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International Monetary Transmission with Bank Heterogeneity and Default Risk

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This paper compares the effectiveness, efficiency and robustness of standard and non-standard monetary policy tools, such as the banks' refinancing interest rate, penalty interest rate on deposit facility holdings and minimum reserve requirements on attracted deposits. The assessment is performed on the basis of a numerically evaluated open economy general equilibrium model for macro-prudential analysis where optimal decisions by internationally linked banks are key determinants of international financial flows and wider economic outcomes. Banks differ in terms of balance sheet endowments and risk preferences, and take decisions rationally and competitively. Default risk, borrowing and lending are endogenous results of individual decisions of private agents (banks and households), as well as systemic outcomes of market interaction.

JEL: C68, D58, E44, E51, E52, E58, G21
Keywords: Banking, Monetary Policy, Non-standard Instruments, Macro-Prudential Policies, Financial Stability, Contingency Planning

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1 Introduction

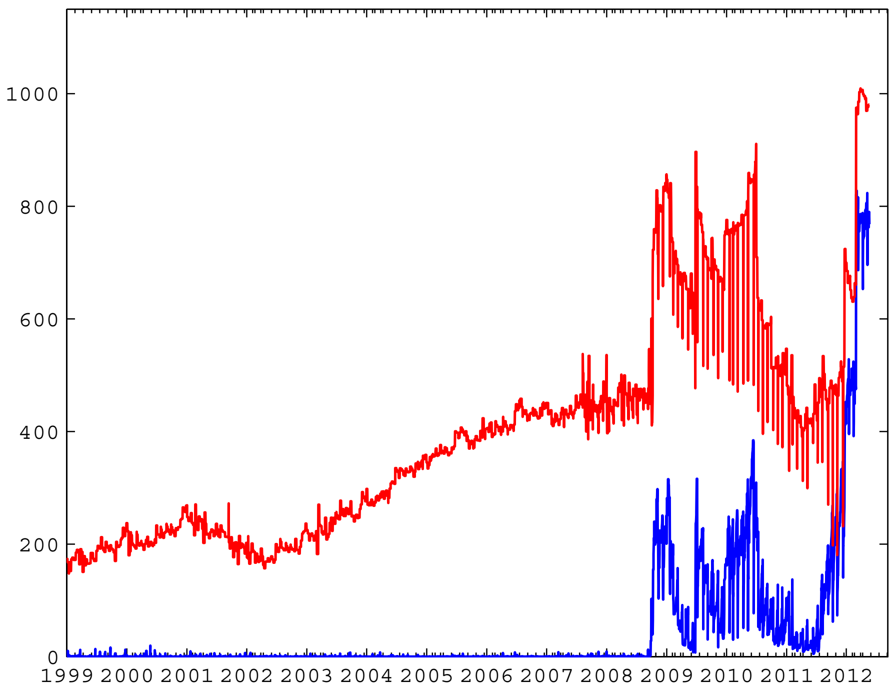
Central banks have two most prominent objectives: the delivery of price stability and the maintenance of financial stability (see Goodhart, 2010). Their implementation through monetary and regulatory policy tools affects the banking system's liquidity conditions and creates spillovers, which have been generally overlooked in conventional formal macroeconomic models.

Increased cross-border interconnectedness of banks through ownership and funding, enhanced by open capital accounts, necessitates the consideration of locally felt spillovers, generated by multiple monetary regimes and regulatory frameworks. Monetary authorities in countries with underdeveloped financial markets with less discretion in controlling local liquidity conditions have traditionally relied on non-standard monetary policy tools, such as minimum reserve requirements with little theoretical insight from academics on the precise transmission of these type of monetary impulses to the wider economy's outcomes, such as nominal income growth. Moreover, the experience during the recent global financial crisis revealed the need to study further the outcomes generated by the presence and active use of non-standard monetary policy tools with financial stability functions in the developed market economies, see Orphanides (2010) and Calomiris et al (2011).

This paper evaluates the system-wide impact of foreign and domestic, standard and non-standard monetary policy tools, modelled in a stochastic general equilibrium context, where optimal decision-making by heterogeneous, internationally-linked banks play central role. The model is designed to reflect policies, economic and financial structure of a small open economy operating outside a major currency area, but considerably linked to its banking system through locally operating bank subsidiaries. The design incorporates wide range of policies applied before and during the financial markets crisis. Following recommendations put forward by Calomiris (2011) the analysis considers ex-ante incentives to economic participants and evaluates not only the effectiveness and efficiency of a monetary policy tool in transmitting impulses through the banking system to the wider economy, but also considers its contribution to the resilience of the system in the event of a liquidity crunch. Independently of its structural generality, the model is empirically evaluated on the case of Bulgaria and its links to the Euro area.

In the model foreign liquidity conditions are determined by a range of monetary policy implementation tools. Alongside the interest rate on refinancing operations to banks by the foreign monetary authority, the model's structure incorporates non-standard tools, such as the penalty rate on banks' deposits at the foreign monetary authority, supported by non-negligible use of the deposit facility and unlimited resort

Fig. 1 Resort to ECB's open market operations (upper red line) and deposit facility (lower blue line)



to foreign monetary authority's refinancing operations to maintain thin interbank markets during crisis. These, so called, non-standard tools, are part of the monetary policy implementation frameworks, but are rarely used during 'normal times' due to lack of interest from banks. For example, even though a framework of interest rate corridor exists permanently in the Euro area, UK and other countries, without stress on the financial and credit markets, banks rarely keep considerable liquid funds at the deposit facility of the monetary authority, see Whitesell (2006). As portrayed on Figure 1 during the crisis banks in the Euro area keep considerable liquidity at the ECB's deposit facility by which they earn a penalty (lower) rate, while at the same time resorting to unlimited supply of liquidity from the ECB at a higher policy rate. Banks' average usage of the deposit was 109 billion Euros in 2009, 145 billion in 2010 and 650 billion in the first five months of 2012.

The local monetary authority steers individual banks' liquidity by implementing unfrequent changes in the minimum reserve requirements for local and foreign deposits, which represents another non-standard monetary policy tool. The purpose is to ensure that banks build up sufficient liquidity buffers on their own to meet cash-flow obligations. At the same time, the banking system as a whole accumulates a stock of liquid reserves to safeguard financial stability. Since risk-taking of financial institutions varies pro-cyclically, requirements are adjusted appropriately.

Furthermore, the local monetary authority exercises regulatory powers on local banks by defining minimal capital adequacy ratios and quarterly public reporting requirements for each bank. The latter are designed to enhance financial markets' transparency, confidence, reputation-building, and prudent balance between competitiveness and risk-aversion. For detailed analysis of the transmission of various regulatory policies and contingencies see Tsenova (2011) and Tsenova (2013) .

Optimal decisions by heterogeneous banks are in the center of the monetary transmission. Banks draw liquidity from a pool of depositors and their foreign bank owners and provide loans to households. Partial default is a part of their feasible set of options and arises endogenously. In choosing their resort to foreign and domestic obligations, lending to households and partial default on obligations, banks take into account their expected pay-offs, which include profits from financial intermediation, alongside reputational costs of partial default and low capital adequacy ratio.

The numerical evaluation of the model is performed in a way that reveals the deep risk aversion parameters of individual banks. For each bank the behavioral non-linear equations are fitted to particularly detailed individual banks' regulatory reports.[1] The empirical evidence relates not only to banks' balance sheet quantities, but also interest rates and loan-loss provisions.

The model builds on a class of models developed by Tsomocos (2003), Goodhart et. al. (2005 and 2006), which possess certain desirable fundamental characteristics. These are multiple heterogeneous banks and financial markets participants avoiding the conventional reliance on representative averages. The approach is truly macro-prudential since outcomes are considered in a general equilibrium context. Borrowing, lending and default risk occur endogenously, as result of optimal decision-making by individual banks and households, as well as systemically due to their interaction on various markets. Default can be partial in the sense that institutions and individuals can decide to partially repay or delay obligations, for which they incur a penalty, but not necessarily leading a wind up. In fact, under certain conditions partial default can improve solvency, which gives rationale for debt restructuring.

There is a wide set of separate financial markets operating under perfect competition. Banks take interest rates as determined by market supply and demand conditions. Interest rate margins embed

[1] This data is publicly available at the internet site of the Bulgarian National Bank.

endogenous default risk premia linked to individual banks' interaction on the financial market and their risk tolerance parameters. This provides an appealing alternative to the New Keynesian Synthesis literature with banks, such as Gerali at al. (2010), founded on supply-side dominance with monopolistic competition and nominal rigidities giving rise to an interest rate markup.

While expectations are rational (i.e. agents are perfectly informed within each period and all markets clear) optimal plans are intertemporally constrained by a finite planning horizon. This constraint adds realism and constitutes a relatively small deviation from a rational expectations hypothesis extended infinitely into the future, which endows economic agents with perfect knowledge and foresight.

This paper extends the existing theoretical framework in the following ways. By incorporating and studying the effects of non-conventional policy instruments for steering liquidity to banks, such as interest rate corridor and requirements for bank reserves on deposits. The model's parametrisation is linked to more detailed data and incorporates heterogeneous interest rates in local and foreign deposit markets, linked to a banks' differing aversion to partial default on those markets. The paper also innovates on the approach of taking the model to the data, by imposing the data to the non-linear structure of the banks' behavioral equations in order to reveal their key deep preference parameters.

2 Empirical Motivation of Model's Structure

The model represents the case of a small open economy with strong banking links to a major currency area. Since the case is built and evaluated on Bulgarian banking micro and macro data during the global financial crisis, it would be useful to consider some underlying structural empirical facts.

The European Union economies function under a set of common economic rules stimulating free movement of capital, goods and labour. Common, as well as national policies have greatly enhanced foreign direct investment in all industries, including banking. The investment flow in banking usually originates from more financially developed older member-states in the Euro area, and is directed towards more dynamic higher-growth new member-states from Central and Eastern Europe, such as Bulgaria.

Banks in Bulgaria are mostly owned by foreign banks, predominantly operating in the the Euro area. Thus, the asset share of banks and subsidiaries owned by Euro area banks is 76%, while the share of locally-owned banks is only 17% (see BNB, 2009).[2]

[2] The assessment is based on banking data as of mid-2009, since this is also the cut-off point for data input for the quantitative model presented in the next section.

Table 1 Example of Stylised Bank Balance Sheet

Item	**Assets**	Item	**Liabilities**
(1)	Loans to other banks	(5)	Deposits of other banks
(2)	Minimum required reserves		
(3)	Market book	(6)	Others
(4)	Loans to households (type borrowers)	(7)	Deposits of households (type savers)
		(8)	**Equity**

The foreign interbank markets are very important in determining local liquidity conditions, since 90% of banking system's loans from other financial institutions originate from abroad (see Table 1 for a stylised representations of the items on a bank balance sheet). While the banking system's short-term debt to other financial institutions is 12.3 billion Lev,[3] 11.0 billion Lev come from foreign banks,[4] and more specifically their foreign bank owners. The local interbank market has little importance as provider of structural liquidity, as as opposed to stochastic daily liquidity.

Local deposits are the most important source of liquid financing for local banks. Deposits account for 73% of total liabilities of the banking system, in nominal terms amounting to 42.2 billion Lev.

On the asset side, the most prominent share take loans extended to households and companies, which amount to 50.9 billion Lev. This item is naturally characterised with both higher return and risk, due to possibility of default and variations in market liquidity.

Furthermore there are three asset items representing relatively liquid portfolio buffers: holdings of minimum reserve requirements, loans to other banks and market book. The market book consists of tradable assets and bonds, which bear certain return, but also risk stemming from valuation, liquidity and default. The banking systems' volume of market book is relatively small amounting to 4.9 billion Lev.

Banks' holdings of required minimum reserves are kept at the local monetary authority at zero return and no risk. In Bulgaria the maintenance of a fixed exchange rate regime prevents the central bank from direct discretionary intervention on the local interbank market. Instead the approach is rather "passive-aggressive" – the local monetary authority ensures that banks maintain own liquidity buffers by a risk-averse, conservative definition of the required minimum reserves, daily monitoring of their fulfilment and flexible incentive-compatible penalties on structural non-fulfilment. Empirically, banks tend to almost

[3] The Bulgarian Lev is pegged to the Euro at 1 Lev = 0.51129 Euro.

[4] See BNB, Bulgarian Gross Foreign Debt, July 2009, 24 September 2009.

exactly fulfil their required reserve obligations. Required reserve ratios are adjusted counter-cyclically to adjust for banks' attitude towards macro and financial risk. During boom periods banks, as well as other economic agents, usually need stronger encouragement towards prudence than during recessions. For example, in 2009 minimum reserves were lowered to 10% of locally attracted deposits (from 12% previously) and to 15% of deposits from abroad (from 22% previously).

By comparison, countries with sophisticated financial markets, and pro-active in steering interbank liquidity, tend to define the required reserves more liberally, and in a way that is almost neutral with respect to the structural decision-making by banks. For example, in the Euro area the minimum required reserves are set at 2% of the short-term deposits and debt securities in excess of 30% of short-term asset holdings and a lump sum allowance of 0.1 million Euro. Thus, even though reserve requirements are part of the monetary policy implementation tools, in practice they have not been used.

During the financial markets crisis banks' buffers of voluntary liquid reserves in the form of deposits in foreign bank owners have gained prominence. This item has become more than half of the local banking system's loans from their foreign bank owners, in mid-2009 being 6.9 billion Lev. On those deposits banks earn interest but lower than the interest rate they pay on borrowed funds from abroad. The motives should be similar to those underlying euro area's banks keeping substantial liquidity at penalty rate at the ECB's deposit standing facility, namely insurance against liquidity dry-ups, default risk on the interbank market, own balance sheet risk and uncertainty. Further disaggregate data analysis is provided in Section 4.[5]

3 Model Setup

The banking system in the model is represented by three local banks, distinct (heterogeneous) both in their endowments and risk preferences. The banks are identified with superscript $b \in \{\tau, \delta, \gamma\}$. Banks δ and γ represent two of the largest banks in Bulgaria, with share in total assets of 16% and 12% respectively. Bank τ represents the rest of the banking system. The number of banks, however, is not

[5] The paper abstracts from exchange rate issues, because the Bulgarian currency is pegged to the Euro, which is also the only foreign currency with non-negligible presence on the balance sheet of the banking system. Instead, the issue would be of great analytical importance in the case of countries with substantial foreign exchange holdings in the balance sheets of their financial intermediaries. An example of such analysis is reflected in Choi and Cook (2002), Geanakoplos and Tsomocos (2002)

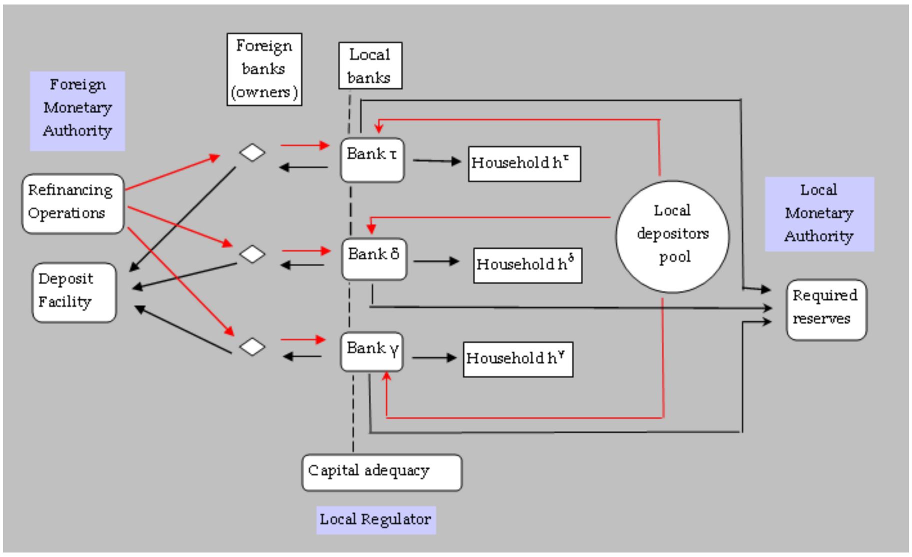


Fig. 2 Model Architecture

pertinent to the model's structure, since that is flexible enough to incorporate the full set of 24 local bank subsidiaries and banks. Figure 3 illustrates the structure of the model.

The local banks provide financial intermediation, having access to several financial markets. Local banks operate under perfect competition, being price-takers with respect to interest rates, which in turn are formed by supply and demand conditions on each market.

3.1 Financial markets and interest rate conditions

3.1.1 Foreign interbank markets

Banks are modelled as subsidiaries of foreign banks, through which they have access to interbank liquidity, ultimately provided by the foreign monetary authority. There are two types of separate interbank markets: for interbank loans and for interbank deposits.

The foreign monetary authority pursues active monetary policy by setting the key interest rate ρ, at which money (liquidity) is supplied to the banks. The total supply of money, borrowed by local banks on this market is denoted as M.

$$M = M^{\tau} + M^{\delta} + M^{\gamma} \tag{1}$$

Banks determine their individual foreign money demand, $\widetilde{\mu}^b$, and foreign money supply M^b, accounted as short-term loans from other financial institutions. All banks borrow at the same key interest rate ρ. [6]

$$\widetilde{\mu}^b = M^b(1+\rho) \tag{2}$$

Banks in the model have opportunity to deposit short-term funds into the foreign monetary authority's deposit facility, through the intermediation of their foreign bank owners. Those deposits D^b earn a rate which equals the key interest rate ρ minus a penalty ψ. Adjustments in the penalty rate are part of the non-standard tools of monetary policy implementation, since during normal times, banks make little structural use of the deposit facility, and the penalty rate is kept constant.

$$\widetilde{d}^b = D^b(1+\rho-\psi) \tag{3}$$

At aggregate level, the overall short-term bank funds at the deposit facility D, equal the sum of deposits of individual banks D^b.

$$D = D^\tau + D^\delta + D^\gamma \tag{4}$$

The markets for short-term loans and deposits from foreign banks are separate. The first is dominated by the interest rate conditions on regular liquidity provision to banks, conventionally known as Open Market Operations or refinancing operations. Demand for loans on that market is determined by banks' motives of attracting liquidity from the interbank market, given the alternatives offered by the local depositors' market. The market for interbank deposits is driven by the interest rate conditions of the standing deposit facility. Banks desire to keep funds there during times of stress on the interbank and other credit markets, due to higher prevailing counterparty and overall risk. In such times, alternative means of storing liquidity at higher return, such as securities and bonds, bear also higher liquidity and default risk. Therefore, deposits can be viewed as voluntary structural reserves, important for the financial stability of the system.

Even though individual banks face the same interest rate conditions on the interbank deposit and lending markets, their net costs of financing differ, depending on their balance sheet positions. It is useful

[6] For simplicity, but no loss of generality, it is assumed that local banks borrow at the same interest rate conditions as foreign banks, save for a fixed risk premium, reflecting country risk. The risk premium of about 0.5% is dictated by the data and only affects the model's parametrisation.

to define the net costs on interbank financing r^b for each bank as a function of net demand for interbank liquidity μ^b and net supply of interbank liquidity $M^b - D^b$.

$$\mu^b = (M^b - D^b)(1 + r^b) \tag{5}$$

The costs r^b critically depend on the quantities of interbank loans (money supply) and interbank deposits held at the foreign bank owners, and ultimately the foreign monetary authority.

Proposition A bank's net cost of financing from interbank markets is the difference between the two market rates plus a premium depending on the volume of interbank loans and deposits. In other words, prices as well as balance sheet quantities matter.

$$r^b = \rho + \frac{D^b \psi}{M^b - D^b} \quad for \quad M^b > D^b \tag{6}$$

The function is non-linear and discontinuous. The premium (mark-up) of a bank's net financing costs from the interbank market r^b above the interbank lending rate (key policy rate) ρ, depends on the deposit rate penalty ψ, multiplied by the ratio of its deposit D^b to its net external financing $M^b - D^b$.

3.1.2 Local depositors markets

The local banks have access to a pool of local depositors called ϕ. Depositors are households, which have the tendency to save. The interest rate paid by bank b depends on quantity of deposit financing demanded μ_d^b, and quantity of deposits supplied by household ϕ to bank b, d_b^ϕ.

$$1 + r_d^b = \frac{\mu_d^b}{d_b^\phi} \tag{7}$$

r_d^b - interest rate on deposits to households faced by bank b; d_b^ϕ - deposits of bank b attracted from household ϕ.

3.1.3 Loans markets

Banks can also invest part of their portfolio into loans to agents, households and companies with the tendency to borrow. Each bank lends to a household b to which they are randomly attached. The interest rate on loans of bank b lent to household h^b, depends on quantities of loans supplied $\overline{m}^b$ and demanded μ^{h^b}.

$$1 + \overline{r}^b = \frac{\mu^{h^b}}{\overline{m}^b} \tag{8}$$

where $\overline{r}^b$ is the interest rate on household loans promised by bank b; $\overline{m}^b$ - loans to households provided by bank b; μ^{h^b} - loan obligation of household h to bank b.

3.2 Decision-making by banks

Banks maximise their expected pay-off under uncertainty as regards the future state of the economy. The model allows for two alternative states of nature $s \in \{i, ii\}$. State i denotes the 'good' state, in other words, a more favorable state of nature, which is expected to occur with higher probability $p_i = p$. State ii is the 'bad' state, a less favorable outcome, expected to occur with lower probability $p_{ii} = (1 - p)$. Banks operate in prefect competition on the financial markets and take interest rates as given.

Banks decide optimally on their supply of loans to households $\overline{m}^b$, demand for net liquidity from interbank market μ^b, demand for liquidity from the pool of depositors market μ_d^b and their state contingent repayment rate on external obligations υ_s^b. Equivalently, the ratio $1 - \upsilon_s^b$ is a bank's state contingent default rate on obligations.

Holdings of interbank deposits at the deposit facility of the foreign monetary authority are assumed to be fixed in normal times, while fully utilised in crisis circumstances, for example in the case of a liquidity crunch. Even though the deposit and lending facility of the monetary authority offer two separate markets for interbank liquidity, given that the central bank accommodates all demand for liquidity and supply of deposits by banks and positive interest penalty on the deposit facility, portfolio allocation considerations cannot justify a non-zero holdings of interbank deposits. The motives underlying such holdings are in the realm of fear of a sudden liquidity crunch. In such a case, the affected bank or banking system would diminish the negative impact of such an eventuality by using at no interest own liquidity buffers, normally viewed as inefficient. Interbank deposits could also be viewed as a cash collateral requirement imposed by mother banks on their subsidiaries with lower risk aversion towards default on obligations.

Banks are risk averse and maximise their expected state contingent pay-off functions Π^b (see Eq. 10), subject to their balance sheet budget constraints (see Eq. 11). The expected pay-off of bank b is a positive, but concave function of the expected profit π_s. The pay-off Π^b increases with profit π_s, but higher profit bears quadratic costs related to higher perceived risk, imbedded in the risk aversion parameter c_s^b. Furthermore, the pay-off function is negatively affected by several non-pecuniary subjective costs, or risk aversion parameters. These are costs of reporting insufficiently high capital adequacy ratio $\lambda_s^{b\,k}$, costs of partial repayment (partial default) on obligations from interbank markets $\lambda_s^{b\,\mu}$ and costs of partial repayment of obligations to the pool of depositors market ϕ.

The bank's expected profit depends positively on expected return on loans to households $\overline{r}^b$, discounted for expected non-performing loans $\upsilon_s^{h^b}$), return on asset trading portfolio r^A, and negatively on default on attracted funds, such as partial repayment υ_s^b on net interbank obligations and obligations to depositors (see Eq. 12).

The bank is obliged to hold minimum required reserves $\overline{l}^b$ at the local monetary authority (see Eq. 14). The minimum reserve requirements are defined as percentage of household deposits ζ^{μ_d} and percentage of interbank loans ζ^M attracted by the bank. Required reserves bear no interest rate, but they are safe of default, since held at the local monetary authority.

The capital adequacy ratio k_s^b of a bank is defined as the state contingent ratio of own funds, made of initial equity e_0^b and profit π_s^b, to its risk-weighted assets (see Eq. 15).

$$\max_{\overline{m}^b, \mu^b, \mu_d^b, \upsilon_s^b} \mathit{\Pi}_s^b \tag{9}$$

Subject to

$$\overline{m}_b + A^b + \overline{l}^b = \frac{\mu^b}{1+r^b} + \frac{\mu_d^b}{1+r_d^b} + e_0^b + Others^b \tag{10}$$

where

$$\mathit{\Pi}_s^b = \sum_{s=i}^{ii} p_s[\pi_s^b - c_s^b(\pi_s^b)^2] - \tag{11}$$

$$-\sum_{s=i}^{ii} p_s[\lambda_s^{b\,k}(\overline{k}^b - k_s^b) + \lambda_s^{b\,\mu}(\mu^b - \upsilon_s^b\mu^b) + \lambda_s^{b\,\mu_d}(\mu_d^b - \upsilon_s^b\mu_d^b)]$$

$$\pi_s^b = \upsilon_s^{h^b}(1+\overline{r}^b)\overline{m}^b + (1+r^A)A^b + \overline{l}^b - \upsilon_s^b\mu^b - \upsilon_s^b\mu_d^b - Others^b - e_0^b \tag{12}$$

$$\overline{l}^b = \zeta^M M^b + \zeta^{\mu_d}\frac{\mu_d^b}{1+r_d^b} \tag{13}$$

$$k_s^b = \frac{e_0^b + \pi_s^b}{\overline{\omega}\upsilon_s^{h^b}(1+\overline{r}^b)\overline{m}^b + \widetilde{\omega}(1+r^A)A^b + w(1+\rho-\psi)D^b} \tag{14}$$

where A^b is the market book held by bank b; $\overline{k}^b$ - the minimum for required capital adequacy ratio of bank b; $\overline{\omega}$ - risk weight on loans to households assigned by regulator; $\widetilde{\omega}$ - risk weight on market book assigned by regulator; w risk weight on loans to interbank market.

3.3 Households' behavior

The private sector behaviour follows closely Goodhart et al. (2005 and 2009). There are four representative households in the model. Three of them are type borrowers, $h \in \{\alpha, \beta, \theta\}$, and determine the demand for loans from their own nature-selected bank, correspondingly $b \in \{\gamma, \delta, \tau\}$. The fourth household ϕ is type lender and represents a collective pool of depositors, determining the supply of household deposits to banks. While banks have exclusive one-to-one relationship with their household type borrower, they are in direct competition for household deposits from agent ϕ.

3.3.1 Supply of households' deposits

The supply of household deposits to banks is determined by the collective behaviour of a pool of depositors, named for convenience agent ϕ. Because all banks have access to this market, agent ϕ is able to arbitrage to certain extent financial opportunities across banks. In doing so, agent ϕ considers expected return on deposits offered by each bank, defined as the contracted interest rate discounted for expected bank partial repayment rates in the 'good' and 'bad' states of nature. Agent ϕ increases own holdings of deposits in one bank, if that bank offers higher expected return, comparative to those expected from the other banks. Other things being equal, higher expected income (GDP) in the economy increases the pool of depositors, in other words, the wealth of agent ϕ, and consequently increases the supply of deposits to all banks. See Eq. 15.

$$\begin{aligned} ln(d^{\phi\ b}) = {} & z_{b,1} + z_{b,2} ln[pGDP_i + (1-p)GDP_{ii}] + z_{b,3}\{r_d^b[pv_i^b + (1-p)v_{ii}^b]\} \\ & - z_{b,4} \sum_{b' \neq b} \{r_d^{b'}[pv_i^{b'} + (1-p)v_{ii}^{b'}]\} \end{aligned} \tag{15}$$

where $z_{b,2}$ is the elasticity of deposit supply to expected income proxied by GDP; $z_{b,3}$ - elasticity to expected interest rate by bank b; $z_{b,4}$ - elasticity to other return opportunities, i.e. expected interest rates offered by the other banks composing the domestic banking system; $z_{b,1}$ - parameter, which captures additional factors, for example inflow of foreign deposits.

Agent ϕ's considerations do not include losses from possible partial repayment on deposit principals, in addition to expected losses on contracted interest rate obligations. This is because the model assumes the existence of deposit guarantee schemes, compensating households, should such losses occur. [7]

3.3.2 Demand for households' loans

The three representative households of type borrowers $h \in \{\alpha, \beta, \tau\}$ determine their demand for loans $\overline{\mu}^h$ from their nature-selected bank b, as well as their state contingent partial repayment rate υ_s^h. Households' demand for loans increases with expected income and declines with loan interest rate. The assumed demand function exhibits Hicksian properties.

$$ln(\overline{\mu}^{h^b}) = a_{h^b,1} + a_{h^b,2} ln[pGDP_i + (1-p)GDP_{ii}] - a_{h^b,3}\overline{r}^b \tag{16}$$

where $a_{h^b,2}$ denotes the elasticity of loan demand to expected income, GDP; $a_{h^b,3}$ - elasticity of loan demand towards interest rates; $a_{h^b,1}$ - parameter summarising the impact of exogenous factors.

The representative households that borrow, choose their demand for loans, $\overline{\mu}^{h^b}$, and loan repayment rates, υ^{h^b}, the inverse of the probability of default. Each individual demand for loans is a positive function of aggregate expected income in the next period, measured by expected GDP, and a negative function of the interest rate on that loan, $\overline{r}^b$.

The state contingent loan repayment rate υ_s of household h, assigned by nature to interact with bank b, increases with state contingent income GDP, and the volume of aggregate loans $\overline{m}$. Lower aggregate incomes and lower availability of credit, decreases the partial repayment rate of households $\upsilon_s^{h^b}$, and therefore default probability on loans in both states of nature.

$$\upsilon_s^{h^b} = g_{h^b,s,1} + g_{h^b,s,2} GDP_s + g_{h^b,s,3} ln(\overline{m}_\gamma + \overline{m}_\delta + \overline{m}_\tau) \tag{17}$$

$g_{h^b,s,2}$ is the elasticity of loan repayment rate with respect to incomes in the corresponding state s; $g_{h^b,s,3}$ - elasticity with respect to total credit to households; $g_{h^b,s,1}$ reflects the impact of other factors, such as external credit.

[7] In the EU countries, such schemes indeed exist, although there are certain bounds to the size of deposits fully covered. For example, in 2010, there was a unification in the minimum deposit size, covered by state guarantee schemes, set to 100 thousand Euros.

3.4 Aggregate equilibrium condition

Aggregate supply of loans in the economy affects output realisations in the 'good' and 'bad' states of nature. This means that not only the financial markets are affected by expected income from the real economy, but also vice versa. In both states of nature, equilibrium on the goods market (where demand meets supply) depends on the availability of credit in the previous period. Monetary and financial conditions are non-neutral with respect to the real economy.

$$ln(GDP_s) = u_{s,1} + u_{s,2} ln(\overline{m}^{\gamma} + \overline{m}^{\delta} + \overline{m}^{\tau}) \tag{18}$$

where $u_{s,2}$ is the elasticity of GDP with respect to credit availability in state s; $u_{s,1}$ - other factors, incl. domestic productivity, net exports (depending on supply and demand conditions in other countries), external finance, e.g. international corporate bond markets, depending on financial markets in other countries.

4 Numerical evaluation: method and procedure, risk preferences and initial equilibrium

The economic system is characterised by the set of equations described in the previous section. Of them, most crucial are the set of banks' behavioral equations – the first order conditions of for each bank's optimal choice of demand for net interbank liquidity, local deposits, supply of loans to households and default probability (inverse of the repayment rate on obligations). The maximisation of a bank's utility function, see in particular Eqs. 10-15, with respect to these four endogenous variables produces four equations for each bank, which depend on four sets of risk preference parameters.

$$\frac{\partial \Pi_s^b}{\partial \overline{m}^b} = F(\overline{m}^b, \mu^b, \mu_d^b, \upsilon_s^b, \upsilon_s^{hb}, r^b, r^{hb}, \overline{r}^b | c_s^b, \lambda_s^b, \lambda_s^{db}, \lambda_s^{kb}) \tag{19}$$

$$\frac{\partial \Pi_s^b}{\partial \mu^b} = G(\overline{m}^b, \mu^b, \mu_d^b, \upsilon_s^b, \upsilon_s^{hb}, r^b, r^{hb}, \overline{r}^b | c_s^b, \lambda_s^b, \lambda_s^{db}, \lambda_s^{kb}) \tag{20}$$

$$\frac{\partial \Pi_s^b}{\partial \mu_d^b} = H(\overline{m}^b, \mu^b, \mu_d^b, \upsilon_s^b, \upsilon_s^{hb}, r^b, r^{hb}, \overline{r}^b | c_s^b, \lambda_s^b, \lambda_s^{db}, \lambda_s^{kb}) \tag{21}$$

$$\frac{\partial \Pi_s^b}{\partial \upsilon_1^b} = J(\overline{m}^b, \mu^b, \mu_d^b, \upsilon_s^b, \upsilon_s^{hb}, r^b, r^{hb}, \overline{r}^b | c_s^b, \lambda_s^b, \lambda_s^{db}, \lambda_s^{kb}) \tag{22}$$

$$\frac{\partial \Pi_s^b}{\partial \upsilon_2^b} = K(\overline{m}^b, \mu^b, \mu_d^b, \upsilon_s^b, \upsilon_s^{hb}, r^b, r^{hb}, \overline{r}^b | c_s^b, \lambda_s^b, \lambda_s^{db}, \lambda_s^{kb}) \tag{23}$$

For each bank, the set of non-linear behavioral equations are imposed on very detailed banking data, in a way that reveals their deep risk aversion preferences. Such parameters are: risk aversion c; aversion from penalty for partial default on obligations from foreign banks λ; aversion from penalty for partial default on obligations to household depositors λ_d and aversion from reporting lower capital adequacy ratio λ_k. The system of non-linear equations is numerically estimated, under the usual conditionality of correctly specified model structure.

More specifically, at the initial equilibrium the parameters of the banks' behavioral equations are estimated to match the actually observed endogenous variables, such as loans, various forms of deposits, default probability, interest rates and default rates, and some exogenous variables, such as market book assets and other. Given plausible values for three of the risk preference parameters in the bad state of nature, the other five parameters are numerically evaluated to solve the system of four equations above. The the solution of this complex system of non-linear equations is found by numerical evaluation through a grid-search of preference values constrained within their plausible ranges.

In this approach, the availability of detailed individual banking data is crucial. The use of individual bank balance sheet data is necessary, but not sufficient, since quantities, such as loans, are reported only as net of expected default, interest income and costs. Therefore, the estimation here uses also individual banks' quarterly reports on liquidity, capital adequacy and provisioning, where there is detailed account of attracted funds and loans, securities and equity, associating the quantities of each item with interest income or costs, as well as assessment of default risk, against which the bank has provisioned.

The heterogeneity in risk parameters enriches market interaction and differences in individual responses to policy. Furthermore, given the theoretical structure of the model, without heterogeneity in the risk preferences of banks, it would have been impossible to incorporate the empirically observed interest rates differentials at the same types of market, e.g. lending or borrowing.

As regards the rest of the system's structural equations, some of parameters are similarly numerically estimated, others are set to reasonable values, based on historical observations. For example, a key macroeconomic relationship, such as the elasticity of nominal income (GDP) to nominal credit (Equation 18) is calibrated to 0.33, based on econometric estimates on historical time-series data. Numerical estimation of parameters, governing the behaviour of local households (and companies) is prevented by the lack of disaggregated household- and firm-level data.

Values for the most important parameters and variables are displayed characterising the initial equilibrium allocation are reposted in Table 2. Furthermore, there are parameters related to policy and some exogenously fixed parameters. The cut-off point of data input is the end of June 2009, i. e. end of 2009Q2, a period reflecting a sufficient part of the experience during the global financial and economic crisis.

The 'good' state p_i, defined as the more favorable state of economy, is expected to occur with 90% probability. Subscripts δ and γ represent the variables related to two major banks, while the rest of the banking system is represented by subscript τ. With actually observed 3.0% annual contraction in nominal GDP in 2009Q2, expected GDP in the 'good' state contracts by 1.5% (18.3 million Lev) and in the 'bad' state by 6% (17.5 million Lev).

The parameters characterising policy of the foreign monetary authority are the key lending rate ρ set at 1.55%, and the deposit penalty rate ψ set at 0.50%. Those match individual and aggregate banks' reports on interest rates on interbank loans and deposits. The interbank lending rate differs only marginally from the 1.00% rate applied by ECB in lending to Euro area's banks. The higher lending rate can be attributed to an overall country risk premium or intermediation premium required by the foreign bank owners.

The local monetary authority sets the reserve requirements at 15% for interbank deposits ζ^d and 10% of local deposits ζ^M. The local regulatory authority defines the formula for calculating the capital adequacy ratios k_s^b, their quarterly public reporting frequency, enhancing market transparency and reputational effects, and their minimal threshold $\overline{k}_s^b$. Due to the strong reputational role of banks reporting on their capital adequacy, loan-loss provisions and profits, all banks exceed the required minimum for capital adequacy. The method of calculating banks' capital adequacy includes setting the asset weights: $\widetilde{w}$ on household loan portfolio at 100%, $\overline{w}$ on market book at 90%; and w on bank's interbank loans of 20%.

Even though the same foreign monetary policy parameters apply to all local banks, the individual cost of finance from foreign bank owners r^b differs. It is lowest for bank γ at 1.70% and highest for bank δ at 2.62%. That is due to the large size of interbank deposits D^b the bank δ holds at the foreign bank owner in relation to its net liquid funds received $(M^b - D^b)$.

Interest rates formed by the supply and demand conditions on the local depositors market r_d^b are equal or slightly lower than their alternative bank funding costs from foreign banks. Bank τ followed by bank γ attracts highest share of local deposits due to the higher interest rates, net of default probability, that they are able to offer.

The default probability of banks is assumed to be small in the 'good' state of nature, with repayment rate on financial obligation v_i^b of 99%. In the 'bad' state of nature, however, the probability of default

Table 2 Initial equilibrium: bank balance sheet variables, market interest rates, and main policy parameters

Levels are in million Lev

	ρ	ψ	r^b	r^b_d	$\overline{r}^b$	D^b	M^b	μ^b	d^b
τ	1.5%	0.05%	2.16%	2.16%	7.08%	4.886	8.518	3.710	33.551
γ	-	-	1.70%	1.60%	10.02%	0.250	0.996	0.758	5.321
δ	-	-	2.62%	1.23%	7.66%	1.799	2.557	0.778	3.343
	v^b_i	v^b_{ii}	$v^{h^b}_i$	$v^{h^b}_{ii}$	π^b_i	π^b_{ii}	$\overline{m}^b$	$\overline{\mu}$	μ^b_d
τ	99.0%	97.0%	97.8%	94.0%	1.361	0.669	35.663	38.187	34.274
γ	99.0%	96.0%	95.2%	92.0%	0.326	0.246	7.412	8.155	5.406
δ	99.0%	98.0%	96.2%	89.0%	0.285	-0.280	7.827	8.427	3.384
	e^b_0	e^b_i	e^b_{ii}	k^b_i	k^b_{ii}	A^b	U^b	GDP_i	GDP_{ii}
τ	7.704	9.065	8.373	21.7%	20.8%	3.715	0.612	18.325	17.488
γ	1.698	2.024	1.944	25.1%	24.9%	0.272	0.189		
δ	1.723	2.008	1.444	23.1%	16.6%	0.910	0.142	(-1.5%)	(-6.0%)
			ζ^M	ζ^d	$\widetilde{w}$	$\overline{w}$	w	r^A	p_i
			15%	10%	100%	90%	20%	2.7%	90%

for banks differ. They are highest for bank γ, with repayment rate v^{γ}_{ii} of 96%, and lowest for bank δ with repayment rate v^{δ}_{ii} of 98%. The default probabilities of households on their loan portfolios are higher. Their debt repayment rates range between 97.8% and 95% in the 'good' state of nature and in the 'bad' state of nature between 94% and and 89%. This is also a factor reflected in the heterogeneity in lending rates to households, which vary between 10.02% and 7.08%. In expectations terms, the loan portfolio of bank γ is most risky, followed by that of bank δ, which corresponds to the same ranking in terms of interest rates on loans charged by banks.

Bank τ ranks highest in terms of expected utility, profits and equity, followed by bank γ ranking second. Market book A^b takes a minor share of bank assets with moderate return of 2.7%. Capital adequacy in the model varies between 25.1% and 21.7% in the 'good' state k^b_i, and between 24.9% and 16.6% in the 'bad' state.

Banks' risk aversion preferences constitute an essential part of model's structure, see Table 3. According to the numerical evaluation, bank γ ranks highest on risk aversion towards ever rising profits c, followed by δ. The banks' risk aversion to high profits is lower during 'bad' states of nature, relative to 'good' ones. This makes sense intuitively, because in the 'bad' states of nature profits are also more moderate.

Banks' aversion towards default on deposits from foreign banks λ appears to be minimal for bank δ, while highest in terms of expectations for bank γ. While bank τ is relatively more averse towards default in the 'bad' state of nature, bank γ fears more default in the 'good' state of nature.

Note that the parameters on risk aversion towards default on interbank liquidity and local deposits should be analysed jointly. For example, in the case of bank δ there appears to be minimal const of default on interbank funds, while exceptionally high cost of default on liquidity from local deposits. Given the rational expectations framework, these preferences are already incorporated in the initial conditions. The bank faces high costs and low volume of net interbank funding, combined with low interest rate and high volume of funding from local deposits. Because a bank chooses its probability of default on all obligations, its choice would equate the marginal costs and benefits between the two alternative liabilities. An increase in the probability of default by the bank will have to be accompanied by an increase in its net interbank obligations and a joint strong decline its holdings of local deposits. The latter would depend on the supply of local deposits, highly sensitive to overall incomes, interest rate conditions and the strategies pursued by the competitors - banks τ and γ. In short, because in a general equilibrium context outcomes and choices result from the initial allocation, risk preferences and the interaction of agents with heterogeneous preferences, no single parameter can be exclusively responsible for a particular decision. Bank δ would choose a certain default on all obligations only on a partial equilibrium setting and only under zero initial holdings of local deposits.

Banks's risk aversion towards default on local deposits λ_d is higher than that on foreign banks deposits for banks δ and γ. Risk aversion becomes particularly high for them in the 'bad' state of nature. Apparently those banks view partial default on local depositors as relatively more costly, due to their fear of the possibility of triggering a bank run. That risk might be particularly important during 'bad' states of nature. The preference towards reporting higher capital adequacy contains the reputational effects of banks' desire to demonstrate stability. It is most moderate for bank τ and highest for bank γ.

Table 3 Banks' risk preference parameters evaluated given initial equilibrium

b	c_i^b	c_{ii}^b	λ_i^b	λ_{ii}^b	$\lambda_i^{b,d}$	$\lambda_{ii}^{b,d}$	$\lambda_i^{b,k}$	$\lambda_{ii}^{b,k}$
τ	0.33	0.19	0.20	0.43	0.10	0.79	0.20	0.15
γ	0.70	0.30	0.80	0.20	0.58	1.00	0.50	0.38
δ	0.51	0.26	0.01	0.01	0.90	1.50	0.20	0.66

5 Monetary Transmission

5.1 Monetary policy of foreign monetary authority: a decline in policy interest rate

Consider the case of a decline by 0.5% in the policy interest rate set by the foreign monetary authority. The overall effect to the wider economy is expansionary and estimated to increase the GDP growth by 0.8% in the good state of nature and 0.7% in the bad state, see Table 5. The results stem from three mutually interlinked forces: initial conditions, risk preferences and market interaction.

The cost of borrowing from the foreign monetary authority's lending facility becomes 1.0%, from 1.5% previously. Banks' deposit facility holdings are kept constant in non-crisis times earning an penalty interest rate of 0.5%, from 1% previously. On aggregate there is higher demand for interbank liquidity and to maintain the reduced interbank lending rate, the foreign monetary authority supplies increased aggregate liquidity M. The cost of net interbank funding declines for all banks.

The new portfolio allocation of the banking system is determined by the decisions of bank τ and bank γ. They demand more liquidity from the interbank market, but that is partly substituted by less demand for local deposits. The effect is driven by the desire to equate the marginal cost of default on interbank liquidity to the marginal cost of default on local deposits, given a single default probability. Because for both banks default on interbank liquidity is relatively more costly, a unit of interbank liquidity is substituted by less than a unit of local deposits. The upward pressure on the default probabilities of the two banks is motivated by higher interbank funding, being only partially offset by downward pressures from reduced resort to local deposits.

The banks τ and bank γ undertake an expansionary credit policy increasing the supply of credit to their respective households, which on aggregate relaxes the overall liquidity constraints in the economy and contributes to higher rationally anticipated household income. That feeds back into safer return on investment in household loans, exerting positive pressure on profits, capital adequacy and overall utility.

Table 4 Transmission of a decline in policy interest rate of foreign monetary authority

$\Delta\rho = -0.5 \Longrightarrow \{\Delta GDP_i = +0.142(+0.8\%); \Delta GDP_{ii} = +0.136(+0.7\%)\}$

b	Δr^b	Δr_d^b	$\Delta \overline{r}^b$	ΔM^b	$\Delta \mu^b$	Δd^b	$\Delta \mu_d^b$	$\Delta \overline{m}^b$	$\Delta \overline{\mu}^b$
τ	-0.66%	-0.69%	-1.05%	1.257	1.252	-0.082	-0.316	1.006	0.694
γ	-0.54%	-0.63%	-1.05%	0.253	0.252	-0.011	-0.045	0.208	0.148
δ	-0.44%	1.09%	0.74%	-0.039	-0.043	0.028	0.065	-0.008	0.049
b	Δv_i^b	Δv_{ii}^b	$\Delta v_i^{h^b}$	$\Delta v_{ii}^{h^b}$	$\Delta \pi_i^b$	$\Delta \pi_{ii}^b$	Δk_i^b	Δk_{ii}^b	ΔU^b
τ	-0.04%	-0.11%	0.15%	0.19%	-0.005	0.029	-0.04%	-0.11%	-0.007
γ	-0.16%	-0.92%	0.15%	0.19%	-0.006	0.046	-0.16%	-0.92%	-0.014
δ	1.10%	1.64%	0.15%	0.18%	-0.010	-0.033	1.10%	1.64%	0.027

Levels are in million Lev

There are also negative pressures, which prevail in equilibrium, determined by the reduced interest return on household loans.

In this environment bank δ makes a different portfolio choice, leading to increased overall utility. This bank is characterised with exceptionally high costs of default on domestic deposits relative to those on foreign liquidity. In that case, a unit increase in the demand for interbank liquidity would induce more than a unit contraction in the demand for deposits. A potential increase in the bank's probability of default would induce depositors to switch to other banks. This would be most unfortunate since according to the initial market allocation, the bank faces lower interest rates on the local deposit market.

By deciding to increase its demand for local deposits, bank δ benefits from the increased pool of local deposits due to higher household income. The bank optimally chooses lower probability of default on obligations in order to further attract new local depositors switching from the other two banks, which pursue the opposite strategies (i. e. increased default probability and lower demand for deposits). To ensure equal marginal benefit of default on all obligations, a unit increase in local deposits is substituted by a slight decline in demand for interbank liquidity.

Higher household incomes also contribute to lower probabilities of household default delivering safer return from household lending. Given the aggregate expansion, bank δ decides to be more conservative than its competitors by keeping nearly fixed its supply of loans to households resulting in higher equilibrium return on lending to households. Independently of the reduced profit, this delivers higher capital adequacy ratio and utility.

5.2 Monetary policy of foreign monetary authority: a decline in penalty on deposit interest rate

The foreign monetary authority is endowed with a non-standard monetary policy instrument – the penalty rate on the interest rate earned by interbank liquid funds kept at its deposit facility. The penalty rate is the difference between the lending rate on interbank liquidity and the deposit interest rate earned when keeping it safe but unutilised at the central bank. Let us compare and contrast the effectiveness of this policy instrument to the already considered standard one.

A decline by 0.5% in the penalty rate on interbank deposits at the foreign monetary authority would reduce the markup on net interbank funding. Banks which initially face higher markup due to their large deposit holdings at the foreign monetary authority would benefit most. For example, bank δ which keeps interbank deposits amounting to 70% of its interbank borrowing, experiences a reduction in net interbank funding costs by 1.07%. For bank γ which deposits only 25% of borrowed interbank funds, the reduction in net interbank funding costs is only 0.15%. For the rest of the banking system represented by bank τ, the reduction in interbank funding costs is 0.61%.

The transmission mechanism is very similar to that resulting from the previous experiment involving a comparable reduction in the interbank lending rate. The decline in the penalty rate on interbank deposits, however, leads to lower impact on wider economy by increasing income in the good and bad states of nature by only 0.5%, see Table 5. This is because the reduced interbank funding costs benefit banks unevenly, placing higher benefit on most conservative banks, such as bank δ, for structural reasons collateralising larger proportion of interbank borrowing. As in the standard benchmark, banks τ and bank γ underly the overall increase in demand for interbank liquidity, decline in demand for domestic deposits, higher probability of default and credit supply. Their expected profits decline, along with capital adequacy and utility. The magnitude of the systemic response to the shock is more muted, due to the slightly lower decline in interbank borrowing costs to bank τ and γ, and the more pronounced contractionary impact of the behaviour of bank δ.

5.3 Monetary policy of the local monetary authority: a decline in required reserves on foreign interbank liquidity

The local monetary authority is in possession of an alternative non-standard implementation tool consisting of setting and changing the required reserves ratio. This experiment studies the transmission of a

Table 5 Transmission of a decline in penalty on deposit interest rate of foreign monetary authority

$\Delta\psi = -0.5\% \Longrightarrow \{\Delta GDP_i = 0.098(+0.5\%); \Delta GDP = 0.093(+0.5\%)\}$

b	Δr^b	Δr^b_d	$\Delta \overline{r}^b$	ΔM^b	$\Delta \mu^b$	Δd^b	$\Delta \mu^b_d$	$\Delta \overline{m}^b$	$\Delta \overline{\mu}^b$
τ	-0.61%	-0.64%	-0.92%	1.063	1.058	-0.120	-0.336	0.806	0.528
γ	-0.15%	-0.20%	-0.43%	0.130	0.131	-0.005	-0.016	0.107	0.086
δ	-1.07%	1.58%	1.15%	-0.134	-0.144	0.033	0.087	-0.085	-0.003
b	Δv^b_i	Δv^b_{ii}	$\Delta v^{h^b}_i$	$\Delta v^{h^b}_{ii}$	$\Delta \pi^b_i$	$\Delta \pi^b_{ii}$	Δk^b_i	Δk^b_{ii}	ΔU^b
τ	-0.04%	-0.10%	0.11%	0.13%	-0.004	0.025	-0.30%	-0.22%	-0.006
γ	-0.05%	-0.44%	0.10%	0.13%	-0.003	0.024	-0.32%	0.02%	-0.006
δ	1.85%	3.46%	0.10%	0.12%	-0.029	-0.093	-0.36%	-1.09%	0.038

Levels are in million Lev

decline by 0.5% of the required reserve ratio on foreign liquidity. The overall impact on wider economy is evaluated at 0.2% increase in income growth in both states of nature, see Table 6.

Under the lower reserve ratio, all banks would need to keep lower amount of reserves as proportion of their total interbank borrowing M. Other things being equal, this would free up liquidity in the banking system, which is partly utilised to support higher supply of household loans. The credit expansion is strongest in banks with higher initial interbank borrowing. Banks rationally expect higher household income resulting in safer but less profitable lending activity, due to lower equilibrium interest rates.

Furthermore enquired reserves kept at the local monetary authority serve as a partial guarantee on bank's total borrowing obligations limiting the benefit of default. A reduction in reserves, increases the benefit of default inducing higher probability of default. Part of extra liquidity is superfluous and results in reduced demand for net interbank funding, and to a lesser extent reduced demand for local deposits. Higher anticipated income results in an increase in the pool of local depositors, and increased supply of local liquidity to all banks. The equilibrium deposit rates decline. The overall utility of the banking system declines slightly, driven by declining expected capital adequacy, profits and default penalties. The overall impact on economic expansion and banking sector utility is most muted in comparison with the considered interest rate policies.

Table 6 Transmission of a decline in required reserves on foreign interbank liquidity

$\Delta\zeta^M = -5.00\% \Longrightarrow \{\Delta GDP_i = 0.036(+0.2\%); \Delta GDP_{ii} = 0.034(+0.2\%)\}$

b	Δr^b	Δr_d^b	$\Delta \overline{r}^b$	ΔM^b	$\Delta \mu^b$	Δd^b	$\Delta \mu_d^b$	$\Delta \overline{m}^b$	$\Delta \overline{\mu}^b$
τ	0.06%	-0.07%	-0.12%	-0.307	-0.312	0.023	0.001	0.167	0.137
γ	0.00%	-0.07%	-0.15%	-0.015	-0.016	0.003	-0.001	0.039	0.031
δ	0.04%	-0.55%	-0.61%	-0.024	-0.025	-0.007	-0.026	0.099	0.058
b	Δv_i^b	Δv_{ii}^b	$\Delta v_i^{h^b}$	$\Delta v_{ii}^{h^b}$	$\Delta \pi_i^b$	$\Delta \pi_{ii}^b$	Δk_i^b	Δk_{ii}^b	ΔU^b
τ	-0.01%	-0.01%	0.04%	0.05%	0.001	-0.007	-0.07%	-0.09%	-0.001
γ	-0.04%	-0.01%	0.04%	0.05%	0.000	-0.003	-0.10%	-0.15%	-0.002
δ	-0.43%	-0.33%	0.04%	0.05%	-0.003	-0.012	-0.19%	-0.24%	-0.017

5.4 Contingent stress scenario: externally generated liquidity crunch

The model quantifies the systemic and macro consequences of a scenario in which one of the local banks experiences an externally generated liquidity crunch and stops receiving net financing from its foreign bank owner. The hypothetical consequences of this type of adverse scenarios have long been debated by policy-makers and economists, both before and during the global financial crisis, without a rigorous quantification by a structural macro model. The model presented here is able fill this knowledge gap. According to it, if a major bank in the banking system experiences a liquidity crunch, the wider economy would shrink by 1.1%. Thus, the impact would be significant, but by no means a disorderly and disastrous scenario. This is because individual banks adjust their optimal response and absorb the shock, utilising available own and systemic liquidity buffers. The monetary transmission results are listed in Table 7.

During such a liquidity crunch, bank γ would receive no net funding from its foreign owner, but it would still be able to use own deposits initially held at its foreign bank owner (i.e. $M^\gamma = D^\gamma$). The effective cost of borrowing from the interbank market will decline to zero, there would be no reputational cost on non-repayment of foreign obligations, as well as no minimum reserve requirements on foreign interbank loans. Bank γ would choose to increase its demand for local deposits, reduce substantially its default probability, and support higher interest rates on deposits. Other banks not directly affected by the liquidity clunch, experience insufficient supply of local deposits. This is because some local depositors decide to switch to bank γ, and additionally because of the shrinking pool of depositors due to rationally

Table 7 Externally generated liquidity crunch to bank γ: no net borrowing from foreign bank owner

$\{M^\gamma = D^\gamma; r^\gamma = 0\} \Longrightarrow \{\Delta GDP_i = -0.212(-1.1\%); \Delta GDP_{ii} = -0.202(-1.1\%)\}$

b	Δr^b	Δr_d^b	$\Delta \overline{r}^b$	ΔM^b	$\Delta \mu^b$	Δd^b	$\Delta \mu_d^b$	$\Delta \overline{m}^b$	$\Delta \overline{\mu}^b$
τ	0.50%	0.53%	0.96%	-1.270	-1.278	-0.048	0.128	-1.136	-0.873
γ	-1.61%	3.30%	4.62%	-0.828	-0.841	0.082	0.262	-0.637	-0.383
δ	0.58%	-1.46%	-0.99%	0.043	0.048	-0.045	-0.094	-0.004	-0.081
b	Δv_i^b	Δv_{ii}^b	$\Delta {v_i^h}^b$	$\Delta {v_{ii}^h}^b$	$\Delta \pi_i^b$	$\Delta \pi_{ii}^b$	Δk_i^b	Δk_{ii}^b	ΔU^b
τ	0.03%	0.09%	-0.23%	-0.29%	0.005	-0.030	0.50%	0.41%	0.006
γ	1.04%	4.38%	-0.22%	-0.28%	0.024	-0.176	1.53%	-1.11%	0.062
δ	-1.48%	-2.13%	-0.22%	-0.27%	0.012	0.041	0.40%	0.65%	-0.037

expected reduction in income. Bank δ seems particulary affected since it is only able to offer declining deposit interest coupled with increase in its default probability.

All banks supply less credit to their nature-selected households, the latter also characterised with higher probability of default. Still, banks manage to maintain healthy increase in expected profit and capital adequacy ratios.

6 Conclusion

This paper extends a class of models developed by Tsomocos (2003) and Goodhart et al. (2005, 2006) to evaluate and compare the international transmission of standard and non-standard monetary policies used during the global financial and economic crisis. The model represents a numerically evaluated open economy general equilibrium model for macro-prudential analysis where optimal decisions by internationally linked financial intermediaries are key determinants of international financial flows and wider economic outcomes. Financial intermediaries are different in terms of balance sheet endowments, liquidity and risk preferences, and take decisions on borrowing, lending and partial default rationally and competitively impacting the wider economy. Default risk is an endogenous result of individual decisions of private agents (banks and households), as well as a systemic outcome of market interaction. The deep risk preference parameters are numerically estimating by mapping the non-linear behavioral conditions to detailed individual regulatory banking data on Bulgaria.

The paper studies the systemic financial transmission to wider economy of comparable policy impulses stemming from standard policy, which involves the refinancing rate of the foreign monetary authority, and two non-standard instruments, related to the penalty rate on banks' holding at the foreign deposit facility and the minimum reserve requirements imposed by the local monetary authority. The non-standard policies are found to be meeting expectations in terms of directions of aggregate impulses to the wider economy. However, their effectiveness is smaller due to inefficient distribution of stimulus within the banking system and the financial markets. Nevertheless, the non-standard policies are found to contribute to the resilience of the banking system and wider economy in case of a liquidity crunch in the interbank market by ex-ante encouraging banks to be more self-reliant and maintain sufficient liquidity buffers.

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