

# Persistent Liquidity Shocks and Interbank Funding\*

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## Abstract

I develop a theory of multiple maturity segments on the interbank market based on banks' liquidity management and persistence of liquidity shocks. The developed framework is embedded in a micro-founded network model which features interbank funding as an over-the-counter phenomenon and replicates financial system phenomena of network formation, monetary policy transmission, and endogenous money creation. This setup is used to shed light on the purpose of the interbank market and its role for allocation and stability in the financial system. An optimal policy analysis, in which the policymaker faces a trade-off between credit supply and financial fragility, provides evidence that an efficient interbank market though being a potential channel of contagion allows for considerable gains in economic activity.

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## 1. Introduction

The interbank market plays a fundamental role for an efficient and stable financial system, transmission of monetary policy, and ultimately economic activity. I develop a theory of multiple maturity segments on the interbank market based on persistence of liquidity shocks and banks' liquidity management. Understanding as to why banks fund each other at longer maturities is important, because it affects the interbank market's role

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in the financial system, in particular as regards network structure and banks' liquidity risk exposure. In an interbank market with term component, part of the network becomes 'hard-wired', and banks can use it as an instrument to address (term) funding and interest rate risks. That is, the term interbank market affects both, systemic risk as well as bank-individual risk management. The developed framework is embedded in a micro-founded network model, which features interbank funding as an over-the-counter (OTC) phenomenon and replicates financial system phenomena of network formation, monetary policy transmission, and endogenous money creation. This setup is used to shed light on the purpose of the interbank market and its role for allocation and stability in the financial system. An optimal policy analysis, in which the policymaker faces a trade-off between credit supply and financial fragility, provides evidence that an efficient interbank market though being a potential channel of contagion allows for considerable gains in economic activity.

To motivate multiple maturity segments on the interbank market, this paper extends the prevalent co-insurance motive in the interbank literature with a maturity dimension driven by persistence of liquidity shocks. Crucially, being financial intermediaries, banks provide credit and liquidity to the real economy. To efficiently fulfill this function, banks insure on the interbank market against liquidity shocks, that is, in- or outflows of funds.<sup>1</sup> Faced with persistent, that is long lasting liquidity shocks, most financial institutions carry out liquidity management by limiting expected future cash flow mismatches in future periods.<sup>2</sup> In particular, limiting the gaps of expected cash in- and outflows in a so-called maturity ladder allows banks to reduce investment risks (interest change and funding risks) and to fulfill regulatory requirements. Given that cash-flows largely remain within the banking system, banks can hedge emerging liquidity gaps at different maturity brackets on the interbank market.<sup>3</sup> For example, if a bank provides a new business loan, it subsequently faces a persistent outflow of liquidity (the debtor uses the 'created deposits')<sup>4</sup> over the time horizon of the loan. The bank can subsequently refinance this

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<sup>1</sup>For the important role of banks in credit and liquidity provision see, for example, Diamond and Dybvig (1983). See Allen, Carletti and Gale (2009). Also see Allen and Gale (2000) who show that the interbank market can overcome a maldistribution of liquidity in a setting where banks face liquidity shocks.

<sup>2</sup>See Committee of European Banking Supervisors (2008) who outlines that "the vast majority of credit institutions use maturity mismatch approaches [for liquidity management]: i.e., models that compare cash inflows and outflows for different time horizons in order to calculate net funding requirements, which are then used to set liquidity limits. This method is recommended by the Basel Committee on Banking Supervision's Sound Practices for Liquidity Risk Management." Similarly, the Federal Deposit Insurance Corporation (2015, Chapter 6.1) prescribes that "Policies [for liquidity management] should reflect the board's tolerance for risk [...]. Typical risk guidelines include [...] targeted cash flow gaps over discrete and cumulative periods and under expected and adverse business conditions. Also see European Central Bank (2002) and Basel Committee on Banking Supervision (2008).

<sup>3</sup>While banks don't conduct their liquidity management exclusively via the interbank market, note that Bluhm, Georg and Krahnert (2016) provide evidence that banks indeed match maturities of (persistent) liquidity shocks in their client book, which consists of deposits and business loans, with their interbank book, consisting of interbank lending and borrowing. In particular, they find an interbank book that reflects the underlying changes in the client book in the sense of a mirror image: A bank's interbank borrowing increases in the term segment subsequent to providing a business loan with a longer maturity. Similarly, if the bank faces an inflow of term deposits, its interbank lending increases mainly in the same maturity segment.

<sup>4</sup>See McLeay, Radin and Thomas (2014) for an outline of money creation by banks' when emitting business loans.

persistent liquidity outflow on the interbank market, matching expected future inflows of credit down-payments for the loan with outflows of the money borrowed. As a further example for persistent liquidity shocks consider liquidity surpluses or shortfalls driven by random deposit fluctuations. Noting that banks have a broadly stable deposit base,<sup>5</sup> temporary deviations from that ‘socket’, driven by customers’ transactions, gradually vanish over time. Similar to the example above, banks can include their expectation about these cash-flow dynamics for their liquidity management. Existing liquidity regulation stemming from these considerations allows banks to invest up to 90% of (short-term) liquidity inflows at long-term maturities.

Overall, interbank studies, persistence of liquidity shocks, and banks’ practice of liquidity management point toward an important role of a maturity dimension on the interbank market. In line with the extant literature, this paper models the interbank market as a mutual liquidity insurance scheme. However, unlike previous theoretical and empirical analyses, which mainly take into account the interbank market’s short-term segment, the focus is put on the entire maturity structure.

Given that the interbank market is a network of banks, tools developed for complex systems analysis are well suited for an analysis of its role as a buffer for (persistent) liquidity shocks.<sup>6</sup> From a network perspective, each bank is a node and connected to other banks by lending and borrowing (so-called edges in network theory). However, as opposed to physical networks such as electricity grids, the nodes on the interbank market are heterogeneous and dynamically react to the system’s evolution to achieve their profit maximization objective. To take this into account and investigate the interbank market and its maturity structure, a micro-founded network model which interacts with a firm sector as well as a household sector is developed. This theoretical approach combines several advantages. First, it allows for modeling heterogeneity in the financial system. Banks’ assets and liabilities are determined endogenously based on an analytically derived profit maximization objective. Second, the interbank market is modeled as an OTC market with different term segments in which banks interact and bargain for funds. Network formation is not random but depends on micro-foundations and reflects real world interbank phenomena such as relationship lending, and interbank intermediation.<sup>7</sup> Third, a central bank that acts as lender of last resort, and whose policy decisions are transmitted by the interbank market is included to allow for policy driven welfare analysis.

By extending the literature on interbank markets with a maturity dimension in a micro-founded network model, the paper relates to four strands of the theoretical literature. First, it is related to the literature which models the interbank market as a mutual insurance instrument for liquidity shocks as in Bhattacharya and Gale (1987), Allen and Gale (2000), Freixas, Parigi and Rochet (2000), and Allen, Carletti and Gale (2009).<sup>8</sup>

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<sup>5</sup>See Wagner (1857).

<sup>6</sup>For an overview on network and complex systems analysis see, for example, Lewis (2009). See Georg (2013), Bluhm and Krahn (2014), Bluhm, Faia and Krahn (2014), and Faia, Delli Gatti and Ladasoro (2015) for analyses of the financial system using complex systems analysis.

<sup>7</sup>See Bluhm et al. (2016) who define interbank intermediaries as banks which simultaneously hold sizable amounts of interbank assets and liabilities at similar maturities. In their sample of German commercial banks, the large majority (70% to 80%) are interbank intermediaries.

<sup>8</sup>Alternative approaches view the interbank market as an instrument for peer monitoring (see, for example, Rochet and Tirole (1996)) or as a mechanism to become too interconnected to fail and engage in herding behavior (see Eisert and Eufinger (2014)).

The basic role of interbank markets in these models is to re-allocate liquidity from banks with an excess to banks with a deficit. The contribution of this paper lies in extending the theoretical interbank literature with an explicit maturity dimension to shed light on the role of the interbank market as a buffer for persistent liquidity shocks.

Second, the paper is related to the literature on financial networks (see Gale and Kariv (2007), Georg (2013), Bluhm and Krahnén (2014), Farboodi (2014), in ‘t Veld, van der Leij and Hommes (2014), Vuillemeij and Breton (2014), Blasques, Bräuning and van Lelyveld (2015), and Babus (2016)). In particular, Georg (2013) as well as Bluhm and Krahnén (2014) investigate the effect of different network structures on financial fragility in models of interlinked bank balance sheets. The main innovation of this paper relative to that strand of the literature is to extend interbank network models along several dimensions, including heterogeneous and endogenously evolving interlinked bank balance sheets and an adverse feedback loop between real and financial sectors in the spirit of Bernanke, Gertler and Gilchrist (1996) and Kiyotaki and Moore (1996)’s financial accelerator.

Third, the paper relates to the literature on monetary policy carried out in an interest rate corridor with standing facilities (see Poole (1968), Whitesell (2006), Berentsen and Monnet (2008), and Blasques, Bräuning and van Lelyveld (2015)). Here, the main innovation is to introduce endogenous money creation and financial stability considerations resulting from the central banks policy stance to the model. In particular, the model allows for optimal monetary policy analyses in which the policymaker maximizes sustainable economic activity in a trade-off between loan supply and financial fragility.

Fourth, the paper is related to bargaining among trading partners in OTC markets as in G. Afonso and Lagos (2012), Bech and Monnet (2013), Babus and Kondor (2013), and Babus and Hu (2015). I add to that literature by using valuation of trading assets similar to Duffie, Gârleanu and Pedersen (2007), however in a discrete time setting and focus on network formation among profit maximizing banks.

The remainder paper is structured as follows. Section 2 develops a stylized model to motivate and investigate the (term) interbank market as a tool for banks’ liquidity management. Furthermore, this framework is embedded in a micro-founded network model. Section 3 investigates the model’s (network) properties and carries out an optimal policy analysis. Section 4 concludes.

## 2. Interbank Funding as Insurance Mechanism for Persistent Liquidity Shocks

### 2.1. A Theory of Persistent Liquidity Shocks

Persistence of liquidity shocks arises from banks’ loan emissions as well as deposit fluctuations. First, consider a bank which provides a new business loan. Unlike assumed in fractional reserve banking and loanable funds theories,<sup>9</sup> a bank which provides a loan does not lend deposits it has acquired previously (or obtained as an inflow) but creates them ‘ex nihilo’.<sup>10</sup> That is, when a bank emits a loan (expansion on bank’s asset side) it credits the deposit account (expansion of bank’s liability side) of the loan recipient with the loan. This leads to a balance sheet expansion by the size of the assigned loan amount.

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<sup>9</sup>See, for example, Mankiw (2012) for an outline of the loanable funds model.

<sup>10</sup>See McLeay, Radin and Thomas (2014).

Since the customer uses the loan to finance spending (which was the reason for the loan application), a large fraction of these new deposits leaves the bank for the term of the loan, resulting in a long-term (over the contractual period of the loan) liquidity outflow in the form of cash or reserves from the bank's balance sheet to other banks. The bank can subsequently refinance itself on the interbank market to fulfill liquidity regulations, matching the maturity profile of the loan, that is, the customer's scheduled tranches of loan repayment, with the interbank loan maturity profile.<sup>11</sup>

Second, consider a bank which experiences an inflow of deposits. Depending on its experience of past in- and outflows it forms an expectation about how long this increased stock of liquidity remains. Based on that expectation it can invest (part of) the inflow in higher yielding (long-term) assets instead of holding them as reserves until they vanish. This persistence of liquidity shocks from deposit fluctuations is motivated by building on the 'socket-theory' which provides a rationale for banks' maturity transformation.<sup>12</sup> In particular, Wagner (1857) points out that while the 'contractual' maturity of demand deposits is daily, many customers leave their deposits for much longer periods without withdrawing them. At the same time some of the outflows which actually take place are substituted by inflows of demand deposits. Since a bank has a large number of customers, and deposit in- and outflows are independent, the law of large numbers can be used to predict a stable base of deposits, which the bank can use for longer term investments, that is, carry out a maturity transformation. Existing liquidity regulations ultimately stem from the considerations laid out in that basic theory.<sup>13</sup> Below I use theoretical extensions of Wagner (1857) to show how banks can use the interbank market as a buffer against liquidity shocks across a range of maturities. I first focus on persistent liquidity shocks from deposit fluctuations to highlight the interbank market's scope for banks' liquidity management, but later also include banks' business loan emission as a source of persistent liquidity shocks.

To investigate persistence of liquidity shocks in a simple framework, consider the following stylized modeling approach. For an individual bank, the amount of deposit outflows depends on *its* customers' payments which they carry out for economic transactions. For the same bank, the amount of deposit inflows depends on *all* banks' customer transactions and *that bank's* branch share. Banks with a bigger network of branches in the economy likely face higher deposit inflows than those with a smaller network of branches. Deposit withdrawals and inflows are both assumed to be uniformly and independently distributed. Figure 1 displays deposit fluctuations from Bank  $i$ 's perspective. In Figure 1,  $U$  denotes a draw from a uniform distribution,  $d^i$  is bank  $i$ 's stock of deposits, and  $BS^i$  denotes its branch share. Note that in expectation bank  $i$ 's stock of deposits is constant if its deposit inflows equal its outflows, that is,  $IF = OF$ . Assuming that  $BS^i = \frac{d_{init}^i}{\sum_j d_{init}^j}$ ,  $i \in j$  with the index '*init*' indicating a bank's initial endowment with deposits, in expectation each bank's deposits remain stable as long as the amount of deposits in the economy does not change and banks maintain their share of bank

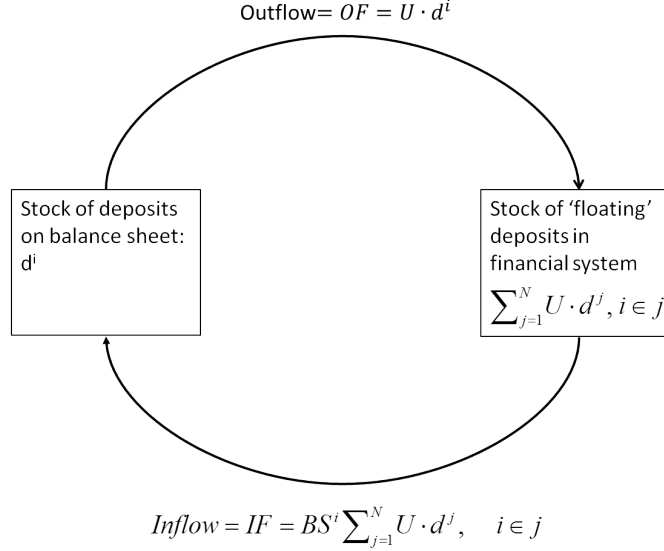
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<sup>11</sup>For further details on banks' asset-liability and liquidity management see European Central Bank (2002), Basel Committee on Banking Supervision (2008), Committee of European Banking Supervisors (2008), and Federal Deposit Insurance Corporation (2015, Chapter 6.1).

<sup>12</sup>The socket theory was introduced by Wagner (1857).

<sup>13</sup>For example, German liquidity regulations require 10% of demand deposits be held as reserves while 90% can be held at longer maturities. See Deutsche Bundesbank (2014).

Figure 1: Deposit Flows Between Bank  $i$  and the Financial System



Note: The figure displays deposit flows between bank  $i$  and the financial system consisting of  $j$  banks,  $j = 1 \dots i, \dots N$ .  $U$  denotes a draw from a uniform distribution,  $d^i$  is bank  $i$ 's stock of deposits, and  $BS^i$  denotes its branch share.

branches. However, random deposit fluctuations can lead to temporary disequilibria which gradually disappear when the bank reverts to the amount of deposits consistent with its relative branch share in the economy,  $E(d^i) = BS^i \sum_j d^j$ . Consider bank  $i$ 's expected amount of deposits in period  $t + 1$ ,  $E(d_{t+1}^i)$  outlined in Equation (1).

$$\begin{aligned}
 E(d_{t+1}^i) &= d_t^i + E(IF_t^i) - E(OF_t^i) \\
 &= d_t^i + E(BS^i \sum_j U d_t^j) - E(U d_t^i) \\
 &= d_t^i + 0.5 \left( BS^i \sum_j d_t^j - d_t^i \right) \\
 &= d_t^i + 0.5(\text{deposit disequilibrium})
 \end{aligned} \tag{1}$$

Note that in expectation with each additional period, the existing disequilibrium disappears by half, that is, after 5 periods most of the disequilibrium (about 97%) has disappeared.

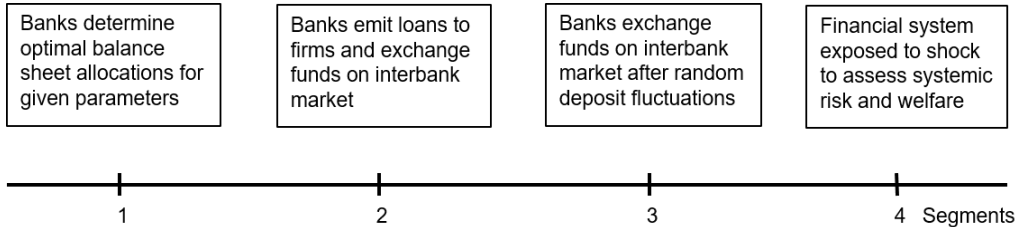
After this stylized formalization of persistence of disequilibria arising from random deposit fluctuations, next consider how the interbank market offers banks a convenient way to buffer these fluctuations. In aggregate, given the nature of deposit in- and outflows, banks can mutually insure, taking into account the maturity profile of shocks. In the following, a similar stylized framework of persistent liquidity shocks driven by business loan emission as well as deposit fluctuations is included in a micro-founded bank-network model of the financial system interacting with household and real sectors.

## 2.2. A Micro-founded Network Model with Persistent Liquidity Shocks

To investigate the effects of persistent liquidity shocks on banks' balance sheets, network structure, systemic risk, and welfare, I develop a micro-founded network model consisting of a financial system with  $N$  banks, a central bank, a household sector, and a real sector. Each bank chooses its optimal portfolio consisting of reserves, loans to the real economy, interbank lending, deposits, and interbank borrowing to maximize expected profit. Banks use the interbank market, which is modeled as an OTC market featuring multiple maturities, to fulfill regulatory requirements and buffer persistent liquidity shocks. The central bank transmits monetary policy decisions by an interest rate corridor on the interbank market, providing unlimited amounts of reserves to banks who are willing to borrow at the marginal lending rate and accepting unlimited amounts of funds from banks who are willing to lend for the deposit rate. Households carry out random economic transactions using bank deposits, and firms, driving real economic activity, demand bank-supplied credit. Importantly, the model features a negative feedback loop between the financial and real sectors, which serves as spillover and amplifying mechanism for shocks emerging in the real economy.

Banks are endowed with an exogenous amount of equity as well as a proportion of the branch network in the economy. Because of different branch endowments, banks are subject to different (i) credit demand from the real economy, and (ii) deposit shocks from households. In particular, banks with a more extensive branch network face higher credit demand from companies and feature a bigger stable socket of deposits. The model can be broken down into 4 consecutive segments. First, the  $N$  banks choose their portfolio to maximize expected profit subject to regulatory constraints. Second, after emitting loans to the real economy, banks lend and borrow on the interbank market to fulfill regulatory requirements. Given that loans generally feature long maturities, banks use the longest maturity segment on the interbank market when exchanging funds. Third, households carry out economic transactions causing a number of random deposit fluctuations, which in turn lead banks again to the interbank market to lend and borrow across multiple maturities to carry out their liquidity management. Fourth, the financial system is exposed to a shock from the real economy and then assessed in terms of systemic risk and welfare. Figure 2 gives an overview of the four segments. Note that, an important innovation with respect to the literature lies in endogenously deriving all banks' (heterogeneous) balance sheet positions based on micro-foundations. That is, in essence the model developed here extends the modeling of Cifuentes, Ferrucci and Shin (2005) and Bluhm and Krahen (2014) by endogenizing and extending the financial system structure (Model Segments 1 to 3) while using the same shock transmission mechanism (Model Segment 4) as these authors. The focus of the following outline therefore lies on Model Segments 1 to 3. In Segment 1 (Figure 2) each bank, endowed with a random amount of equity, determines its desired individual portfolio positions, that is interbank lending and borrowing (including lending and borrowing with the central bank), the amount of loans to the real economy, deposits, and reserves. In particular, each bank maximizes profit which is the revenue from providing loans to the real economy and lending on the interbank market net of the cost from borrowing on the interbank market and holding deposits, subject to

Figure 2: Model Segments



Note: The figure summarizes the four segments of the micro-founded network modeling approach.

regulatory requirements as outlined in Equation (2).

$$E(\pi) = \text{revenue from interbank lending} + \text{revenue from emitting loans} \\ - \text{cost of interbank borrowing} - \text{cost of deposits}$$

$$s.t. \quad \text{capital and liquidity requirements} \tag{2}$$

A detailed outline and derivation of the banks' optimization problem and all individual elements of Equation (2) are given in Bluhm (2015).

After each bank has determined its optimal portfolio, it emits the according amount of loans and deposits (Segment 2 in Figure 2) and turns to the interbank market in case it has a regulatory shortfall or surplus of reserves. The interbank market is modeled as an OTC market where counter-parties are matched and bargain for funds. Furthermore, short term interest rates are steered by a central bank which stands ready to provide reserves at the marginal lending rate and borrow funds at the marginal deposit rate, both in the short term, which in the model is one period. To derive the cost of borrowing on the interbank market across different maturities, I build upon Duffie, Gârleanu and Pedersen (2007) who investigate the valuation of assets in OTC markets. Assume that on the interbank market a lender's reservation price is  $r^{cbdn}$ , the central bank's marginal deposit rate and a borrower's reservation price is  $r^{cbup}$ , the central bank's marginal lending rate. The value of a trade between two counter-parties,  $V$ , is given by the spread on the interbank market:  $V = r^{cbup} - r^{cbdn}$ , and is shared between lender and borrower according to their bargaining power. In any possible lender-borrower match the bargaining power depends on the riskiness of the debtor, that is, riskier counter-parties have weaker bargaining power in sharing the value of the trade. In case of a risky borrower, the lender is compensated with a fair risk premium. To derive this markup, first consider the profit,  $\pi$ , from lending in absence of counter-party risk:  $\pi^l = [\frac{1}{2}(r^{cbup} - r^{cbdn}) + r^{cbdn}] \cdot bl^{ij} = r^{mid} \cdot bl^{ij}$  with  $bl^{ij}$  the interbank lending provided from bank  $i$  to bank  $j$ . In the absence of risk, lender and borrower have equal bargaining power and equally share the gains from trade. That is, the trade takes place at  $r^{mid}$  which results in a gain of 50 basis points for the lender relative to lending its funds to the central bank at the marginal deposit facility and likewise for the borrower who gets the funds 50 basis points cheaper relative to borrowing at the central bank's marginal



lending facility if the central bank puts a corridor of 100 basis points around its desired interest rate,  $r^{mid}$ , on the interbank market.<sup>14</sup>

In case of a risky borrower, expected profit from lending becomes  $E(\pi^{bl}) = (1 - PD) \cdot (r^{mid} + r^r) \cdot bl^{ij} + PD \cdot (bl^{ij} - LGD \cdot bl^{ij}) \cdot (r^{mid} + r^r)$  with  $r^r$  a risk premium for the borrower's default risk, and  $PD$  and  $LGD$  a borrower's probability of default and loss given default, respectively. In a competitive market the lender charges a fair risk premium, that is, in expectation the profit from risky lending equals the profit from safe lending. Therefore  $[\frac{1}{2}(r^{cbup} - r^{cbdn}) + r^{cbdn}] \cdot bl^{ij} = (1 - PD) \cdot (r^{mid} + r^r) \cdot bl^{ij} + PD \cdot (bl^{ij} - LGD \cdot bl^{ij}) \cdot (r^{mid} + r^r)$ . Solving for  $r^r$  yields  $r^r = r^{mid} \cdot \frac{PD \cdot LGD}{1 - PD \cdot LGD}$ . Therefore, the interest rate on the interbank market between two counter-parties is  $r^{ibb} = r^{mid} + r^r = r^{mid} + \frac{PD \cdot LGD}{1 - PD \cdot LGD} \cdot r^{mid} = r^{mid} \cdot (\frac{1}{1 - PD \cdot LGD})$ . Note that a possible trade only takes place if  $r^{bb} \leq r^{cbup}$ . If a bank faces a higher interest rate on the interbank market than charged by the central bank it borrows from the latter. Assuming market participants expect no interest rate changes by the central bank, an interbank yield curve can be computed as the geometric mean of the expected return of short term lending with a liquidity premium,  $\epsilon$ .<sup>15</sup> Note that interest rates on interbank loans and deposits are paid from banks' revenue from lending activity on the interbank market as well as loan provision to the real economy. Any remaining surplus, that is profit, is paid out to the equity holders.

Optimal counter-party matches on the interbank market are found by an iterative scoring algorithm following two criteria, a relationship criterion<sup>16</sup> and an efficiency criterion. The relationship criterion captures that banks tend to form links with counter-parties they have exchanged funds with before, and the efficiency criterion ensures that banks exchange funds with counter-parties seeking relatively similar amounts. In particular, matching consists of two steps. In Step 1, for each possible lender-borrower pair  $ij, i \neq j$ , a score is computed as  $S_{ij} = (1 + \mathbf{1}_{connected} \cdot \pi_{ij}) \pi_{ij}$  with  $\mathbf{1}$  an indicator function equal to 1 if the bank-pair is connected on the interbank market and  $\pi_{ij} = \frac{1}{|ibl_i - ibb_j|}$  where  $ibl$  and  $ibb$  denote desired interbank lending and borrowing, respectively.<sup>17</sup> Note that the relationship criterion is weighed higher, that is, ceteris paribus for similar amounts of lending and borrowing, banks who traded with each other before will tend to exchange funds.<sup>18</sup> In Step 2, based on the scores, funds are exchanged among lender-borrower pairs. The highest score identifies the optimal lender-borrower pair, which exchanges  $\min(ibl_i, ibb_j)$ .<sup>19</sup> Both banks,  $i$  and  $j$  are removed from the current set of scores and the next highest score identifies the following optimal lender-borrower pair. Once there

<sup>14</sup>See Poole (1968), Whitesell (2006), Berentsen and Monnet (2008), and Blasques, Bräuning and van Lelyveld (2015) for similar models in which monetary policy carried out in an interest rate corridor with standing facilities.

<sup>15</sup>For example, the return for lending for two periods,  $r_2$ , instead of one period,  $r_1$ , can be computed as  $(1 + r_2)^2 = \epsilon_2^2 + (1 + r_1)^2$ . In the model the liquidity premium  $\epsilon$  is generally set to  $1E - 7$ .

<sup>16</sup>The existence of interbank relationship lending has been shown in Furfine (1999), Ashcraft and Duffie (2007), Iori, Masi, Precup, Gabbi and Caldarelli (2008), Cocco, Gomes and Martins (2009), Affinito (2012), Afonso, Kovner and Schoar (2014), Blasques, Bräuning and van Lelyveld (2015), and Bräuning and Fecht (2016).

<sup>17</sup> $S_{ij}$  is only computed for bank pairs in which at least one,  $ibb$  or  $ibl$  is different from zero.

<sup>18</sup>Other weights are possible, however apart from affecting the resulting network metrics, don't qualitatively influence the following optimal policy analysis. For example, putting a negative weight on existing relationships results in a less sparse interbank network.

<sup>19</sup>Note that in the model, no bank takes net exposure to a counter-party in excess of 50% of its equity.

are no nonzero scores left and as there are lenders and borrowers, Steps 1 and 2 are repeated. Any residual amount, resulting if there are only lenders or only borrowers left, is exchanged with the central bank. In the second segment (Figure 2), funds among banks are only lent at the longest maturity available because the lack/surplus of funds persists over the entire period business loans have been emitted to firms. Note that business loans feature a maturity of five periods which is the longest maturity on the model's interbank market as well.

Next, in Segment 3 in Figure 2, random deposit fluctuations are carried out. Similar to the stylized model in Sub-Section 2.1, each bank's outflows follow a uniform distribution. Assuming as before that banks' initial amount of deposits reflects their branch share in the economy, banks have an idea about emerging disequilibria and their persistence. Further assuming a closed banking system and a cash-less economy (in the sense that all money is always circulating among deposits, for example by debit card payments), all deposit outflows end up as inflows at banks of the financial system. In particular, inflows are modeled by re-assigning the sum of all deposit outflows as a function of banks' branch network with larger branch networks resulting in larger deposit inflows. After a random deposit re-distribution some banks find themselves in (regulatory) excess of funds while others face a shortfall. As outlined before, it is mutually beneficial for these banks to trade on the interbank market, taking into account the expected persistence of the liquidity shock. Given that any emerging deposit disequilibrium disappears in expectation by about 97% after 5 random deposit fluctuations the longest maturity on the interbank market is 5 periods.<sup>20</sup> Overall, 5 random deposit fluctuations are carried out, that is, at the end of Segment 3 any disequilibrium from the initial deposit fluctuation has almost completely disappeared in expectation.

Finally, in Segment 4 (Figure 2), the model is exposed to a shock to the real economy. In particular, an exogenous increase in non-performing loans leads to losses in the financial system, putting banks' balance sheets under pressure. In turn, banks aiming to fulfill regulatory requirements liquidate part of their loan-portfolio, thus reducing loan supply. This eventually lowers economic activity, further increasing the rate of non-performing loans, which again increases pressure on banks' balance sheets etc.<sup>21</sup> In the model, this negative feedback loop causes losses which eventually lead to the default of some banks in the financial system. Since the financial system is interconnected by interbank borrowing and lending, further defaults can arise by direct contagion from counter-parties not honoring their debt. Shock transmission is taken from Cifuentes, Ferrucci and Shin (2005) and described in more detail in Bluhm (2015). After a shock has been transmitted, resulting real activity is computed as the aggregate value of loans which are not in distress.

As regards timing in the model, Segments 1 and 2 are initialization steps, followed by five random deposit fluctuations in Segment 3 (5 periods). Segment 4 is the evaluation step. In the following section the model is analyzed.

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<sup>20</sup>More than 5 maturity segments could be modeled on the interbank market, however, the amounts borrowed and lent at longer maturities become increasingly negligible. Therefore it is assumed that banks allocate any residual which is expected to remain in disequilibrium beyond a horizon of 5 periods into the longest maturity bracket.

<sup>21</sup>Similar adverse feedback mechanisms between financial sector and real economy have previously been investigated in Bernanke and Gertler (1989), Kiyotaki and Moore (1996), and Bernanke, Gertler and Gilchrist (1996).

### 3. Model Analysis

In this section I investigate the model's network properties and carry out an optimal policy analysis in which the policymaker faces a trade-off between credit supply and financial stability to maximize welfare. Throughout these analyses the model is calibrated with the parameter values outlined in Table 1. Banks' (weighted) capital and liquidity

Table 1: Model Parameters

Parameter	Variable in Model	Value
Liquidity requirement ratio	$\alpha$	0.1
Capital requirement ratio	$\gamma$	0.08
Capital weight on loans	$\chi_1$	1
Capital weight on interbank credits	$\chi_2$	0.2
Branch network	$C^i$	$60 \cdot U \cdot \text{Equity}^i$
Feedback loop parameter	$\iota$	$-\frac{\text{LOG}(0.75)}{\sum C^i}$
Equity distribution	$\zeta$	W(3,7)
Shock distribution to real economy	$\Psi$	$ N(0.06, 0.01) $

Note: The table displays the main model parameters. 'Capital weight on loans' and 'Capital weight on interbank credits' are the weights assigned to banks' loans and interbank assets in the capital requirement ratio, respectively. 'Branch network' determines credit demand a bank faces from the real economy as well as its deposit inflows. The 'Feedback parameter' determines the severity of the negative feedback loop between the real economy and the financial system. 'Equity distribution' assigns each bank a random amount of equity. 'U' and 'W' denote uniform distribution and Weibull distribution with scale parameter 3 and shape parameter 7, respectively. 'Shock to real economy' is an exogenous increase in the rate of non-performing loans sufficiently big to trigger defaults in the financial system with  $N$  a normal distribution.

requirements are set to 8% and 10%, respectively, with the weight on loans and interbank credits set to 1 and 0.2, respectively. The parameter for banks' branch network ( $C^i$ ), which determines the amount of individual credit demand and deposit inflows, is set such that on average banks' leverage ratio can reach about 30 with a maximum possible value of about 60 if regulatory requirements are set to their minimum value (capital and liquidity requirements both set to 1%). These values are considered to be an upper band because they were among the most extreme observed before the financial crisis. The negative feedback loop between financial system and real economy is calibrated such that a worst case scenario leads to a 20% non-performing loan rate in the real economy.<sup>22</sup> Banks' equity is drawn from a Weibull distribution calibrated to match the first two moments in the empirical distribution of a sample of 150 German commercial banks. Note that all following results hold qualitatively across a reasonable range of parameter values. The specific values chosen here are regarded to reflect settings that can actually be found in financial systems and regulatory approaches.<sup>23</sup> Finally, the shock to the real economy which is a random increase in the rate of non-performing loans, is drawn from a normal distribution with a mean of 6% and standard deviation of 1%.

To investigate the model, simulations are carried out with  $N = 150$  banks.

Note that here and in the following analyses the central bank chooses the interest rate which maximizes expected welfare, defined as the amount of 'performing' loans

<sup>22</sup>See World Bank (2015) for an overview on non-performing loan ratios in a panel of countries. 20% is chosen here as a value associated with severe financial crises.

<sup>23</sup>As in any model, choosing extreme values can affect results. For example, setting the capital requirement ratio to very high values, say beyond 20%, makes emerging financial systems extremely robust to shocks, yet results in less credit supply from the banking sector to the real economy, therefore eventually decreasing welfare.

conditional on the shock distribution,  $P \cdot \sum loans | \Psi$ .<sup>24</sup> As outlined above, the market price of loans reflects the proportion of non-performing loans in the real economy, with lower prices indicating a higher proportion of non-performing loans. Therefore, the sum of 'performing loans' is a proxy for economic activity. Several metrics are used to investigate network characteristics: A network's *average degree* is the average number of borrowing and lending counter-parties a bank has in the network. The *density* of a network is the proportion of existing lender borrower relationships relative to all possible lender-borrower relationships. The *Eigenvector centrality* indicates the importance of each node in a graph by giving relative scores to all nodes, with nodes connected to other high-scoring nodes obtaining a higher centrality measure. The *average shortest path* length is defined as the average number of steps along the shortest paths of connected nodes for all possible pairs of network nodes and gives an indication about the efficiency of intermediation in a banking network. *Interbank assets to total assets* indicates the size of the interbank market relative to the financial system's total assets. Table 2 displays averages and standard deviations of the model's network metrics based on 1000 financial systems generated with the parameters in Table 1. On average, banks have 7 counter-

Table 2: Network Metrics

Variable	Average	Standard deviation
Degree	6.96	0.74
Density	0.02	0.00
Eigenvector centrality	0.05	0.01
Average shortest path	4.95	0.60
Interbank assets to total assets	0.18	0.01

Note: The table displays the averages and standard deviations of the network metrics based on 1000 financial systems generated using parameters in Table 1.

parties, about 2% of possible links in the financial system exist, and Eigenvector centrality as well as shortest path equal 0.05 and 5, respectively. These metrics are relatively close to those found for the German banking system on which the equity distribution is modeled.<sup>25</sup> Battiston, Roukny and Georg (2014) find a degree and density between 6 to 25 and 0.2 and 0.7 percentage points, respectively, for exposure networks in a data set of more than 1000 German banks, including commercial, cooperative and savings banks.<sup>26</sup> Furthermore they find an Eigencentrality between 0.3 and 0.6 percentage points. The average shortest path in their sample is 2.24.<sup>27</sup> Finally, note that the average ratio

<sup>24</sup>The optimum is found with a pattern search algorithm, which can be used on functions which are neither continuous nor differentiable.

<sup>25</sup>Note that while other banking system's equity distributions, such as for example the U.S.', could be taken as input, network metrics for those banking systems are not publicly available.

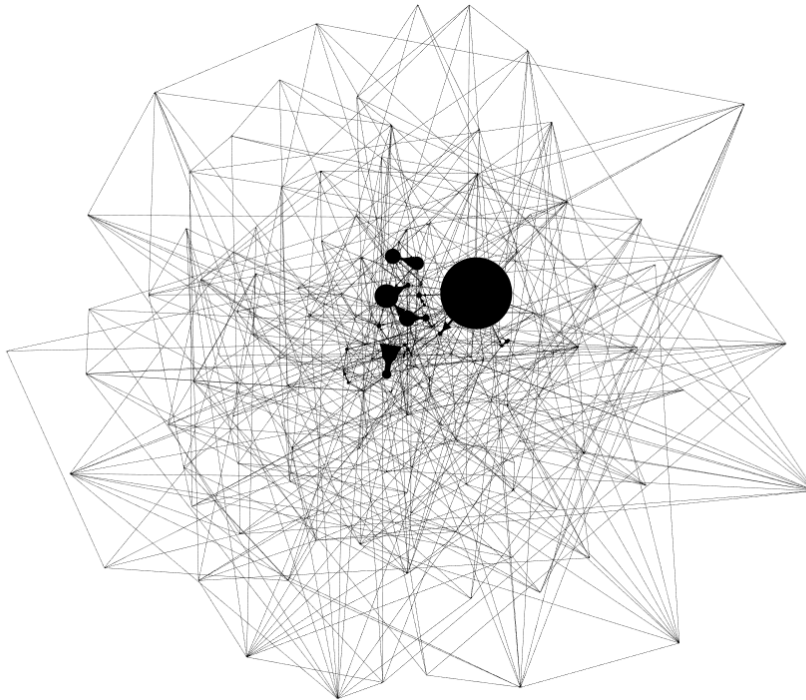
<sup>26</sup>Note that a larger number of banks usually results in a sparser network given sectoral clustering - focusing on the subset of 150 German commercial banks results in a density and Eigenvector centrality of about 5%.

<sup>27</sup>Blasques, Bräuning and van Lelyveld (2015) also provide similar network metrics. However, given that they exclusively focus on the overnight segment of the 50 biggest Dutch banks, results are less comparable.

of interbank loans to total assets is about 0.18, that is, the model features a sizeable interbank market.

Figure 3 displays a typical financial system obtained in the simulation analyses. Each bank is represented by a ball, whose diameter indicates the bank's total assets. Lending and borrowing among banks are expressed by an arrow emerging from the creditor and pointing to the debtor, with the thickness of the arrow indicating the relative amount lent (thicker lines indicate bigger amounts lent/borrowed). The main impression provided by

Figure 3: Financial System for N=150 Banks



Note: The figure displays a typical financial system on which the average financial system metrics from Table 2 are based. Each bank is represented by a ball, whose diameter gives an indication of the total assets of the bank. Lending and borrowing among banks are expressed by an arrow emanating from creditor to debtor, with the thickness of the arrow indicating the relative amount lent (thicker lines indicate bigger amounts lent/borrowed).

the sample financial system is that of a core-periphery structure with few money center banks at the core and many small peripheral banks connected to these hubs.<sup>28</sup>

Overall, the model developed in this paper reflects the stylized facts outlined in the introduction, namely that banks hold relatively high proportions of interbank assets at

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<sup>28</sup>A money center bank is generally associated with large banks that dominate wholesale activity in money markets. For example, a bank in the core of a tiered interbank market can be regarded as a money center bank. See Craig and von Peter (2010).

multiple maturity dimensions. Furthermore, network metrics of the generated financial systems result in values which are close to those found empirically.

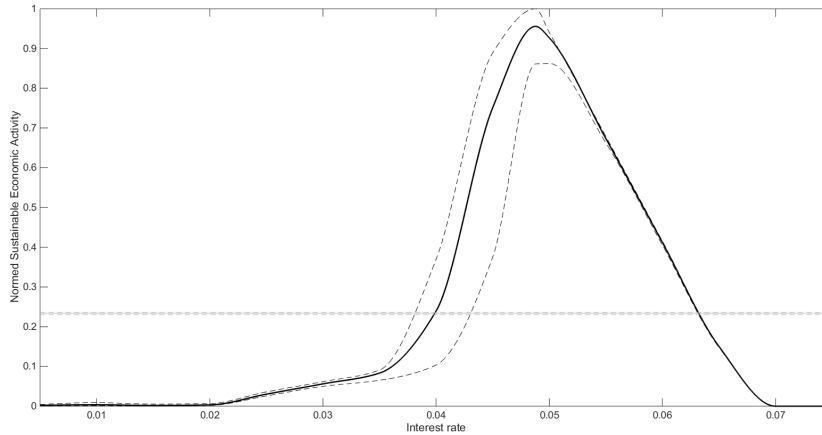
To investigate systemic risk and welfare in the model, an optimal monetary policy analysis is carried out. Following Khan, King and Wolman (2003), optimal monetary policy is defined as maximizing welfare in the economy. In the model, sustainable economic activity—which is measured as the amount of loans not in distress conditional on a distribution of shocks—is used as the metric for welfare. Besides investigating economic activity in an optimal monetary policy setting, outcomes are compared to a financial system without interbank market and central bank.<sup>29</sup> Note that such a setting is similar to early financial systems and can therefore give an indication about the efficiency gains emerging with a more sophisticated financial system. In particular, in case a bank cannot pay out the cash demanded by customers, it is forced to liquidate its assets, eventually turning from being illiquid to being insolvent. As a result, in the reduced financial system the lack of an interbank market to buffer liquidity shocks as well as the absence of a lender of last resort leads banks to hold a much higher amount of reserves. In the model without interbank lending and borrowing, banks hold 85% of their deposits in liquid assets.<sup>30</sup> Figure 4 displays the results of the optimal policy exercise for a typical outcome of the monetary policy analysis using parameter values from Table 1. The solid black and gray lines show sustainable economic activity across a range of interest rates for financial systems with and without interbank markets, respectively. The dashed lines are two standard deviation error bands. Two points are important. First, sustainable economic activity in the financial system with interbank market is hump-shaped, with the maximum reached at the optimal interest rate. Across the range of possible interest rates there is a tension between credit supply and financial fragility. At low interest rates, banks extend more credit to firms, eventually resulting in a credit bubble, which can lead to an adverse feedback loop between the real economy and the financial system when exposed to shocks. The higher the interest rate, the lower the probability of adverse crisis events, but the less economic activity is supported by banks' credit supply. Second, a more sophisticated financial system results in higher real economic activity across most interest rates. This is partly driven by the ability of the central bank to steer the interest rate to the optimal value but also by the fact that being able to buffer liquidity shocks, banks can *ceteris paribus* supply more credit relative to a situation in which banks' illiquidity leads to insolvency. In a further simulation exercise, the optimal policy exercise is carried out 1000 times based on financial systems generated from the parameter values in Table 1. On average, the more sophisticated financial system featuring an interbank market results in a (sustainable) increase of economic activity by a factor of 2.5 (with a *p*-value < 0.001). Of course, to realize welfare gains of that magnitude, the policymaker needs to know and set the optimal policy rate.

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<sup>29</sup>Interbank market and central bank can be shut down in the model by adding a set of further constraints, namely that banks' lending and borrowing on the interbank market, including the central bank, are zero.

<sup>30</sup>Lower liquidity ratios result in bank runs on major parts of the financial system, leading to very low economic activity.

Figure 4: Optimal Monetary Policy Exercise



The figure displays the results of the optimal policy exercise across a range of interest rates for a typical financial system generated using the parameter values from Table 1. The black and gray lines show normed sustainable economic activity –defined as the amount of business loans not in distress conditional on a distribution of shocks– across a range of interest rates for the financial system with and without interbank market, respectively. The dashed lines are two standard deviation error bands.

#### 4. Conclusion

In this paper I extend the literature on interbank markets with a maturity dimension driven by persistence of liquidity shocks and banks’ liquidity management. The term segment of the interbank market has an important role for the network structure as well as banks’ liquidity risk exposure. It therefore affects both, systemic risk and bank-individual risk management. A stylized framework of persistent liquidity shocks is included in a micro-founded network model in which heterogeneous and endogenously evolving interlinked bank balance sheets interact with firm and household sectors. Furthermore, it features interbank funding as an OTC phenomenon, and replicates financial system phenomena of network formation, monetary policy transmission, and endogenous money creation.

The model is used to carry out a welfare analysis which underlines the importance of an efficient and stable financial system for real activity. In particular, it features a trade-off between credit provision (allowing for higher real activity) and financial fragility (decreasing real activity). This real world phenomenon currently confronts central banks which have been criticized for not taking into account that trade-off sufficiently. That is, while today’s lax monetary policy supports short-run economic activity, it eventually sows the seeds of the next financial crisis by creating credit bubbles. For example, the Bank for International Settlements (2015) argues that central banks should raise rates from an abnormally low level because there is a risk that long-run growth is adversely affected from low interest rates by ensuing financial fragility and severe financial shocks. Furthermore, the analyses show that while a financial system without interbank markets features stable but relatively low output, an interbank market with lender of last resort

makes the financial system more efficient and therefore allows for higher sustainable economic activity.

The developed model is ‘hybrid’ because it embeds analytic micro-foundations in a flexible simulation framework. To provide for robustness of results, analyses are carried out with a large number of banks and simulation exercises. Despite highlighting these desirable features, it is important to be aware of its limitations as well. While a large number of draws allows for robustness of results as regards financial system and network properties (which can be gauged when observing the second moments of results), employing specific data of an existing group of banks unlikely results in a model outcome which closely resembles the actual network in the ‘real world’. That is, while simulation exercises using parameter and shock distributions provide for robustness by giving a distribution of outcomes, individual draws should be taken with caution.

Model and analyses can be extended in several dimensions. For example, a central bank featuring also an inflation objective besides its real activity and financial stability mandates would allow for analyzing a policymaker’s trade-offs among competing objectives. Given that endogenous money creation by the banking sector is already realistically included in the model, one could link real activity, price level and money supply by borrowing from the quantity theory of money to introduce a price level to the model. Furthermore, in a dynamic setting, a government could be introduced to smooth emerging business cycles and stabilize the financial system. Finally, the model could be used to analyze the trade-off between banks’ regulatory requirements and real economic activity.



## Bibliography

- Affinito, M., 2012. Do interbank customer relationships exist? And how did they function in the crisis? Learning from Italy. *Journal of Banking and Finance* 36, 3163–3184.
- Afonso, G., Kovner, A., Schoar, A., 2014. Trading partners in the interbank lending market. Federal Reserve Bank of New York Staff Reports 620.
- Allen, F., Carletti, E., Gale, D., 2009. Interbank market liquidity and central bank intervention. *Journal of Monetary Economics* 56, 639–652.
- Allen, F., Gale, D., 2000. Financial contagion. *Journal of Political Economy* 108, 1–33.
- Ashcraft, A.B., Duffie, D., 2007. Systemic illiquidity in the federal funds market. *American Economic Review* 97, 221–225.
- Babus, A., 2016. The formation of financial networks. *RAND Journal of Economics* 47, 239–272.
- Babus, A., Hu, T.W., 2015. Endogenous intermediation in over-the-counter markets. SSRN Working Paper 1985369.
- Babus, A., Kondor, P., 2013. Trading and information diffusion in over-the-counter markets. CEPR Discussion Paper 9271.
- Bank for International Settlements, 2015. Annual Report 85.
- Basel Committee on Banking Supervision, 2008. Principles for sound liquidity risk management and supervision. URL: <http://www.bis.org/publ/bcbs144.pdf>.
- Battiston, S., Roukny, T., Georg, C., 2014. A network analysis of the evolution of the German interbank market. *Deutsche Bundesbank Discussion Papers* 22.
- Bech, M., Monnet, C., 2013. The Impact of Unconventional Monetary Policy on the Overnight Interbank Market. Reserve Bank of Australia.
- Berentsen, A., Monnet, C., 2008. Monetary policy in a channel system. *Journal of Monetary Economics* 55, 1067–1080.
- Bernanke, B., Gertler, M., 1989. Agency costs, net worth, and business fluctuations. *American Economic Review* 79, 14–39.
- Bernanke, B., Gertler, M., Gilchrist, S., 1996. The financial accelerator in a quantitative business cycle framework. *Review of Economics and Statistics* 78, 1–15.
- Bhattacharya, S., Gale, D., 1987. Preference shocks, liquidity, and central bank policy, in: Barnett, W.A., Singleton, K.J. (Eds.), *New Approaches to Monetary Economics*. Cambridge University Press.
- Blasques, F., Bräuning, F., van Lelyveld, I., 2015. A dynamic network model of the unsecured interbank lending market. *BIS Working Papers* 491.
- Bluhm, M., 2015. Interbank funding as insurance mechanism for (persistent) liquidity shocks. *SAFE Working Paper* 117.
- Bluhm, M., Faia, E., Krahn, J., 2014. Endogenous banks' networks, cascades and systemic risk. *SAFE Working Paper* 12.
- Bluhm, M., Georg, C., Krahn, J., 2016. Interbank Intermediation. *Deutsche Bundesbank Discussion Paper* 16/2016.
- Bluhm, M., Krahn, J., 2014. Systemic risk in an interconnected banking system with endogenous asset markets. *Journal of Financial Stability* 13, 75–94.
- Bräuning, F., Ficht, F., 2016. Relationship lending in the interbank market and the price of liquidity.
- Cifuentes, R., Ferrucci, G., Shin, H.S., 2005. Liquidity risk and contagion. *Journal of the European Economic Association* 3, 556–566.
- Cocco, J., Gomes, F., Martins, N., 2009. Lending relationships in the interbank market. *Journal of Financial Intermediation* 18, 24–48.
- Committee of European Banking Supervisors, 2008. Second Part of the CEB's Technical Advice to the European Commission in Liquidity Risk Management. URL: <https://www.eba.europa.eu/cebs-technical-advice-on-liquidity-risk-management-second-part>.
- Craig, B., von Peter, G., 2010. Interbank tiering and money center banks. *BIS Working Papers* 322.
- Deutsche Bundesbank, 2014. Regulation on the liquidity of institutions. URL: [https://www.bundesbank.de/Navigation/EN/Tasks/Banking\\_supervision/Liquidity/liquidity.html](https://www.bundesbank.de/Navigation/EN/Tasks/Banking_supervision/Liquidity/liquidity.html).
- Diamond, D., Dybvig, P., 1983. Bank runs, deposit insurance, and liquidity. *Journal of Political Economy* 91, 401–419.
- Duffie, D., Gârleanu, N., Pedersen, L., 2007. Valuation in over-the-counter markets. *Review of Financial Studies* 20, 1865–1900.
- Eisert, T., Eufinger, C., 2014. Interbank network and bank bailouts: Insurance mechanism for non-insured creditors? SSRN Working Paper 1976383.
- European Central Bank, 2002. Developments in banks' liquidity profile and manage-

- ment. URL: <https://www.ecb.europa.eu/pub/pdf/other/banksliquidityprofile02en.pdf?8950706fec023edde5cd670de575d31b>.
- Faia, E., Delli Gatti, D., Ladasoro, I., 2015. Bank networks: Contagion, systemic risk and prudential policy. CEPR Discussion Paper DP10540.
- Farboodi, M., 2014. Intermediation and voluntary exposure to counterparty risk. Mimeo.
- Federal Deposit Insurance Corporation, 2015. Risk Management Manual of Examination Policies.
- Freixas, X., Parigi, B., Rochet, J.C., 2000. Systemic risk, interbank relations and liquidity provision by the central bank. *Journal of Money, Credit and Banking* 32, 611–38.
- Furfine, C.H., 1999. The microstructure of the federal funds market. *Financial Markets, Institutions and Instruments* 8, 24–44.
- G. Afonso, G., Lagos, R., 2012. Trade dynamics in the market for federal funds. Federal Reserve Bank of New York Staff Reports 549.
- Gale, D.M., Kariv, S., 2007. Financial networks. *The American Economic Review* 97, 99–103.
- Georg, C.P., 2013. The effect of the interbank network structure on contagion and common shocks. *Journal of Banking and Finance* 37, 2216–2228.
- in 't Veld, D., van der Leij, M., Hommes, C., 2014. The formation of a core periphery structure in heterogeneous financial networks. Tinbergen Institute Discussion Papers 14-098/II.
- Iori, G., Masi, G.D., Precup, O., Gabbi, G., Caldarelli, G., 2008. A network analysis of the Italian overnight money market. *Journal of Economic Dynamics and Control* 32, 259–278.
- Khan, A., King, R.G., Wolman, A.L., 2003. Optimal monetary policy. *Review of Economic Studies* 70, 825–860.
- Kiyotaki, N., Moore, J., 1996. Credit cycles. *Journal of Political Economy* 105, 211–48.
- Lewis, T. (Ed.), 2009. *Network Science*. John Wiley & Sons.
- Mankiw, G. (Ed.), 2012. *Macroeconomics*. Worth Publishers.
- McLeay, M., Radin, A., Thomas, R., 2014. Money creation in the modern economy. Bank of England Quarterly Bulletin Q1.
- Poole, W., 1968. Commercial bank reserve management in a stochastic model: Implications for monetary policy. *Journal of Finance* 23, 769–791.
- Rochet, J.C., Tirole, J., 1996. Interbank lending and systemic risk. *Journal of Money, Credit, and Banking* 28, 733–762.
- Vuillemeys, G., Breton, R., 2014. Endogenous derivative networks. Banque de France Working Papers 483.
- Wagner, A. (Ed.), 1857. *Beiträge zur Lehre von den Banken*. L. Voss.
- Whitesell, W., 2006. Interest rate corridors and reserves. *Journal of Monetary Economics* 53, 1177–1195.
- World Bank, 2015. Bank nonperforming loans to total gross loans (%). URL: <http://data.worldbank.org/indicator/FB.AST.NPER.ZS>.