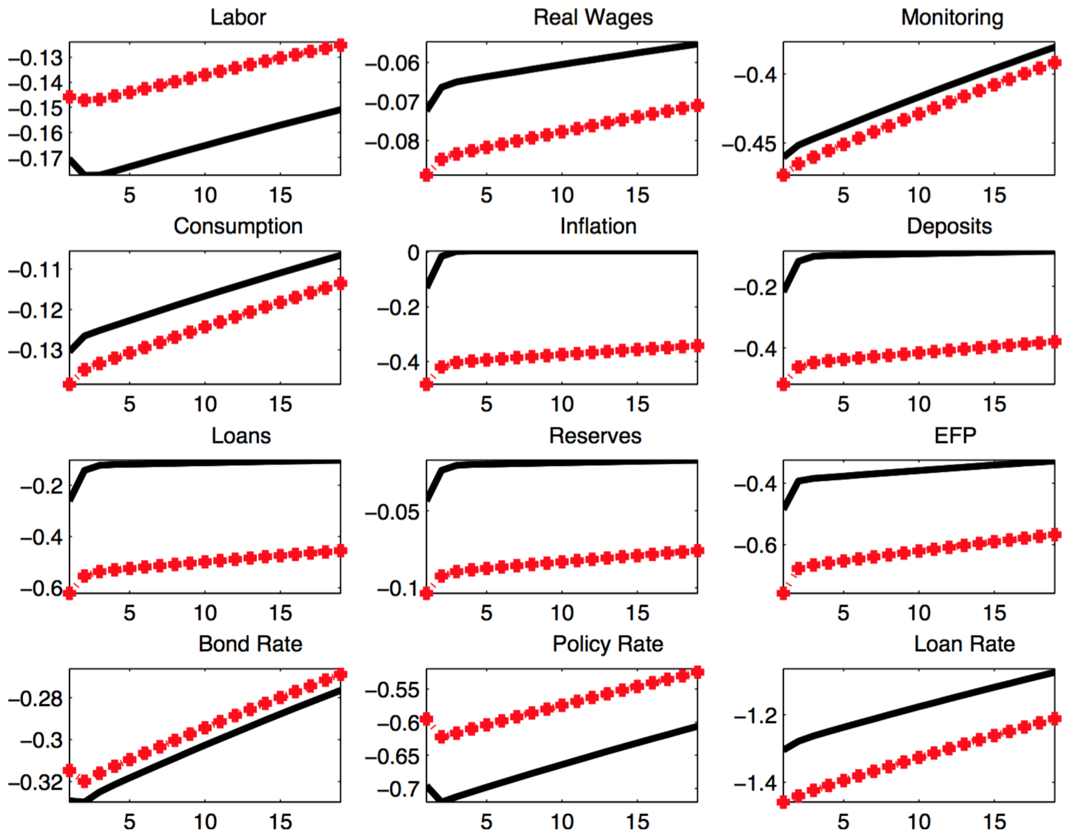


Figure 9: Impulse response from 1% shock to interbank rate under 20% liquidity ratio and a 8% capital requirement ratio with 1) no direct policy reaction to the interbank spread (red) and 2) policy reaction to the interbank spread (black).
*Note:* All interest rates are shown as absolute deviations from the steady state, expressed in percentage points. All other variables are percentage points deviations from the implied steady state value.

## 6 Simulation

Simulating business cycles in this model economy with productivity, interbank, equity rate and monetary policy shocks provides insights on the role of having a capital requirement along with a liquidity ratio and their impact on the economy. For the simulation we employ the baseline setup with the canonical Taylor rule. A comparison between a simulation for this model economy with and without a capital adequacy requirement is shown in Figure 10.

The introduction of an equity requirement aligns the movement of inflation to the change

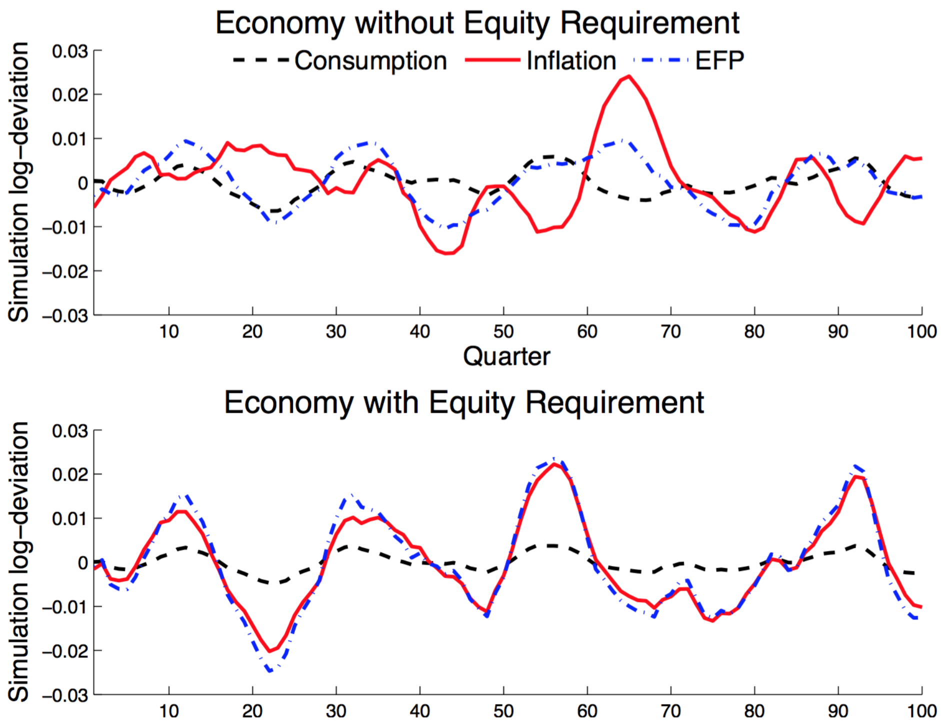


Figure 10: Long-run simulation without and with a capital requirement.
*Note: HP-filtered, two-year moving average series. The first chart reflects the liquidity requirement only, whilst the second reflects both the liquidity requirement and the capital requirement together.*

in the external finance premium. As the Central Bank reacts to inflation and output, this translates into a change in the return on equity. Therefore the capital requirement has a role as a shock absorber as return on equity co-moves together with the policy rate.

The simulation illustrates the procyclicality of the capital requirement in an economy with banking shocks. This result has already been found in other studies, as in Goodhart *et al.* (2004), Saurina and Trucharte (2007), and Repullo *et al.* (2009). In our setup procyclicality comes through the alignment of the EFP with the Central Bank's interest rate policy. Thus the attenuator effect as described in Goodfriend and McCallum (2007), is dominated by a procyclical (or accelerator) effect.

### 6.1 Impact of higher capital requirement on model moments

Table 6 shows a comparison of the effect of varying the CRR. The correlations are defined with respect to output. By increasing the capital requirement, loans and the loan rate become more correlated with output. This procyclicality arises from the link between the return on equity and the external finance premium (EFP). In general, by increasing the CRR, volatility is added to the banking sector reflected by higher standard deviation for the loan rate. This translates into lower overall welfare as will be shown in the following section.

Table 6: Model Moments under low and high CRR

| | Low Capital Requirement | | High Capital Requirement | |
|---|---|---|---|---|
| | S.D. | Corr. | S.D. | Corr. |
| Consumption | 0.0040 | 1.0000 | 0.0039 | 1.0000 |
| Inflation | 0.0150 | 0.7824 | 0.0143 | 0.8021 |
| EFP | 0.0192 | 0.9396 | 0.0188 | 0.9490 |
| Loans | 0.0192 | 0.8584 | 0.0186 | 0.8738 |

*Note: Low CRR (8%) and high CRR (15%) is studied under a liquidity requirement of 20%. Moments are calculated on the basis of simulated Hodrick-Prescott filtered time series. S.D. denotes the standard deviation, Corr. denotes the contemporaneous cross correlation with consumption.*

## 6.2 Welfare

We perform a second order approximation to welfare along the lines of Rotemberg and Woodford (1998). Welfare can be represented by changes in the volatility of the output gap and inflation changes as follows:

$$W = E_0 \sum_{t=0}^{\infty} \beta^t (U_t - U) = -\frac{1}{2} E_0 \sum_{t=0}^{\infty} \beta^t \left[ \varphi \tilde{y}_t^2 + \varpi \pi_t^2 \right] + t.i.p. \tag{40}$$

with $\varphi = (1 + \phi\nu^2 + \phi\mu^2)$ and $\varpi = \frac{\phi\epsilon}{\Theta\lambda}$, calculated based on parameter values and steady state values of the variables, i.e. $\nu = \frac{l^s}{(1-l^s-m^s)(1-\eta)}$ and $\mu = \frac{m^s}{(1-l^s-m^s)(1-\alpha)}$.

The output gap is defined as

$$\tilde{y}_t \equiv \hat{y}_t - \widehat{y_t^n}, \tag{41}$$

i.e. changes in output relative to the natural rate of output. The natural rate of output reads as

$$\widehat{y_t^n} = \frac{1}{(\Omega + O)(1-\eta)} a1_t + \frac{\alpha}{(\Omega + O)(1-\alpha)} a2_t. \tag{42}$$

The terms $\Omega$ and $O$ depend on parameters only.[25] The welfare function can be expressed in terms of a quadratic loss function

$$\mathfrak{L}_t = \varphi\sigma_{\tilde{y}}^2 + \varpi\sigma_{\pi}^2, \tag{43}$$

with $\sigma_{\tilde{y}}^2$ being the output gap variance and $\sigma_{\pi}^2$ the volatility of inflation.

We compare welfare in the case of various values for LCR and CRR under a canonical Taylor rule and a Taylor rule responding to the interbank spread. Table 7 presents the estimations of the absolute welfare loss measures.

Table 7: Welfare loss comparison for LCR and CRR

| | Canonical Taylor Rule | Augmented Taylor Rule |
|---|---|---|
| LCR 10%, CRR= 0% | 4.0359 | 4.0322 |
| LCR 20%, CRR= 0% | 4.0185 | 4.0160 |
| LCR 20%, CRR= 8% | 2.3483 | 2.3481 |
| LCR 20%, CRR=15% | 3.5107 | 3.5103 |

*Notes: The table shows the loss from the welfare approximation for LCR=10% and LCR=20% with CRR= 0% vs. CRR = 8% and CRR = 15% under the canonical Taylor rule and the augmented Taylor rule responding to the interbank spread. Values are multiplied up by a factor 100.*



We found above that a capital ratio increase does not affect real variables as much as does an increased liquidity ratio. However, the presence of a capital requirement reduces volatility in the economy leading to a lower loss in welfare. From this we conclude that liquidity related measures and capital related measures can act complementarily in case of shocks to interbank lending conditions. In Table 7 we see that the augmented rule does little to improve welfare. Overall, the best welfare value is achieved with a high liquidity ratio and a moderate capital requirement ratio.

With regard to the policy rate as a macro-prudential instrument McLeay et al. (2014) argue that monetary policy can have a significant effect on the quantity of credit and money through the interest rate. As with the standard Taylor rule monetary policy controls inflation and output fluctuations, whereas the influence on the growth of credit and money tends to be insignificant. For Europe, Altunbas et. al (2009) find in an empirical study that there is only a

[25]See Appendix E for the complete welfare derivation.

weak and incidental effect of the interest rate instrument on credit and money growth. Instead, as shown above, liquidity requirements and regulatory capital affect the banks incentives to lend in a much more targeted fashion than the policy rate.

# 7 Conclusion

We have developed a model to study how changes in macro-prudential policy measures affect loan and deposit creation, inflation and interest rates, as well as real variables such as consumption, employment and wages. We take a modeling approach which gives a structural role to the interbank market and find supporting evidence for some stylized facts, in particular in the period of the recent financial crisis. Especially, we confirm that a shock to the interbank spread can explain short-to-medium term variations in the loan spread, CPI, output and monetary policy rate. Based on these insights we compare the performance of several macro-prudential and Central Bank policies. We find that an increase in the liquidity measure, LCR and the NSFR, effectively reduces the impact of an interbank shock on output and employment, while an increased capital requirement propagates only through financial variables as inflation and interest rates. For an augmented policy rule which reacts towards the spread in the interbank market we do not find supporting evidence with regard to welfare.

We conclude that stricter liquidity measures which limit inside money creation, can mitigate the severity of a breakdown in interbank lending. Targeting interbank financing directly through liquidity measures along with a capital requirement generates lower welfare losses. We thereby provide a comprehensive rationale in favor of the regulatory measures in Basel III.

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# A Variables

Table 8: Notation

| Variable | Description | Variable | Description |
|---|---|---|---|
| $y$ | Output | $\lambda$ | Lagrange multiplier |
| $c$ | Consumption | $mc$ | Marginal cost |
| $l^s$ | Labor supply | $L$ | Loan |
| $l$ | Labor demand | $D$ | Deposit |
| $m^s$ | Monitoring supply | $B$ | Bonds |
| $m$ | Monitoring demand | $e$ | Bank equity |
| $w$ | Wages | $a1$ | Productivity shock |
| $R^P$ | Policy rate | $a2$ | Interbank shock |
| $R^L$ | Loan rate | $a3$ | Policy rate shock |
| $R^D$ | Deposit rate | | |
| $R^f$ | Bank financing rate | | |
| $R^B$ | Bond rate | | |
| $R^e$ | Return on equity | | |

# B Equilibrium Conditions

## B.1 F.O.C. of Bank Monitoring Work Demand

The bank profit function is given by[26]

$$\Pi_t^B = \left(R_t^L - R_t^f\right)\frac{L_t}{P_t} - w_t m_t. \tag{B.1}$$

The representative bank choosing optimal monitoring work demand $m_t$ yields the following optimality condition

$$R_t^L - R_t^f = w_t / \frac{\partial L_t/P_t}{\partial m_t}, \tag{B.2}$$

which equates the marginal product of loan management with its marginal cost. Loan production technology is $L_t/P_t = Qm_t^{1-\alpha}$, which in turn gives

$$\frac{\partial L_t/P_t}{\partial m_t} = m_t^{-1}(1-\alpha)L_t/P_t, \tag{B.3}$$

[26]Abstracting from the interbank solution and leaving out the shock to loan provision in the production technology for the derivation.

and, by the "money in advance"constraint, $c_t = vL_t/P_t$, we have

$$R_t^L - R_t^f = \frac{vw_t m_t}{(1-\alpha)c_t}. \tag{B.4}$$

## B.2 F.O.C. of Household Bank Services Demand

The representative household choosing the optimal demand for loan management activities $m_t$ has to satisfy the following first order condition:

$$\frac{\partial logc_t}{\partial m_t} = \lambda_t \frac{\partial c_t}{\partial m_t} + \lambda_t \frac{\partial L_t/P_t}{\partial m_t}(R_t^L - R_t^D) \tag{B.5}$$

Substituting for the loan management technology

$$\frac{L_t}{P_t} = Qm_t^{1-\alpha}. \tag{B.6}$$

and by the "money in advance" constraint

$$c_t = vQm_t^{1-\alpha} \tag{B.7}$$

Thus

$$\frac{\partial logvQm_t^{1-\alpha}}{\partial m_t} = \lambda_t \frac{\partial vQm_t^{1-\alpha}}{\partial m_t} + \lambda_t \frac{\partial Qm_t^{1-\alpha}/P_t}{\partial m_t}\left(R_t^L - R_t^D)\right) \tag{B.8}$$

Taking the partial derivatives gives:

$$\frac{(1-\alpha)}{m_t}\left(1 - \lambda_t c_t - \lambda_t \frac{L_t}{P_t}(R_t^L - R_t^D)\right) = 0. \tag{B.9}$$

## B.3 Interbank Lending Shock

The shock to the interbank rate affects the refinancing rate, thus

$$R_t^f = R_t^D + (rr + \kappa\zeta)R_t^P + A2_t. \tag{B.10}$$

From the household first-order condition we get

$$\frac{(1-\alpha)}{m_t}\left(\frac{1}{\lambda_t} - c_t - \frac{L_t}{P_t}\left(R_t^L - R_t^D\right)\right) = 0. \tag{B.11}$$

The External Finance Premium is given by

$$R_t^L - R_t^f = \frac{vw_t m_t}{(1-\alpha)c_t}. \tag{B.12}$$

Inserting the expression for $R_t^f$ into condition for EFP

$$R_t^L - (R_t^D + (rr + \kappa\zeta)R_t^P + A2_t) = \frac{vw_t m_t}{(1-\alpha)c_t} \tag{B.13}$$

Rearranging

$$R_t^L - R_t^D = \frac{vw_t m_t}{(1-\alpha)c_t} + (rr + \kappa\zeta)R_t^P + A2_t \tag{B.14}$$

Combining with the FOC

$$\frac{(1-\alpha)}{m_t}\left(\frac{1}{\lambda_t} - c_t - \frac{L_t}{P_t}\left[\frac{vw_t m_t}{(1-\alpha)c_t} + (rr + \kappa\zeta)R_t^P + A2_t\right]\right) = 0. \tag{B.15}$$

First, multiplying out the EFP and by the money in advance we have

$$\frac{(1-\alpha)}{m_t}\frac{L_t}{P_t}\frac{vw_t m_t}{(1-\alpha)c_t} = \frac{L_t}{P_t}\frac{vw_t}{c_t} = w_t \tag{B.16}$$

Second, multiplying out terms with $R_t^p$ in square brackets

$$\frac{L_t}{P_t}(rr + \kappa\zeta)R_t^P = R_t^P\left(\frac{Res_t}{P_t} + \frac{\zeta e_t}{P_t}\right) \tag{B.17}$$

and finally, moving $w_t$ to the lhs

$$w_t = \frac{(1-\alpha)}{m_t}\left(\frac{1}{\lambda_t} - c_t - R_t^P\left(\frac{Res_t}{P_t} + \frac{\zeta e_t}{P_t}\right) - \frac{L_t}{P_t}A2_t\right). \tag{B.18}$$

## C Steady States

In the steady state, there is no technological progress, i.e. $A1_t$=$A1$=1, and no price change, i.e. $P_t$=$P$=1. Given these assumptions, the steady state equilibrium is the following system of 11 equations [(C.1) - (C.11)] plus 2 conditions imposed on variables and 13 unknowns:

Supply of labor:

$$w\lambda = \frac{\phi}{1 - l - m} \tag{C.1}$$

Demand for production labor:

$$w = (1 - \eta)l^{-\eta} \tag{C.2}$$

Demand for monitoring work:

$$\frac{(1-\alpha)}{m}\left(\frac{1}{\lambda} - c - R^P Res - \zeta R^P e\right) = w \tag{C.3}$$

Money in advance constraint:

$$c = vD \tag{C.4}$$

Loan production:

$$L = Qm^{1-\alpha} \tag{C.5}$$

Bond rate:

$$1 + R^B = 1/\beta \tag{C.6}$$

External finance premium:

$$EFP = \frac{vmw}{(1-\alpha)c} \tag{C.7}$$

Loan rate:

$$R^L = R^f + EFP \tag{C.8}$$

Deposit rate:

$$R^D = R^P(1 - rr) \tag{C.9}$$

Equity rate:

$$R^e = \zeta R^P \tag{C.10}$$

Refinancing rate:

$$R^f = R^D + (rr + \kappa\zeta)R^P \tag{C.11}$$

## D Linearized Model

Let $\hat{x}$ denote the deviation of a variable x from its steady state. The model then can be reduced to the following linearized system of equations:

Supply of production and monitoring labor:

$$\hat{\lambda}_t + \hat{w}_t = \frac{l}{1-l-m}\hat{l}_t + \frac{m}{1-l-m}\hat{m}_t \tag{D.1}$$

Demand for production labor:

$$\hat{w}_t = -\eta\hat{l}_t + a1_t \tag{D.2}$$

Monitoring demand:

$$\hat{w}_t + \hat{m}_t - (1-\alpha)\left(c\hat{c}_t + \frac{1}{\lambda}\hat{\lambda}_t + R^P Res(\hat{R}^P_t + \widehat{Res}_t) + \zeta R^P e(\hat{R}^P_t + \widehat{e}_t) + La2_t\right) = 0 \tag{D.3}$$

Production:

$$\hat{c}_t = (1-\eta)\hat{l}_t + a1_t \tag{D.4}$$

Supply of banking services:

$$\hat{c}_t = (1-\alpha)\hat{m}_t + a2_t \tag{D.5}$$

Money in advance constraint:

$$\hat{c}_t + \hat{P}_t = \hat{D}_t \tag{D.6}$$

Inflation:

$$\hat{\pi}_t = \hat{P}_t - \hat{P}_{t-1} \tag{D.7}$$

Calvo (1983) pricing:

$$\hat{\pi}_t = \beta E_t\{\hat{\pi}_{t+1}\} + \vartheta\widehat{mc_t} \tag{D.8}$$

with $\vartheta = \frac{(1-\theta)(1-\beta\theta)}{\theta}\frac{1-\eta}{1-\eta+\eta\epsilon}$

Marginal cost:

$$\widehat{mc_t} = \hat{w}_t - \frac{1}{1-\eta}(\eta\hat{c}_t) + (1-\eta)\hat{l}_t \tag{D.9}$$

Bond holding:

$$\hat{B}_t = 0 \tag{D.10}$$

Reserves:

$$\widehat{Res}_t = rr\hat{D}_t \tag{D.11}$$

Loans:

$$\hat{L}_t = (1 - rr)\hat{D}_t \tag{D.12}$$

Equity:

$$\hat{e}_t = \kappa \hat{L}_t \tag{D.13}$$

Bond rate:

$$\hat{R}_t^B = \hat{\pi}_t + \hat{\lambda}_t - E_t\{\hat{\lambda}_{t+1}\} \tag{D.14}$$

External finance premium:

$$\widehat{EFP}_t = \hat{m}_t + \hat{w}_t - \hat{c}_t \tag{D.15}$$

Loan rate:

$$\hat{R}_t^L = \hat{R}_t^f + \widehat{EFP}_t \tag{D.16}$$

Deposit rate:

$$\hat{R}_t^D = (1 - rr)\hat{R}_t^P \tag{D.17}$$

Policy feedback rule:

$$\hat{R}_t^P = (1 - \rho)(\phi_\pi \hat{\pi}_t + \phi_c \hat{c}_t) + \rho \hat{R}_{t-1}^P + a3_t. \tag{D.18}$$

Equity rate:

$$\hat{R}_t^e = \psi \hat{R}_t^P \tag{D.19}$$

Refinancing rate

$$\hat{R}_t^f = \hat{R}_t^D + (rr + \kappa\zeta)\hat{R}_t^P + a2_t \tag{D.20}$$

The benchmark model has 20 endogenous variables $\{$ $c$, $l$, $m$, $w$, $mc$, $P$, $\pi$, $B$, $Res$, $L$, $D$, $e$, $EFP$,$R^B$, $R^P$, $R^L$, $R^D$, $R^e$, $R^f$, $\lambda\}$, 5 lagged variables $\{$ $P_{-1}$, $B_{-1}$,$R^B_{-1}$, $R^p_{-1}$, $\lambda_{-1}\}$ and 3 exogenous shocks $\{$ a1, a2, a3$\}$.

# E Derivation of Welfare

Defining $\hat{x}_t$ as the log deviation from the steady state ($\hat{x}_t$=$x_t$-$x$), each variable can be restated as a second order approximation of its relative deviation from the variable's steady state, which reads as:

$$\frac{X_t - X}{X} \simeq \hat{x}_t + \frac{1}{2}\hat{x}_t^2$$

From the problem above, household utility is described by additive functions of consumption and leisure

$$U_t = log(c_t) + \phi log(1 - l_t^s - m_t^s) \tag{E.1}$$

## E.1 Taylor expansion

Taking the deviation from the steady state we get the initial approximation

$$U_t - U \approx \frac{1}{c}(c_t - c) - \frac{\phi}{1 - l^s - m^s}(l_t^s - l^s) - \frac{\phi}{1 - l^s - m^s}(m_t^s - m^s) - ... \tag{E.2}$$

$$... - \frac{1}{2}\frac{1}{c^2}(c_t - c)^2 - \frac{1}{2}\frac{\phi}{(1 - l^s - m^s)^2}(l_t^s - l^s)^2 - \frac{1}{2}\frac{\phi}{(1 - l^s - m^s)^2}(m_t^s - m^s)^2$$

Restating as a second order approximation

$$= \hat{c}_t - \frac{1}{2}\hat{c}_t^2 - \frac{\phi}{1 - l^s - m^s}(l^s\hat{l}_t^s + m^s\hat{m}_t^s) - \frac{1}{2}\frac{\phi}{(1 - l^s - m^s)^2}(l^{s2}\hat{l}_t^{s2} + m^{s2}\hat{m}_t^{s2}) \tag{E.3}$$

Now we rewrite $m^s$ and $l^s$ in terms of output. Production labor demand $l_t$ is given by

$$l_t = \left(\frac{y_t}{A1_t}\right)^{\frac{1}{1-\eta}} \int_0^1 \left(\frac{P_t(i)}{P_t}\right)^{-\frac{\epsilon}{1-\eta}} di \tag{E.4}$$

Log-linearizing this condition yields

$$(1-\eta)\hat{l}_t = \hat{y}_t - a1_t + (1-\eta)log \int_0^1 \left(\frac{P_t(i)}{P_t}\right)^{-\frac{\epsilon}{1-\eta}} di. \tag{E.5}$$

Now we need to approximate the expression for the relative prices:

$$\int_0^1 \left(\frac{P_t(i)}{P_t}\right)^{-\frac{\epsilon}{1-\eta}} di = \int_0^1 exp\left[-\frac{\epsilon}{1-\alpha}(p_t(i)-p_t)\right] di \tag{E.6}$$

a second-order approximation yields

$$\simeq 1 - \frac{\epsilon}{1-\eta}\int_0^1 (p_t(i)-p_t)di + \frac{1}{2}\left(\frac{\epsilon}{1-\eta}\right)^2 \int_0^1 (p_t(i)-p_t)^2 di \tag{E.7}$$

By the definition of the price index

$$P_t = \left[\int_0^1 P_t(i)^{1-\epsilon} di\right]^{\frac{1}{1-\epsilon}} \tag{E.8}$$

we get

$$1 = \int_0^1 \left(\frac{P_t(i)}{P_t} di\right)^{1-\epsilon} = \int_0^1 exp\left((1-\epsilon)(p_t(i)-p_t)\right) di \tag{E.9}$$

according to the lemmas in Galì (2008)

$$\int_0^1 \left(\frac{P_t(i)}{P_t}\right)^{\frac{-\epsilon}{1-\eta}} di \simeq 1 + \frac{1}{2}\left(\frac{\epsilon}{1-\eta}\right)\frac{1}{\Theta} var_i\{P_t(i)\} \tag{E.10}$$

Loan management demand $m_t$ is given by

$$\hat{m}_t = \frac{1}{1-\alpha}(\hat{c}_t - a2_t). \tag{E.11}$$

By substitution from the market clearing conditions

$$\hat{c}_t = \hat{y}_t, \hat{l}_t^s = \hat{l}_t, \hat{m}_t^s = \hat{m}_t \tag{E.12}$$

with production labor $l_t^s$

$$\hat{l}_t = \frac{1}{(1-\eta)} \left( \hat{y}_t - a1_t + (1-\eta) log \int_0^1 \left( \frac{P_t(i)}{P_t} \right)^{-\frac{\epsilon}{1-\eta}} di \right). \tag{E.13}$$

and monitoring labor $m_t^s$

$$\hat{m}_t = \frac{1}{(1-\alpha)} (\hat{y}_t - a2_t) \tag{E.14}$$

we get

$$U_t - U = \hat{y}_t + \frac{1}{2}\hat{y}_t^2 + ... \tag{E.15}$$

$$... + \frac{1}{1-l^s-m^s} \left[ \frac{\phi}{1-\eta} l^s \left( \hat{y}_t - a1_t + (1-\eta) log \int_0^1 \left( \frac{P_t(i)}{P_t} \right)^{-\frac{\epsilon}{1-\eta}} di \right) + m^s \frac{\phi}{1-\alpha} (\hat{y}_t - a2_t) \right] - ...$$

$$... - \frac{1}{2} \frac{\phi}{(1-l^s-m^s)^2} \left[ \left( \frac{l^s}{1-\eta} (\hat{y}_t - a1_t) \right)^2 + \left( \frac{m^s}{1-\alpha} (\hat{y}_t - a2_t) \right)^2 \right]$$

We move $a1_t$ and $a2_t$ into the terms independent of policy and substitute in inflation, so

$$U_t - U = \hat{y}_t - \frac{1}{2}\hat{y}_t^2 - \phi \left[ \nu(\hat{y}_t + \frac{\epsilon}{2\Theta} var_i\{p_t(i)\}) + \frac{1}{2}\nu^2 (\hat{y}_t - a1_t)^2 \right] - \phi \left[ \mu \hat{y}_t + \frac{1}{2}\mu^2 (\hat{y}_t - a2_t)^2 \right] + t.i.p. \tag{E.16}$$

where $t.i.p.$ includes shocks not affected by policy. The coefficients $\nu$ and $\mu$ are given by

$$\nu = \frac{l^s}{(1-l^s-m^s)(1-\eta)} \tag{E.17}$$

and

$$\mu = \frac{m^s}{(1 - l^s - m^s)(1 - \alpha)}. \tag{E.18}$$

Using Woodford's (2003) result (Lemma 2, Galì (2008)) for the price variance across sectors

$$\sum_{t=0}^{\infty} \beta^t var_i\{p_t(i)\} = \lambda \sum_{t=0}^{\infty} \beta^t \pi_t^2 \tag{E.19}$$

gives the following expression

$$U_t - U = \hat{y}_t - \frac{1}{2}\hat{y}_t^2 - \phi\left[\nu\left(\hat{y}_t + \frac{\epsilon}{2\Theta}\pi_t^2\right) + \frac{1}{2}\nu^2(\hat{y}_t - a1_t)^2\right] - \phi\left[\mu\hat{y}_t + \frac{1}{2}\mu^2(\hat{y}_t - a2_t)^2\right] + t.i.p. \tag{E.20}$$

We collect all terms on the rhs:

$$U_t - U = (1 - \phi(\nu + \mu))\hat{y}_t + \phi\hat{y}_t(\nu^2 a1_t + \mu^2 a2_t) - \frac{1}{2}(1 + \phi\nu^2 + \phi\mu^2)\hat{y}_t^2 - \frac{1}{2}\frac{\phi\epsilon\nu}{\Theta\lambda}\pi^2 + t.i.p. \tag{E.21}$$

By setting the parameter for the weight of leisure in utility to $\phi = 0.65$ which results in 1/2 of available time working in either goods production or banking, similar to Goodfriend and McCallum (2007), $\nu + \mu$ cancel out from the first expression.[27]. Thus we have

$$U_t - U = -\frac{1}{2}\left[(1 + \phi(\nu^2 + \mu^2))\hat{y}_t^2 - 2\phi(\nu^2 a1_t + \mu^2 a2_t)\hat{y}_t + \frac{\phi\nu\epsilon}{\Theta\lambda}\pi^2\right] + t.i.p. \tag{E.22}$$

We compare this expression to the change in the natural output

$$\widehat{y_t^n} = \frac{1}{(\Omega + O)(1 - \eta)} a1_t + \frac{\alpha}{(\Omega + O)(1 - \alpha)} a2_t \tag{E.23}$$

with

$$\Omega = \left(1 + \frac{1 + \eta}{1 - \eta} + \frac{1}{1 - \alpha}\right) \tag{E.24}$$

[27] This is necessary as the path for aggregate output is accurate only to the first order, see Benigno and Woodford (2012).

and

$$O = \left(1 + \frac{1}{1-\alpha} - \frac{\eta}{1-\eta}\right). \tag{E.25}$$

In the expression for welfare we have

$$U_t - U = -\frac{1}{2}\left[(1+\phi(\nu^2+\mu^2))\hat{y}_t^2 - 2\phi\left(\begin{bmatrix}\nu^2 & \mu^2\end{bmatrix}\begin{bmatrix}a1_t \\ a2_t\end{bmatrix}\right)\hat{y}_t + \frac{\phi\nu\epsilon}{\Theta\lambda}\pi^2\right] + t.i.p. \tag{E.26}$$

By substitution we get an expression depending on $\widehat{y_t^n}$

$$U_t - U = -\frac{1}{2}\big[(1+\phi(\nu^2+\mu^2))\hat{y}_t^2 - ... \tag{E.27}$$

$$... - 2\phi(\Omega+O)\left(\nu^2\frac{\frac{1}{1-\eta}}{\left(\frac{1}{1-\eta}\right)^2+\left(\frac{\alpha}{1-\alpha}\right)^2} + \mu^2\frac{\frac{\alpha}{1-\alpha}}{\left(\frac{1}{1-\eta}\right)^2+\left(\frac{\alpha}{1-\alpha}\right)^2}\right)\hat{y}_t\widehat{y_t^n} + \frac{\nu\phi\epsilon}{\Theta\lambda}\pi^2\big] + t.i.p.$$

Hence,

$$U_t - U = -\frac{1}{2}\left[\frac{\nu\phi\epsilon}{\Theta\lambda}\pi^2 + (1+\phi(\nu^2+\mu^2))\left[\hat{y}_t^2 - 2\aleph\hat{y}_t\widehat{y_t^n}\right]\right] + t.i.p. \tag{E.28}$$

with

$$\aleph = \frac{\phi(\Omega+O)}{1+\phi(\nu^2+\mu^2)}\left(\nu^2\frac{\frac{1}{1-\eta}}{\left(\frac{1}{1-\eta}\right)^2+\left(\frac{\alpha}{1-\alpha}\right)^2} + \mu^2\frac{\frac{\alpha}{1-\alpha}}{\left(\frac{1}{1-\eta}\right)^2+\left(\frac{\alpha}{1-\alpha}\right)^2}\right) \tag{E.29}$$

By definition of the output gap,

$$\tilde{y}_t = \hat{y}_t - \widehat{y_t^n} \tag{E.30}$$

this finally yields

$$U_t - U = -\frac{1}{2}\left[(1+\phi(\nu^2+\mu^2))\tilde{y}_t^2 + \frac{\nu\phi\epsilon}{\Theta\lambda}\pi^2\right] + t.i.p. \tag{E.31}$$

The welfare measure is therefore approximately

$$W \simeq E_0 \sum_{t=0}^{\infty} \beta^t (U_t - U) = -\frac{1}{2} E_0 \sum_{t=0}^{\infty} \beta^t \left[\varphi \tilde{y}_t^2 + \varpi \pi_t^2\right] + t.i.p. \tag{E.32}$$

with $\varphi = (1+ \phi\nu^2 + \phi\mu^2)$ and $\varpi = \frac{\nu\phi\epsilon}{\Theta\lambda}$.

**Highlights: DSGE Model with Interbank Market Failure**

- We model an interbank sector in a New Keynesian DSGE framework.
- We examine a systemic banking crisis through an interbank lending shock.
- We assess the effectiveness of macro-prudential policies.
- Increasing the liquidity requirement mitigates real and financial effects.
- Increasing the capital requirement only dampens financial effects.