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## Systemic instability of the interbank credit market: A contribution to a resilient financial system

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# Systemic Instability of the Interbank Credit Market - A Contribution to a Resilient Financial System

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## Abstract

This theoretical model analyzes the impact of interbank credit market dynamics on the resilience of the financial system. Based on a stochastic model of interbank market credit flows, lending in the interbank market is restricted by the availability of liquidity. Following a shock materialization, a sequential flow adjustment process sets in. While the market smoothly adjusts under normal conditions, the characteristics of the market adjustment process change under volatile conditions, resulting in a bifurcation of the equilibrium. Market resilience declines under higher volatility, including a potential market freeze. A change in the volatility of reserve flows, which is more likely when central banks tighten monetary policy, may threaten the resilience of interbank markets and increase the probability of the market to fall into a regime of unstable dynamics. Thus, we stress that monetary policy could incidentally reduce financial stability. When switching the regime, policymakers should be aware of a potential reduction in interbank credit market resilience and the consequences for financial stability.

JEL classification code: E44, E52, G11, G21

JEL keywords: Financial Markets, Interbank Lending, Monetary Policy

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*"We still know very little how the interbank market works, despite the existence of many recent studies on interbank market risk and interconnections." (Allen et al., 2018: 2)*

## 1 Introduction

The smooth reallocation of liquidity within the interbank market (IBM) from banks with a surplus to banks with a deficit contributes substantially to financial system resilience (Gabrieli and Georg, 2014). In addition, the interest rate in the interbank credit market serves as operational target of monetary policy implementation, consequently affecting the whole economy via various transmission channels. Under normal circumstances, the smooth functioning of the IBM seemed to be reliable (e.g., Afonso et al., 2011). However, in an adverse scenario, the IBM can become dysfunctional, in the extreme case leading to a complete dry out of IBM liquidity and inducing central banks (CB) to intervene in order to re-establish normal conditions.

Having decreased the policy rates to the zero-lower bound in the aftermath of the financial crises, CB's policymakers in advanced economies are recently considering to tighten monetary policy. For instance, the ECB has decided to end net asset purchases in December 2018 and considers a tightening, although uncertainties relating to financial market volatility have gained in importance (ECB, 2018). The Federal Reserve Bank has already started to increase policy rates since 2016, while it did so also in the period between 2005 and 2008, shortly before the financial crisis materialized. Is this regime-switch of monetary policy an inevitably smooth return to "normal" or is it a risk-bearing operation? And can this switch trigger an IBM instability, which reduces the resilience of the financial system?

This paper examines the risk of illiquidity in the IBM as a general market instability, indicating a substantial vulnerability of the financial system.<sup>1</sup> We identify determinants of financial system resilience and offer first insights in the avoidance of the adverse scenario in IBM. In light of the recent tendency to monetary policy normalization, we additionally shed light on the effect of monetary policy tightening on the resilience of the IBM.

Our theoretical model adds to the general understanding of the operation of the IBM and associated financial vulnerabilities. Departing from portfolio equilibria in financial markets, we derive a new dynamic adjustment process of banks' interbank lending for two different conditions. We show that under normal conditions, an unexpected, exogenous shock leads to a smooth adjustment process of the IBM to the new equilibrium. By contrast, under volatile

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<sup>1</sup>We are aware of the fact that a liquidity crunch is unlikely to occur in the current environment in the euro area, given that the banking sector is currently highly liquid and banks receive liquidity from the ECB at cheapest financing rates. However, we claim that this mechanism is important in understanding the general market stability, due to the fact that the standard literature refers to a stock analysis and leaves dynamic issues open to debate.

conditions, a bifurcation of the equilibrium changes the characteristics of the adjustment process, including a potential market instability. Hence, we show that under volatile conditions, the probability of switching to an unstable adjustment path increases and market resilience declines. While we do not claim that volatility causes financial turmoil, which is a well-known phenomenon, we emphasize that higher volatility can also result in a fundamental market instability.

**Related Literature** The IBM allows a bank to cover its individual need for liquidity and share risks (e.g. Bhattacharya and Gale, 1987). In the pre-crisis period, the IBM was generally regarded to operate perfectly (Bucher et al., 2017, Jakab and Kumhof, 2015), consequently leading to a rare literature on the operation of the IBM. For instance, Allen and Gale (2000) have shown that liquidity risk is not present, when the IBM is complete and aggregate shocks are absent.

The seizing up of the IBM in the financial and sovereign debt crises (see, e.g., Frutos et al., 2016 for a European focus on the crises), has led to a renewed interest of academic research in the functioning of the IBM. The resulting theoretical literature explains this illiquidity by moral hazard and financial frictions within the IBM, impeding an efficient risk-sharing process across the market. Examples for more recent theoretical models on IBM imperfections include asymmetric information about counterparty risk (e.g., Afonso et al., 2011, Freixas and Jorge, 2008, Heider et al., 2015), search costs for trading partners (e.g., Afonso and Lagos, 2015, Bech and Monnet, 2016, Vollmer and Wiese, 2016) or regulatory costs due to post-crisis newly implemented financial regulations (e.g., Bech and Keister, 2017, Bindseil, 2016, Jackson and Noss, 2015). These costs can hinder the smooth reallocation of liquidity across banks and as a result, can lead to liquidity issues, forcing the CB to intervene.

Associated with the implementation of monetary policy, our paper is also related to theoretical models of banks' reserve management in the tradition of Poole (1968), who introduces uncertainty in a bank's reserve management. Using a stochastic model, Poole (1968) explains a single bank's profit-maximization under uncertainty and examines excess reserves, bank borrowing from the CB and the CB policy rate in an environment with scarce reserves (see also, e.g., Ho and Saunders, 1985). Following this first strand, academic research focused on micro-mechanisms of bilateral trading in the IBM (Afonso and Lagos, 2015, Ennis and Weinberg, 2013, Bianchi and Bigio, 2017). Finally, the introduction of unconventional monetary policy has induced a third strand to investigate the operation of the IBM under excess reserves (Armenter and Lester, 2017, Ennis, 2014, Martin et al., 2013, 2016, Williamson, 2019). We refer to the second strand, dealing with micro-mechanisms of trading in the IBM on a bilateral basis.

Furthermore, systemic risk, i.e. negative externalities between institutions (Acharya, 2009), can build up endogenously in the financial system. The theoretical literature identifies mainly three sources of systemic risk with respect

to liquidity issues. First, excessive risk-taking of single institutions can lead to systemic risk. For instance, systemic liquidity risk of single institutions arises when banks hold too much illiquid assets (Bhattacharya and Gale, 1987) or too illiquid liabilities (Brunnermeier and Oehmke, 2013). By contrast, we do not refer to single banks but the interactive lending process within the IBM. Second, contagion and spillover effects can result from direct bilateral linkages of institutions, e.g. via balance sheet contagion. For instance, Allen and Gale (2000) or Freixas et al. (2000) use network models to show how interbank claims can propagate shocks. However, we do not refer to direct contagion mechanisms but to an exogenous shock only that can, given sufficiently large, drive the IBM into the illiquidity scenario. Third, amplification mechanisms can give rise to small shocks having large impacts. Examples are liquidity crises, market freezes and bank runs. In the first case, the liquidation of assets can lead to a market price decline, which induces further fire sales of assets and thereby a liquidity crisis (e.g. Shleifer and Vishny, 1992, Brunnermeier and Pedersen, 2009). Market freezes can occur when IBM imperfections like adverse selection (Flannery 1996) or asymmetric information (Heider et al., 2015) hinder safe banks from borrowing in the IBM. Bank runs and panics build on the seminal work of Diamond and Dybvig (1983), showing that bank runs can be self-fulfilling and put the banks' liquidity at risk. Consequently, we are closest to the models on market freezes explained by IBM imperfections. However, in our model an aggregate shock hinders the smooth reallocation of reserves by impeding the planned portfolio adjustment process.

To the best of our knowledge, the closest paper to ours is Bech and Keister (2017) who examine the impact of the newly implemented Basel III liquidity coverage ratio (LCR) on interbank interest rates using a model of monetary policy implementation. Bech and Keister (2017) find that when CBs return to pre-crisis policy operations while the LCR is implemented, they might face substantial difficulties in controlling IBM interest rates. We also refer to liquidity risk with regard to the availability of CB reserves but deviate from the model of Bech and Keister (2017) by not taking regulatory measures, such as the LCR into account. We differ from the theoretical analyses on IBM imperfections by showing that an IBM may be driven into illiquidity following a sufficiently large exogenous shock by introducing a stochastic adjustment process of interbank lending as financial market imperfection. The effect of an aggregate liquidity shock on the unsecured IBM is also analyzed, e.g., by Sarmiento (2019), whose regression results show that aggregate liquidity shocks can be mitigated by CB liquidity injections. In addition, we investigate the effect of monetary policy normalization following the period of excess reserves in the IBM.

Furthermore, to our knowledge these models traditionally assume banks to act as financial intermediaries between savers and borrowers, which exposes them to liquidity risk due to maturity transformation. For instance, Bianchi and Bigio (2017) model an individual bank's liquidity management, where idiosyncratic liquidity risk can be reduced by holding large precautionary reserves, although reducing intermediation profits. While intermediation issues, such as bank runs, could still materialize in our model, we shift the focus of liquidity

risk from the private-banking sector link to the link between the banking sector and the monetary authority. Thus, we show the existence of another vulnerability in the financial system, which exists even in the absence of intermediation issues as sources of systemic risk.

The following section will introduce the baseline of the model, and define the economy, that is, markets as well as agents dealt with. Afterwards, Section 3 introduces a dynamic flow mechanism in the IBM, which explains how dynamic adjustment processes can affect the resilience of the IBM. Section 4 adds model implications for policymaking, and finally, Section 5 concludes.

## 2 Baseline model

We consider a model in discrete time, where the domestic banking sector consists of a large number of competing investment banks. We exclude traditional depositary institutions and hence, private money creation via credit provision, and refer to investment banks. In accordance with Saunders and Cornett (2007: 104), we define an investment bank as a non-deposit holding institution, which operates in two broad areas, namely securities underwriting as well as trading or brokerage services. For instance, the Bank of America Merrill Lynch is assumed to be a full-line investment bank, operating in both of these areas. Consequently, the banks in our model do not hold (minimum) reserves as a back-up for deposit withdrawals. Instead, we refer to excess reserves as precautionary liquidity buffer. Although the Gramm-Leach-Bliley-Act in 1999 abolished the strict separation between commercial and investment banks in the U.S., this did not change the underlying separation between these two groups (cf. Hartmann-Wendels et al., 2015). While the biggest investment banks in terms of revenue are traditionally headquartered in the U.S. (e.g., JPMorgan, Goldman Sachs, Morgan Stanley), further locations also refer to Europe with Switzerland (CreditSuisse, UBS), the United Kingdom (e.g., Barclays Investment Bank, HSBC) and the core euro area (e.g., BNP Paribas in France, Deutsche Bank in Germany) as main locations (Statista 2019). We simplify the operation of the investment banks to three competitive markets, namely reserve holdings deposited in the CB money market, the trade of excess reserves in the IBM and an investment in a representative security in the asset market.

**Central bank money market** Overall, the aggregate liquidity of the banking sector is managed by the CB, which provides and absorbs liquidity in the geographical headquarter location of the respective bank. The reserves of the banking sector are deposits held at the account of the CB plus the currency banks hold. The banking sectors need for reserves result from minimum reserve requirements and autonomous liquidity factors. If we look at the ECB, several standard instruments are used to manage the euro area banking sector's liquidity (see ECB (2011) for a detailed description of its instruments). The operational framework uses two regular instruments, the open market operations as well as two standing facilities. Open market operations include the main

refinancing operation (MRO), longer-term refinancing operations, fine-tuning operations, and structural operations. We reduce our analysis to the monetary policy instruments of the three key interest rates. These are the main open market operation (MRO) and the two rates for the standing facilities.

The MRO, which traditionally satisfies approximately 74% of the liquidity needs of the euro area's banking sector (ECB, 2002) represents a credit operation. The respective main refinancing rate ( $i_R$ ) is the interest rate banks have to pay for the loan from the CB. Furthermore, banks have to provide adequate collateral as specified by the ECB in order to guarantee the repayment of the loan. The MRO takes place weekly and also matures after one week. In "normal" times (between 27 June 2000 and October 2008), the ECB used variable rate tenders, under which banks bid both, the amount of credit as well as the rate they are willing to pay. The ECB estimates an allotment volume, which reflects the liquidity needs of the banking sector during the maturity of the MRO. In these normal times, bids in the MRO will be rationed if aggregate bids exceed the estimated allotment, serving the highest interest rate bids first. Since October 2008, the ECB uses fixed rate tenders with full allotment in order to mitigate adverse effects of the dysfunctional money market (ECB, 2011). However, we refer to the operations in normal times in order to emphasize the presence of a vulnerability in the financial system under normal conditions. Moreover, CBs are recently considering to normalize monetary policy, ultimately returning to the pre-crisis procedure.

Furthermore, the ECB also sets the interest rates on its short-term standing facilities. Under normal conditions, these are unfavorable when compared with market rates. The rate on the marginal lending facility ( $i_{LF}$ ) provides overnight liquidity from the CB at higher costs than those of the one-week MRO, while banks also have to pledge adequate collateral for this short-term liquidity. By contrast, the deposit facility absorbs liquidity from the banking sector, where the CB pays an interest rate ( $i_{DF}$ ) on overnight deposits. Usually, the interest rates on these facilities determine a symmetric corridor around the MRO-rate (cf. figure 1), with the deposit facility acting as a floor and the lending facility as a ceiling.

**Interbank market for reserves** In addition to the CB money market, liquidity is traded in the IBM for reserves. Banks reallocate the reserves provided by the CB mainly for two reasons. First, usually, the one-week MRO is the shortest maturity available for liquidity from the CB. While the banking sector's aggregated need of liquidity may remain broadly constant within one week, individual bank's liquidity needs usually vary daily (Hauck and Neyer, 2014). Second, only a fraction of banks covers its liquidity need directly from the CB. There are also banks, which prefer to cover their needs of reserves exclusively in the IBM.<sup>2</sup>

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<sup>2</sup> At the end of January 2011 the euro area recorded 6334 credit institutions. Only 2267 credit institutions were eligible for participation in the open market operations by fulfilling the ECB's criteria, 2395 credit institutions had access to the marginal lending facility and

In accordance with Hauck and Neyer (2014), the market is characterized by two types  $i = d, s$  of banks, according to the banks' demand or supply of liquidity in the IBM, which is mirrored in the IBM of the euro area. In this context, we define liquidity as excess reserve holdings of single banks. Each type of banks consists of a continuum of banks with unit mass. Banks of type  $s$  supply excess reserves in the IBM, whereas banks of type  $d$  demand liquidity in the IBM. Each single bank is randomly assigned to its type, while Brousseau and Manzanares (2009) claim that its main business activities are a key indicator for the bank's liquidity situation. By contrast to Hauck and Neyer (2014), we do not refer to commercial banks trading in the IBM but to investment banks instead.

The unsecured interbank credit market is characterized by an OTC market, where contracts are negotiated bilaterally (e.g., Vollmer and Wiese, 2014, Bianchi and Bigio, 2017). The empirical analysis of these contracts is a major challenge, because there is no public information on them. Although individual interest rates are negotiated in every OTC contract, we assume that banks trade liquidity in the IBM at one common rate ( $i_{IB}$ ). Furthermore, the IBM is regarded as uncollateralized exchange market for liquidity.<sup>3</sup> Regarding the time horizon, the IBM is generally regarded as a very short-term market, where mainly overnight credits are traded among banks of group  $s$  and  $d$ . For instance, Arciero et al. (2014) show more than 90% of overall turnover in the Italian IBM to be overnight, likewise the majority of trades in the Eurosystem's IBM. Kuo (2013) finds 67% of American interbank loans to be overnight, Heijmans et al. (2010)'s analysis shows 59% of the total number of loans in the Dutch IBM to be overnight. The same holds true for further analyses, such as Cocco et al. (2009) (Portugal), de Bonis et al. (2013) (Italy) or Raddant (2012) (Italy). The empirical reference rate is the European Overnight Index Average (EONIA), which is a market index calculated by the ECB as a weighted average of the interest rates on unsecured overnight lending transactions denominated in Euro, undertaken by a representative panel of 28 contributing banks.<sup>4</sup>

How do the CB money market and the IBM relate to each other? Figure 1 depicts the key interest rates charged by the ECB (ECB, 2019b) as well as the market interest rate in the unsecured European overnight interbank market (EMMI, 2019) between July 2000 and October 2008. We see that a bank with excess liquidity could hold an overnight deposit at the CB, which yields a return of the deposit facility rate (grey dashed) or supply liquidity in the IBM, which yields the higher EONIA rate (yellow). Consequently, arbitrage opportunities

2789 to the deposit facility. (ECB, 2011: 97)

<sup>3</sup>In the euro area, the secured lending in the IBM ("repo" market, market for swaps against foreign currencies) only recently gained prominence, i.e. under distressed market conditions (see ECB, 2011). The ECB (2019a) published statistics on the secured euro money market for the first time on January 11th, 2019. Referring to the 2018 maintenance period, the turnover in the secured market is more than twice of the turnover in unsecured markets. For the analysis under "normal" conditions we stick to a traditional focus on the unsecured lending in the IBM.

<sup>4</sup>For more information on this reference rate see EMMI (2019).



**European key interest rates of the CB and  
the interest rate in the interbank market (EONIA)  
(July 2000 - October 2008)**

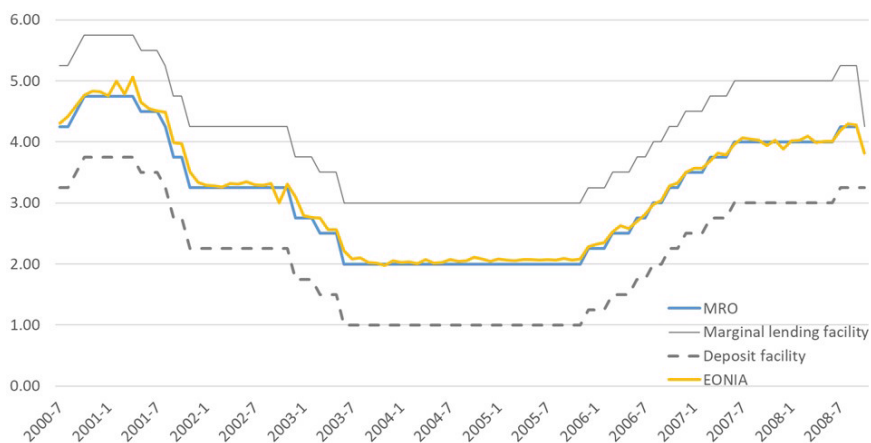


Figure 1: Key interest rates of the European CB and IB market

would suggest that a surplus bank rather invests in the IBM and lends to other banks than stores its liquidity at the CB. Second, if the bank has to cover a liquidity need, it has three possibilities. First, it can take a loan from the CB for one-week, which would charge the MRO-interest rate (blue). This is the cheapest way of covering its liquidity need, though the bank has to pledge adequate collateral and the liquidity can only be accessed at a one-week frequency. Second, the bank can take a short-term credit from the CB, which is given at the marginal lending facility rate (grey) for one day (overnight). However, the bank can also receive short-term liquidity from other banks, borrowing in the IBM is OTC, but, on average, the EONIA rate is charged (yellow). Hence, if the bank needs liquidity on short-term notice, arbitrage conditions would suggest to rather take an IBM credit (yellow), which is cheaper than borrowing from the CB (grey).

Moreover, figure 1 reveals the interest rate relations applying in the markets for reserves under normal conditions with  $i_{LF} > i_R > i_{DF}$ . First, in the overnight market, the interest rate on the deposit facility ( $i_{DF}$ ) acts as a floor for the market rate, while the interest rate on the marginal lending facility ( $i_{LF}$ ) acts as a ceiling. The facilities thus determine a corridor, within which the overnight interest rate in the IBM can fluctuate, usually settling of close to the middle of the corridor. Furthermore, in normal times, the overnight IB

rate for liquidity has generally remained close to the one-week CB rate, but mainly averaging slightly above the interest rate charged by the CB ( $i_{IB} \geq i_R$ ). This positive spread between the overnight IB rate and the one-week CB rate is of highest interest, indicating a non-perfect adjustment of IB market rates to monetary policy rates.

**Asset market** Besides the markets for reserves, several investment opportunities for each bank exist in the asset market, regardless of its bank type. We simplify to a representative asset, such as a zero-coupon bond, which provides an investment opportunity for banks of both groups. It matures after one period and is traded at the bond's price (in %) of  $P_B = \frac{100}{(1+i_B)^T}$  where  $i_B$  is a fixed interest payment (in %). This bond carries various types of risks, such as interest rate risk or default risk.

In a standard static economic analysis, the lending bank  $s$  would determine its optimal stock of portfolio asset holdings within its balance sheet in order to maximize its profits. The asset side of a simplified balance sheet of bank  $s$  would record its excess reserve holdings deposited overnight at the CB, which yield a profit ( $i_{DF}$ ), likewise the lending in the IBM at rate  $i_{IB}$ , as well as the investment in the representative asset, assuming, for instance, a zerobond, which matures after one period and yields return at the end of the period. When bank  $s$  maximizes its profits, it determines its optimal credit supply in the IBM, subject to the market interest rates. Whenever an exogenous interest rate changes, the adjustment process of bank  $s$ 's portfolio, embedded in the three markets, would set in. Under a comparative static analysis, such a model would show the effect of an unexpected, exogenous shock in the monetary policy rate (interpreted as the effect of monetary tightening) on interbank credit provision, which would lead to an increase in the interbank credit volume.

We now deviate from the standard analysis of a unique portfolio stock equilibrium and focus on the flow adjustment process. We introduce a new, periodic flow mechanism that could set in following an exogenous shock (e.g., a monetary policy shock). We assume that even if portfolio adjustment is fast, it takes some short periods to arrive at a new portfolio equilibrium. While the speed of the adjustment process is still rapid, it cannot take place indefinitely quick. More specifically, the interbank credit supply of bank  $s$  is modelled in a periodic flow concept, which can guide the financial system into a stable or unstable equilibrium. This dynamic adjustment process is examined below, offering new insights into the fragilities of the financial system during the dynamic adjustment process.

### 3 Flow mechanism in the interbank market

Following an exogenous shock, a flow adjustment leads the economy from the already determined, initial stock equilibrium ( $CR_{IB,s,t}$ ) to a new stationary stock

equilibrium ( $CR_{IB_{s,t+\tau}}$ ) as could be described in traditional portfolio choice models.

The time span between the two equilibria, the adjustment period, is assumed not to be instantaneous but rather to take a few days until the flow process terminates in the new stock equilibrium.

Following an increase in the main monetary policy rate ( $i_R$ ), the arbitrage opportunities in the market for liquidity change. This induces an adjustment of the banks' portfolio choices. The borrowing bank  $d$  is now willing to demand a higher volume of liquidity in the IBM at the currently given interbank interest rate ( $i_{IB}$ ) instead of the now relatively more expensive CB liquidity. Within the European framework, the interbank liquidity demander would now have to pay a higher marginal lending facility ( $i_{LF}$ ) on its overnight credit from the CB, while the EONIA would still be at a lower, and hence cheaper, level.

Furthermore, bank  $s$  would like to lend a higher volume. This behavior is reasoned in the business activities of bank  $s$ . Bank  $s$  is supposed to take a cheap one-week loan from the CB, which is charged at the MRO ( $i_R$ ) and requires pledging collateral. The bank uses this liquidity to lend it in the IBM at the higher rate of EONIA ( $i_{IB}$ ) for several times, potentially lending six times overnight in the IBM until the CB loan matures after one week.

Theoretically, an immediate adjustment of the interbank credit interest rate to the new policy rate could clear markets instantaneously. However, institutional properties of the IBM hinder a momentarily adjustment to the excess demand of interbank credits and slow down the adjustment process. For instance, the IBM is an OTC market, where credit contracts are negotiated on a bilateral basis (e.g., Vollmer and Wiese, 2014, Bianchi and Bigio, 2017). However, generally, bank  $s$  is now willing to expand its credit provision in the interbank credit market accordingly ( $CR_{IB_s} > 0$ ), until it reaches its new equilibrium stock of interbank credit supply ( $CR_{IB_{s,t}}$ ).

### 3.1 Adjustment path to the new equilibrium

In the previous period, bank  $s$  has already offered interbank credits, resulting in the stock of interbank credits currently recorded in its balance sheet ( $CR_{IB_{s,t}}$ ). The net credit expansion path of bank  $s$  is now determined by two opposing gross forces.

**Non-revolving mechanism** First, a flow adjustment ( $\dot{C}R_{IB_s}^{ng}(t)$ ) reduces the current stock of interbank credit provision of bank  $s$ , which is captured by the non-growth ( $ng$ ) equation (1):

$$\dot{C}R_{IB_s}^{ng}(t) = -CR_{IB_s}(t) + \rho(i_R)(CR_{IB_s}(t))^{1-\alpha}. \quad (1)$$

The IBM is characterized as a very short-term market and consists of mainly overnight credits (see section 2). Thus, at every point in time  $t$  (every day) a large number of these credits is repaid ( $-CR_{IB_s}(t)$ ). For simplicity, we assume

that all credits are overnight credits and paid back every day. As we assume no defaults in normal interbank relations, the total number of credits issued on the previous day are repaid to 100%, resulting in an equivalent return flow.

However, bank  $s$  tries to expand its lending in the IBM for arbitrage reasons. Consequently, the bank starts in the easiest available way, by revolving some part ( $\rho \in (1, \infty)$ ) of the existing former borrower relationships on an ongoing basis. The parameter  $\rho$  refers to bank  $i$ 's traditional relationships to borrowing banks that have developed over time (see e.g. Cocco et al., 2009; De la Motte et al., 2010; Afonso et al., 2013, on relationship lending). The IBM is regarded to have a hierarchical structure, where liquidity in the IBM is distributed via bank-pairwise relationships. While the reason for this structure is still open, Fricke and Lux (2012) suggest a comparative advantage of the core banks in gathering and distributing information about their counterparties as a crucial factor. More recently, Bräuning and Fecht (2017) find that lending relationships reduce search frictions in the OTC market as well as a reduction of uncertainty regarding counterparty credit quality. This relationship lending is the first source of credit expansion for bank  $s$ , since it knows its customers from previous credit relationships and can easily and quickly offer and expand credit. Due to the fact that partner institutions are already recorded in the trading books of bank  $s$ , it thereby minimizes its effort with respect to search costs, transaction costs, etc. for the bilateral contracts. Consequently, the credit expansion process cannot take place instantaneously but is a time-consuming process. Starting with the roll-over process on best-known relationships, the information advantage decreases with increasing credit provision (scale effect with  $\alpha < 1$ ). Taken together, equation (1) states that part of current credit provision of bank  $s$ , which is not revolved and thus, represents a reducing force on lending in the IBM.

**Growth mechanism** If bank  $s$  is willing to provide completely new credits within the IBM, it has to acquire new customers in addition to the existing relationships recorded in equation (1).

$$\dot{C}R_{IB_s}^g(t) = b(CR_{IB_d}(i_R) - CR_{IB_s}(t)) = b(CR_{IB_s, t+\tau} - CR_{IB_s, t}) \quad (2)$$

While traditional relationships have already been established, a completely new credit extension is characterized by even higher adjustment obstacles, represented by the parameter  $b$ , where  $b \in [0, 1]$ . A lower value of  $b$  indicates higher adjustment obstacles, such as search and screening costs, present in the IBM. It takes time to search for further trading partners (e.g., Afonso and Lagos, 2015, Vollmer and Wiese, 2016), to gather information about these new borrowers, including their counterparty risk (e.g., Afonso et al. 2011, Heider et al., 2015), as well as to establish the new trading partnership (transaction costs). Consequently, bank  $s$  cannot provide more credit to the market instantaneously.

**Total net credit expansion**

$$\dot{C}R_{IB_s}(t) = \dot{C}R_{IB_s}^g(t) + \dot{C}R_{IB_s}^{ng}(t) \quad (3)$$

$$= b(CR_{IB_d}(i_R) - CR_{IB_s}(t)) + \rho(CR_{IB_s}(t))^{1-\alpha} - CR_{IB_s}(t) \quad (4)$$

$$= bCR_{IB_d}(i_R) + \rho(CR_{IB_s}(t))^{1-\alpha} - (1+b)CR_{IB_s}(t) \quad (5)$$

$$= B + \rho(CR_{IB_s}(t))^{1-\alpha} - (1+b)CR_{IB_s}(t) \quad (6)$$

These two opposing gross forces can be described together in the following relationship, which results in a net increase of interbank credit provision.

**Illustrative example Start-Equilibrium-Period  $t$**

We start-off from the portfolio equilibrium of bank  $s$  in period  $t$ . Given the vector of equilibrium interest rates in the current period, bank  $s$  provides its optimal amount of credit supply,  $CR_{IB_s,t}$  in the IBM. This stock is our point of departure, we therefore equate it with 100%.

$$CR_{IB_s,t} = CR_{IB_s,t} = 100\% = 1$$

**End-Equilibrium-Period  $t + \tau$**

In the next period, the CB raises its policy rates, the MRO ( $i_R$ ) and the marginal lending facility, by 50 bp each. The MRO increases from 1% to 1.05% for a one-week credit. Following that, bank  $s$  desires to reach a new end-equilibrium, which it will reach after  $\tau$  adjustment periods, i.e. in the period  $t + \tau$ . First, bank  $s$  takes at the next possible date a loan from the CB, which it has to repay at the higher rate of 1.05% after one week, pledging adequate collateral. So far, the interbank overnight interest rate has remained at the  $t$ -period equilibrium level of  $i_{IB_t} = 1.1\%$ . But with the new policy rate, bank  $s$  expects the interbank interest rate also to rise up to the new equilibrium level of  $i_{IB_{t+\tau}} = 1.15\%$ . In order to keep its portfolio choice relations and profits, bank  $s$  desires to gain profit from arbitrage opportunities. To do so, it would like to provide a higher stock of overnight interbank credits, receiving the higher rate of 1.15% every day when its IBM borrower repays its loan. This would lead to a weekly yield of  $(1.15\% * 6 \text{ days} - 1.05\%) * \text{amount of credits provided}$ . In addition, borrowing banks now demand a higher amount of overnight credits in the IBM, because the currently still applying equilibrium rate of  $i_{IB_t} = 1.1\%$  in the IBM is still cheaper than borrowing overnight at the 50 bp higher marginal lending facility of currently 1.55% from the CB. And it is even cheaper in relation to the spread before. Therefore, bank  $d$  demands a higher amount of interbank credits in the IBM.

In order to meet this excess demand for credits in the IBM, bank  $s$  would like to expand its credit provision by 10% in addition to the so-far existing stock.

Thus, the new equilibrium stock of credit supply in the end-period is assumed to take an arbitrarily chosen number of 110%.

$$CR_{IB_s, t+\tau} = 110\% \text{ of } CR_{IB_s, t} = 1.1 CR_{IB_s, t}$$

Consequently, bank  $s$  has to expand its credit by 10% as compared to the equilibrium in the start-period. How does it reach this new equilibrium? This is a sequential adjustment process over time.

First, we assume that bank  $d$  repays all of the overnight credits already taken. The stock of interbank credits recorded in the balance sheet of bank  $s$  decreases to zero ( $CR_{IB_s, t+1} = 0\%$ ).

*Bank  $s$  receives a liquidity inflow of  $1CR_{IB_s, t+1}$ .*

Then, bank  $s$  tries to expand its credit provision by 10%, reaching a new end-equilibrium stock of 110%. This expansion process is started in the easiest way, by referring to the former periods' ( $t$ ) relationships. It allows the bank to roll over a fraction of presumably 100% of credits of the previous day ( $CR_{IB_s, t+1} = 100\%$ ). So far, it has successfully restored its previous-period equilibrium credit supply.

*Bank  $s$  has liquidity outflows of  $1CR_{IB_s, t+1}$ .*

However, following that, bank  $s$  tries to extend its credit provision further on by gaining new customers. But new customers incur new risks and tasks to be performed. This process takes time and therefore allows the bank to expand its credit by no more than 2% per day. Therefore, bank  $s$  can only reach a stock of interbank credits of  $CR_{IB_s} = 102\%$  in period  $t + 1$ , which is below its target-value of 110%. It will take 4 further days until bank  $s$  can reach its targeted credit expansion of  $CR_{IB_s, t+5} = 110\%$ .

*Bank  $s$  desires to have liquidity outflows of  $1.1CR_{IB_s, t+\tau}$ . It needs liquidity inflows of  $(1.1 - 1)CR_{IB_s, t} = 0.1CR_{IB_s, t}$ , which it has to gain from bank-external sources.*

**End-Equilibrium in the IBM** This stable dynamic process leads to the new stationary portfolio equilibrium. Total net credit dynamics can be illustrated by figure 2, where the intercept ( $B$ ) is given by  $bCR_{IB_d}(i_R)$ .<sup>5</sup>

<sup>5</sup>The credit expansion process is characterized by the following properties of the non-linear, non-homogeneous differential equation in  $CR_{IB_s}$ .

$$\frac{d\dot{C}R_{IB_s}}{dCR_{IB_s}} = \rho(1 - \alpha)CR_{IB_s}^{-\alpha} - (1 + b) \begin{cases} > 0 \text{ for } CR_{IB_s}^\alpha < \rho(1 - \alpha)(1 + b)^{-1} \\ = 0 \text{ for } CR_{IB_s}^\alpha = \rho(1 - \alpha)(1 + b)^{-1} \\ < 0 \text{ for } CR_{IB_s}^\alpha > \rho(1 - \alpha)(1 + b)^{-1} \end{cases}$$

The first derivate of the change of interbank credits with respect to the stock of interbank credits recorded in bank  $s$ 's balance sheet can be positive or negative, depending on which of the gross forces described above dominates the process. In contrast, the second derivative is negative, such that:

$$\frac{d\dot{C}R_{IB_s}^2}{d(CR_{IB_s})^2} = \rho(-\alpha + \alpha^2)CR_{IB_s}^{-\alpha-1} < 0$$

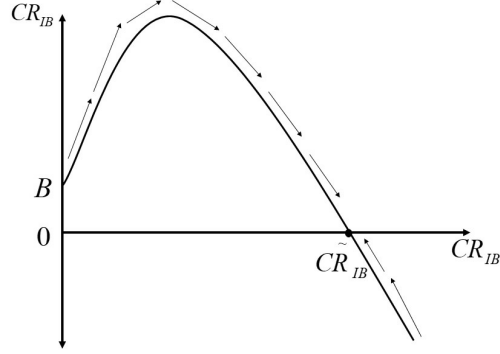


Figure 2: Dynamics and stability in the interbank market under normal conditions

A qualitative analysis of the dynamics of the process indicates that under the described standard conditions we have a stable dynamic process. We can also derive the stationary equilibrium at the end of the stable adjustment path when  $CR_{IB_d}^{(+)}(i_R) - CR_{IB_s}(t) = 0$ , and explicitly state the new equilibrium credit supply:<sup>6</sup>

$$\bar{CR}_{IB_s} = \rho^{(-)}(i_R)^{\frac{1}{\alpha}} = \bar{CR}_{IB_d} \quad (7)$$

In this case, the stationary equilibrium only depends on changes in the policy rate. It indicates a smooth adjustment process of the IBM to the new stable IBM equilibrium. Furthermore, with (7) we have also shown that the portfolio equilibrium is consistently described.

This process is the standard story of a smoothly adjusting financial market to the new equilibrium, a hypothetical idea of the IBM operation in the pre-

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which means that the flow function is concave. That is, higher interbank credit flows imply a higher stock of interbank credits, but at a decreasing rate. The assumption of concavity is a fundamental element in our analysis.

$$\begin{aligned} \dot{CR}_{IB_s}(t) &= 0 = bCR_{IB_d} + \rho^{(-)}(i_R, i_{IB_s}^{(+)})CR_{IB_s}^{1-\alpha} - (1+b)CR_{IB_s} \\ 0 &= \rho^{(-)}(i_R, i_{IB_s}^{(+)})CR_{IB_s}^{1-\alpha} - CR_{IB_i} \\ 1 &= \rho^{(-)}(i_R, i_{IB_s}^{(+)})CR_{IB_i}^{-\alpha} \\ CR_{IB_s} &= \rho^{(-)}(i_R, i_{IB_s}^{(+)})^{1/\alpha} \end{aligned}$$

crisis years. In a standard general portfolio choice model, i.e. the equilibrium analysis, would end here. This solution indicates a stable adjustment process in the IBM, even when financial frictions, such as search costs or counterparty risks, are considered. However, the literature on IBMs claims that the lending process is anchored in a reallocation of CB reserves (see e.g., Hauck and Neyer, 2014). Therefore, it is necessary to shed light on the dynamics when this constraint is taken into consideration.

### 3.2 Adjustment path with constraints

Bank  $s$  plans its credit expansion according to the above equation 3, which is analogue to the stable adjustment path

$$\dot{C}R_{IB_s}^P(t) = \dot{C}R_{IB_s}^g(t) + \dot{C}R_{IB_s}^{ng}(t) \quad (8)$$

However, the reallocation of reserves in the secondary market for reserves, i.e. the IBM, (see, e.g., Affinito, 2013, Allen et al., 2009, Bräuning and Fecht, 2017), means that every credit outflow requires bank  $i$  to receive a respective reserve inflow ( $F(t)$ ). Only if the reserve inflow is large enough, bank  $i$  can provide all credits described in the credit dynamics above ( $F(t) \geq \dot{C}R_{IB_s}(t)$ ). In other words, as reserves are necessary for credit provision, the reserve inflow can be a direct constraint for credit expansion. This reserve inflow is defined as liquidity bank  $i$  gets available and is willing to use for its interbank credit expansion. The reserve inflow is assumed to have two components. According to the general bank business in- and outflows, it is planned at the level of  $F^P(t)$ , but it is also subject to random shocks  $x(t)$  with  $E[x(t)] = 0$ :

$$F(t) = F^P(t) + x(t) \quad (9)$$

Therefore, bank  $s$  plans the respective reserve inflows for each point in time ( $F^P(t)$ ) according to

$$F^P(t) = \dot{C}R_{IB_s}^P(t). \quad (10)$$

Hence, the credit expansion schedule<sup>7</sup> is expected to take the following form:

$$E[\dot{C}R_{IB_i}(t)] \leq \dot{C}R_{IB_s}^g(t) + \dot{C}R_{IB_s}^{ng}(t) + 0 \quad (11)$$

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<sup>7</sup>Derivation:

$$\begin{aligned} \dot{C}R_{IB_s}(t) &\leq F(t) \\ \dot{C}R_{IB_s}(t) &\leq F^P(t) + x(t) \\ \dot{C}R_{IB_s}(t) &\leq \dot{C}R_{IB_s}^P(t) + x(t) \\ \dot{C}R_{IB_s}(t) &\leq \dot{C}R_{IB_s}^g(t) + \dot{C}R_{IB_s}^{ng}(t) + x(t) \end{aligned}$$



The bank expects that the available reserve inflow covers at least the planned outflow resulting from credit expansion. In expected values, the plan works and guides the bank in the stable adjustment path of figure 2.

However, the stochastic realized credit expansion might differ from the expected one. The reserve constraint is binding for credit expansion, whenever the random realization becomes negative ( $x < 0$ ).

$$CR_{IB_s}(t) \leq \dot{C}R_{IB_s}^g(t) + \dot{C}R_{IB_s}^{ng}(t) + x(t) \quad (12)$$

In this randomly realized situation, the available reserve inflow directly restricts the bank's credit expansion, which then falls below the bank's credit expansion schedule. The bank will have to adjust and switches to a new adjustment path ("adjustment path with constraints") because of the realized reserve constraint. The new adjustment path is now given by:

$$\begin{aligned} \dot{C}R_{IB_s}(t) &= x + bCR_{IB_d} + \rho(CR_{IB_s}(t))^{1-\alpha} - (1+b)CR_{IB_s}(t) \\ &= B' + \rho(CR_{IB_s}(t))^{1-\alpha} - (1+b)CR_{IB_s}(t) \end{aligned}$$

Figure 3 shows the adjustment paths without (solid black) and with constraints (dotted and dashed grey), where the black solid line displays the credit expansion schedule of equation (11). The grey lines depict the respectively realized reserve inflows of equation (12), which might be binding. Under normal conditions, the adjustment path without and with constraints can potentially be identical, which would be graphically illustrated by a congruence of the dotted grey and the solid black line ( $CR_{IB_s}^P = F^P$ ). However, under adverse conditions, the adjustment path under constraints can significantly differ from the scheduled path, which is exemplarily illustrated by the dashed grey lines. In this scenario, the smaller reserve inflow determines a credit expansion path along the realized reserve inflow, which is below the desired level.

As long as the random shock  $x < 0$  is sufficiently small in absolute terms  $|x|$  the intersection with the vertical axis in figure 3 remains positive, and the adjustment dynamics do generally not change. However, if in absolute terms the random shock is sufficiently large,  $B = x + bCR_{IB_d}$  may turn negative, and the properties of the dynamic adjustment process may change. Once we know that the intercept of the liquidity flows  $B = x + bCR_{IB_d}$  with  $b \in (0, 1)$ ,  $CR_{IB_d} \geq 0$  is a crucial element in the analysis of the resilience of the IBM, we would like to shed light on it in further detail.

$$B \left\{ \begin{array}{l} > 0 \text{ for } bCR_{IB_d} > -x \\ = 0 \text{ for } bCR_{IB_d} = -x \\ < 0 \text{ for } bCR_{IB_d} < -x \end{array} \right\} \text{ with } b \in (0, 1), \quad CR_{IB_d} \geq 0, \quad x < 0$$

**Illustrative example** Referring to the example above, recapture that in the

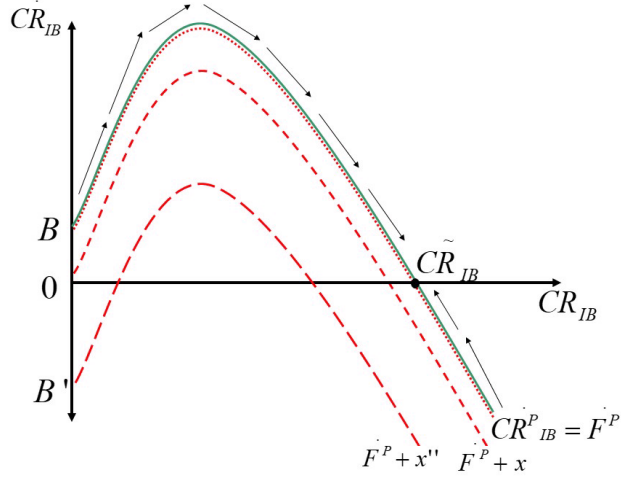


Figure 3: Planned and realized credit expansion

**start-equilibrium-period**  $t$ , bank  $s$  provides its optimal amount of credit supply,  $CR_{IB_s,t} = 100\% = 1$  in the IBM (given the vector of equilibrium interest rates in the current period). While in the **end-equilibrium-period**  $t + \tau$ , the new equilibrium stock of credit supply in the end-period is assumed to be  $1.1CR_{IB_s,t+\tau}$ .

#### Period $t+1$

First, we assume that bank  $d$  repays all of the overnight credits already taken. *Bank  $s$  receives a liquidity inflow of  $1CR_{IB_s,t+1}$ .*

Second, bank  $s$  rolls over a fraction of presumably 100% of credits of the previous day. *Bank  $s$  has liquidity outflows of  $1CR_{IB_s,t+1}$ .*

Third, bank  $s$  tries to extend its credit provision further on by gaining new customers, where information costs allow the bank to expand its credit by no more than 2% per day. Therefore, bank  $s$  can only reach a stock of interbank credits of  $CR_{IB_s} = 1.02CR_{IB_s,t+1}$  on the next day.

#### Periods $t+2$ to $t+\tau$

It takes 4 further days until bank  $s$  can reach its targeted credit expansion of  $1.10CR_{IB_s,t}$ . Bank  $s$  expands its credit by 2% in every period.

*Bank  $s$  desires to have liquidity outflows of  $1.1CR_{IB_s,t}$ . It needs liquidity inflows of  $(1.1 - 1)CR_{IB_s,t} = 0.1CR_{IB_s,t}$ , which it has to gain from bank-external sources. This takes time, with  $0.02F$  manageable every day. This sequential inflow of liquidity is not automatically given, but expected. When a shock hits the*

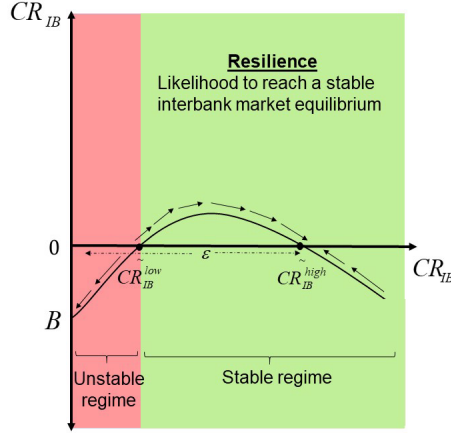


Figure 4: Dynamics and instability in the interbank market in an adverse scenario

bank's total liquidity inflows on the next day, bank  $s$  receives different reserve inflows, depending on the magnitude of the shock.

**(Case a,  $B > 0$ )** minor shock: *Instead of the expected inflows of  $0.02F$ , bank  $s$  receives only  $0.018F$ . Despite the fact that these lower inflows render the bank at a lower expansion path, it is still able to expand credit  $CR_{IB_s} = 1.018CR_{IB_{s,t}}$ . On the next day, it receives again  $0.02F$ , expands lending up to  $1.038CR_{IB_{s,t}}$  and smoothly moves on track into the new end-equilibrium of  $1.098CR_{IB_{s,t}}$ .*

**(Case b,  $B = 0$ )** large shock: Now, bank  $s$  receives no inflows ( $0F$ ). However, bank  $s$  can still expand credit with the help of the inflows stemming from repaid credits. All of its lending comes from a roll-over of credit. Bank  $s$  can exactly expand credit by  $1CR_{IB_{s,t}}$ .

**(Case c,  $B < 0$ )** major shock: *Bank  $s$  does no longer receive any inflows. The shock size prevents external liquidity inflows, with the result that bank  $i$  cannot expand yesterday's lending. Nor, and more importantly, can it roll-over all of yesterday's credit supply. The shock it eats up some fraction of the repaid credits of the borrowing banks and causes outflows of  $0.02F$ . Now, bank  $s$  has to deny a fraction of 2% of credit demand of its banking customers today, restricting bank  $s$ 's credit expansion to  $0.98CR_{IB_{s,t}}$  only.*

In the worst-case scenario, a major shock cuts down bank  $i$ 's interbank credit supply, figure 4 shows this new path for a negative  $B$ .

**End-Equilibrium in the IBM** Before we can discuss the implications for the dynamics we need to formally identify the new, low equilibrium and the

reactions of it with respect to changes in variables. We determine the low equilibrium ( $CR_{IB_s}^{low}$ ) for  $CR_{IB_d} - CR_{IB_s} > 0$

$$0 = G = x + bCR_{IB_d} + \rho CR_{IB_s}^{1-\alpha} - (1+b)CR_{IB_s} \quad (13)$$

As this equation cannot be solved explicitly, we need to apply the implicit function theorem. Looking at figure 4 and using the implicit function theorem at a local point, we can state that equation (13) implicitly defines a function  $CR_{IB_s}$  at potentially two equilibrium points, a low equilibrium point ( $CR_{IB_s}^{low}$ ) and a high equilibrium point ( $CR_{IB_s}^{high}$ ).<sup>8</sup>

**Proposition 1** (*Bifurcation of equilibrium*) *Depending on the magnitude of the shock, the characteristics of the adjustment path can change. In an adverse scenario this results in a bifurcation of the equilibrium with two equilibrium points, which we refer to as low ( $CR_{IB_s}^{low}$ ) and high equilibrium ( $CR_{IB_s}^{high}$ ).*

$$\begin{aligned} CR_{IB_s}^{low} &= CR_{IB_s}^{low}(x, \dots), & \text{with } \frac{CR_{IB_s}^{low}}{dx} > 0 \\ CR_{IB_s}^{high} &= CR_{IB_s}^{high}(x, \dots), \end{aligned} \quad (14)$$

In figure 4 we use this new path for a qualitative dynamic analysis. While figure 2 described a global overall stable process with only one equilibrium, figure 4 shows two equilibria. In this figure the high equilibrium is comparable to the one equilibrium in figure 2. We see a locally stable process as the  $\dot{C}R_{IB_s}(t)$ -curve has a negative slope around the high equilibrium. The high equilibrium is a locally stable point. This is different for the low equilibrium. Here, the slope

<sup>8</sup>Implicit function theorem:  $0 = G = x + bCR_{IB_s}^D + \rho CR_{IB_s}^{1-\alpha} - (1+b)CR_{IB_s}$  implicitly defines a function  $CR_{IB_s}^{low} = CR_{IB_s}^{low}(x, \dots)$  if  $\frac{dG}{dCR_{IB_s}} \neq 0$ : Thus, taking the derivative of  $G$  with respect to  $CR_{IB_s}$  gives

$$\begin{aligned} \frac{\partial G}{\partial CR_{IB_s}} &= (1-\alpha)\rho CR_{IB_s}^{-\alpha} - (1+b) > 0 & \text{for } CR_{IB_s} < \left(\frac{\rho(1-\alpha)}{1+b}\right)^{\frac{1}{\alpha}} \\ &= (1-\alpha)\rho' CR_{IB_s}^{-\alpha} - (1+b) < 0 & \text{for } CR_{IB_s} > \left(\frac{\rho(1-\alpha)}{1+b}\right)^{\frac{1}{\alpha}}. \end{aligned}$$

Thus,  $CR_{IB_s}^{low} = CR_{IB_s} < \left(\frac{\rho(1-\alpha)}{1+b}\right)^{\frac{1}{\alpha}}$  is the low credit level stationary equilibrium. The derivative of this implicit function is  $\frac{\partial G}{\partial x} = 1$

$$\frac{dCR_{IB_s}}{dx} = -\frac{\frac{\partial G}{\partial x}}{\frac{\partial G}{\partial CR_{IB_s}}} = -\frac{1}{\frac{\partial G}{\partial CR_{IB_s}}} < 0$$

is positive, which implies that the low equilibrium  $CR_{IB_s}^{low}$  is locally unstable. As a result we have two dynamic regimes and overall market resilience declines. At points larger than the low equilibrium level  $CR_{IB_s}^{low}$  the credit creation process will be on a stable path and move smoothly to the high equilibrium  $CR_{IB_s}^{high}$ , which is also the final portfolio equilibrium the banks would like to reach. However, if we look at points below the low equilibrium level  $CR_{IB_s}^{low}$  the process is unstable and bank  $s$  would keep on decreasing credit creation. In this case, the credit creation of bank  $s$  is constrained by a too low reserve inflow  $F(t)$ .

Ultimately, the credit provision may potentially reduce to zero. If this is the case, the IBM will be characterized by a market freeze, indicating no further credit supply in the IBM. This brief discussion already indicates that adjustment processes are no longer only smooth and stable. If the stochastic shock described by a randomly much lower reserve inflow in the adjustment process is sufficiently large or  $CR_{IB_s}$  is still rather low, such that  $CR_{IB_s}(t) < CR_{IB_s}^{low}$ , the process becomes unstable. This critical mechanism is studied in more detail below.

**Resilience of the interbank market** We have described the new adjustment path under constraints, which includes two dynamic regimes. We now focus on the determinants of the regime, in which the IBM operates, especially on the critical adjustment path. Which kind of shocks can lead the IBM into the unstable regime? We now discuss the aggregate process in the IBM as well as some elements that potentially affect the resilience of this market. The term *resilience* in this context stands for the likelihood of the IBM to be in a stable regime and to smoothly reach the new equilibrium ( $CR_{IB_s}^{high}$ ).

A random event determines the actually realized reserve flows  $x$ , which can be binding for credit expansion ( $F(t) \geq CR_{IB_s}(t)$ ) and hence, determine in (15) the shape of the actual adjustment process.

$$d\dot{C}R_{IB_s}(t) = x + bCR_{IB_s} + \rho CR_{IB_s}^{1-\alpha} - (1+b)CR_{IB_s} \quad (15)$$

These randomly realized reserve flows have to be studied in more detail. While  $x$  is a particular realized shock during the adjustment period, we now generalize to each possible shock realization, referring to the random distribution of this shock ( $X$ ).

With this knowledge we determine the market's resilience.

**Definition 2** (*Market resilience*) *The likelihood to reach a stable interbank market equilibrium is defined as market resilience. This gives the likelihood to remain in the stable regime at any moment during the adjustment period.*

First, as described above  $x$  are randomly realized inflows of reserves, with expectation  $E[x] = 0$  and  $Var = \sigma^2$ . We specify the so-far random distribution of the shock by assuming a normal distribution of realized reserve flows

$$X \sim \mathcal{N}(0, \sigma^2) \quad \text{with density} \quad f_X(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{x^2}{2\sigma^2}}. \quad (16)$$

With the help of this normal distribution, we can determine a probability of each particular realized shock  $x$  during the adjustment period. This knowledge will help us to determine the probability of being in the stable or unstable regime, with the latter of primary interest.

According to figure 4 an adjustment process becomes unstable whenever the low equilibrium  $CR_{IB_s}^{low}$  is to the right of the current credit stock  $CR_{IB_s}(t)$ , such that  $CR_{IB_s}(t) \leq CR_{IB_s}^{low}$ . Starting off from any current position  $CR_{IB_s}(t) = \varepsilon$ , we can determine a likelihood to be in the unstable regime ( $P(\varepsilon \leq CR_{IB_s}^{low})$ ). As

analyzed above, the location of  $CR_{IB_s}^{low}$  is determined by the particular realized reserve flow  $x$ . In graphic terms, the larger the shock realization  $|x|$ , the further to the right will the low equilibrium be situated. Hence, the greater the extent of the unstable regime of the adjustment process, and the larger the probability to be in the unstable regime. We now mathematically determine a probability that the position is in the unstable regime ( $P(\varepsilon \leq CR_{IB_s}^{low})$ ). Equation (13)

has specified a function of the low equilibrium with  $CR_{IB_s}^{low} = G(x)$ . From (14) we know that for a particular value  $x$  the derivative of the low equilibrium function with respect to  $x$  is  $\frac{CR_{IB_s}^{low}}{dx} > 0$ . This allows us to use a local and linear approximation at  $CR_{IB_s}^{low}$  and we can rewrite  $CR_{IB_s}^{low}$  as the linear function given by

$$CR_{IB_s}^{low} = g(x) = mx - c. \quad (17)$$

With the help of this linear approximation and the random distribution (16) we now arrive at the following proposition:<sup>9</sup>

**Proposition 3** (*Systemic Stability Challenge*) *For a current interbank credit supply of  $CR_{IB_s}(t) = \varepsilon$ , the probability of randomly falling in the unstable regime*

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$$\begin{aligned} \mathbb{P}(f(X) \geq \varepsilon) &= \int_{x \leq \varepsilon} f_X(g^{-1}(x)) \frac{1}{|g'(g^{-1}(x))|} dx \\ &= \int_{x \geq \varepsilon} f_X\left(\frac{1}{m}(x - c)\right) \frac{1}{|m|} dx \\ &= \int_{\varepsilon}^{\infty} \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(\frac{1}{m}(x-c))^2}{2\sigma^2}} \frac{1}{|m|} dx \end{aligned}$$

of the adjustment path ( $P(\varepsilon \leq CR_{IB_s}^{low})$ ) is given by

$$\mathbb{P}(g(X) \geq \varepsilon) = \int_{\varepsilon}^{\infty} \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(\frac{1}{m}(x-c))^2}{2\sigma^2}} \frac{1}{|m|} dx. \quad (18)$$

By contrast, the probability of being in the stable regime of the adjustment path ( $P(\varepsilon > CR_{IB_s}^{low})$ ), which is defined as market resilience, is given by

$$Resilience = 1 - \mathbb{P}(g(X) < \varepsilon), \quad (19)$$

which gives the complementary probability to fall in the stable regime.

## 4 Model implications

The theoretical considerations of the model presented above add to the general understanding of the mechanisms and dynamics in the IBM. The results show that the IBM can randomly fall in an unstable equilibrium, which, in the extreme case, indicates a collapse of interbank loan provision. Furthermore, we can state a probability of the unstable adjustment path, depending on current interbank credit provision. Based on this simple model, there are two questions ahead. First, what determines the probability of the unstable regime? And second, returning to our initial research question: What is the impact of monetary policy shocks on IBM resilience?

**Comparative static analyses: Determinants of financial fragility** If bank  $s$  is a representative credit provider in our system, all described mechanisms hold for the entire IBM. Therefore, it is interesting to identify elements that can increase or decrease the probability of market instability, and identify the elements that affect market resilience (see definition 2).

First, if current interbank credit provision ( $\varepsilon = CR_{IB_s}(t)$ ) increases, the probability of being in the unstable regime decreases

$$\frac{d}{d\varepsilon} \mathbb{P}(f(X) \geq \varepsilon) = \frac{d}{d\varepsilon} \int_{\varepsilon}^{\infty} \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(\frac{1}{m}(x-c))^2}{2\sigma^2}} \frac{1}{|m|} dx = -\frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(\frac{1}{m}(\varepsilon-c))^2}{2\sigma^2}} \frac{1}{|m|} < 0. \quad (20)$$

That is, close to the high equilibrium the probability of instability is low, the IBM is rather resilient.

Second, it is interesting to note that it is not necessarily the level of the reserve flows that determines the probability of falling into the unstable regime of the adjustment path. The probability of being in the unstable regime increases if we take the derivative of (18) with respect to the variance  $\sigma^2$ ,

$$\frac{d}{d\sigma^2} \mathbb{P}(f(X) \geq \varepsilon) = \frac{1}{|m|} \frac{1}{\sqrt{2\pi\sigma^2}} \frac{\varepsilon}{2\sigma^2} e^{-\frac{\varepsilon^2}{2m^2\sigma^2}} > 0. \quad (21)$$

Thus, a higher volatility of reserve flows increases the probability of switching to an unstable adjustment path. This volatility of reserve flows may even be generated in other financial markets instead of directly resulting from the market for CB money.<sup>10</sup> When a shock applies to the liquidity inflows of bank  $s$ , and these threaten to restrict its lending process, bank  $s$  can try to gain liquidity from other sources in order to remain on its schedule. Supposed, bank  $s$  decides to sell a fraction of the bonds recorded on the asset side of its balance sheet. However, the bond price is subject to volatility, too. When asset markets are characterized by high volatility, the in exchange received liquidity inflows will also be highly volatile. Consequently, the probability for bank  $s$  to switch to the unstable adjustment path will also be higher under higher volatility in the bond market. If it is assumed that volatility in asset markets increases, and shocks to individual banks in the group  $s$  are correlated, i.e., non-diversifiable, this implies that lenders in the IBM are affected simultaneously. The whole IBM may fall into an unstable adjustment path with more volatile reserve flows. Hence market resilience declines under more volatile conditions.

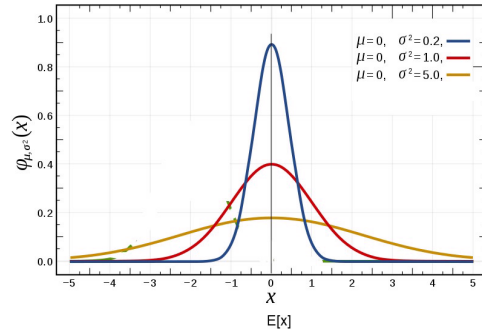
Under these volatile conditions, the higher volatility of liquidity flows changes the characteristics of the market adjustment path, resulting in a bifurcation of the equilibrium. Figure 4 shows different density functions of the standard normal distribution, while figure 4 shows different credit creation processes of the lenders in the IBM, each depending on the respective variance. By assuming that the shock is normally distributed, the credit creation path depends crucially on the variance ( $Var = \sigma^2$ ). A higher variance translates into a flatter density curve, which increases the probability of extreme values. Thus, a higher variance implies a higher likelihood of the unstable adjustment path. In our interpretation, market resilience declines in this case, i.e., the probability of switching to an instable adjustment path increases with higher volatility, which can lead to a potential market freeze.

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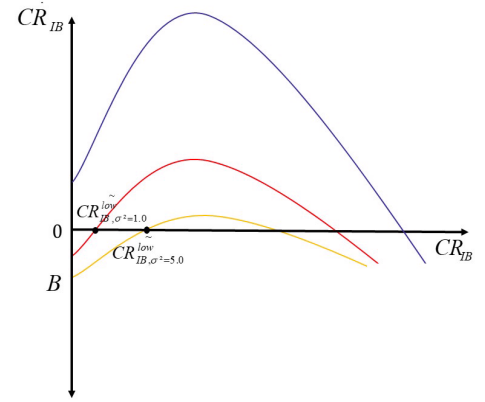
<sup>10</sup>Reasons for higher volatility in other financial markets are shown, for instance, by Daniel et al.(1998). Their model shows that investor overconfidence can cause stock market bubbles and increase volatility in asset markets.



The variance (volatility) determines the likelihood of a specific shock realization  $x$ .



Density function of the normal distribution for different variances



Adjustment path for different volatilities

**Application: Financial fragility from monetary policy tightening?** We

have shown that a higher volatility of reserve flows reduces the resilience of the interbank credit market (defined as the probability to be in a stable regime). In order to investigate the effect of monetary policy on IBM resilience, we first examine the effect of monetary policy tightening on volatility in asset markets. Figure 5 shows the monthly relationship between the key monetary policy rate of the ECB (2019b) (MRO) and a volatility index for the EuroStoxx (VSTOXX) between 2000 and 2018.

Overall, a positive correlation between the monetary policy rate and asset price volatility could potentially be assumed to hold. However, as this is no thorough empirical regression analysis, this figure has to be interpreted in a prudent manner. For instance, shortly before the crisis (e.g. in 2005), we might observe high monetary policy rates accompanied by high volatility, although there might not be a causal relationship between the two.

Although the general relationship between monetary policy and asset prices is also of high interest in recent literature, especially with respect to the assessment of consequences of a monetary policy shock on financial stability (cf. Allen and Gale, 2004, Disyatat, 2010), the theoretical idea of monetary policy tightening coming along with higher volatility in asset markets has to our knowledge not been proven so far. First insights are offered by Alessi and Kersefischer (2016) who examine the response of the asset market following unexpected monetary policy shocks. The authors use a Structural Factor Model (SFM) for the euro area, which yields a wide information set of various impulse response functions (IRF) following a contractionary monetary policy shock of a 50 bp rise in the short-term rate. The IRF of a volatility index of stock prices (EUROSTOXX) is u-shaped and shows that the contractionary monetary policy shock leads volatility to go up on impact. As time passes, the effects of the shock

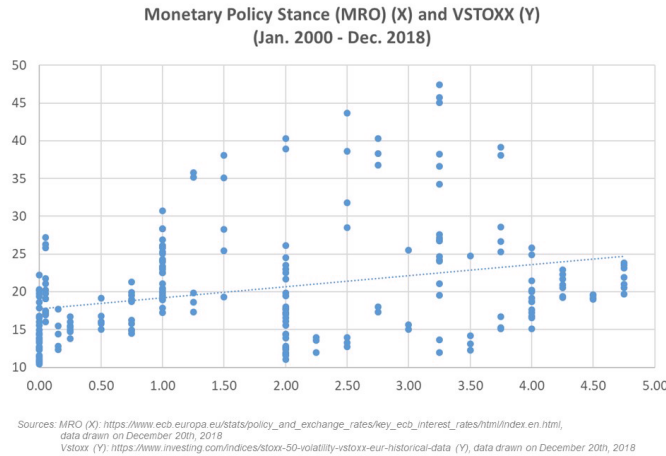


Figure 5: Relation of central bank policy rate and volatility

in volatility decay, reaching zero impact after approximately 10 months. The results of Alessi and Kersefischer (2016) might indicate a higher volatility of the EUROSTOXX following monetary policy tightening in the current environment. At least, they suggest that monetary policy is an important determinant of asset prices as well as asset price movements (forecast error variance). In line with mainstream macroeconomic theory, the authors find empirical evidence for a quick response of asset prices to (unexpected) monetary policy shocks. Furthermore, their results suggest stronger effects on asset prices by monetary policy tightening than by an expansion, which we interpret as an asymmetric reaction scheme to monetary policy. Alessi and Kersefischer (2016) also emphasize that monetary policy tightening can cause repercussions in financial markets, especially in a low interest rate environment.

If the assumption holds true, monetary policy tightening would go hand in hand with higher asset price volatility and hence a higher volatility of reserve flows in banks' balance sheet management, which would reduce the resilience of the IBM.

A positive correlation between monetary policy tightening and volatility in asset markets is also suggested when the trading volume in asset markets is taken into consideration. Figure 6 shows the monthly relationship between the policy rate of the ECB (2019b) (MRO) and the trading volume of the EuroStoxx between February 2006 and March 2019. Figure 7 shows the relationship between the trading volume of the EuroStoxx and the VSTOXX over the same period of time. Due to the fact that both figures show a positive relationship, a positive correlation between the monetary policy rate and volatility in asset prices could be suggested to hold. However, these relationships have to be examined in detail

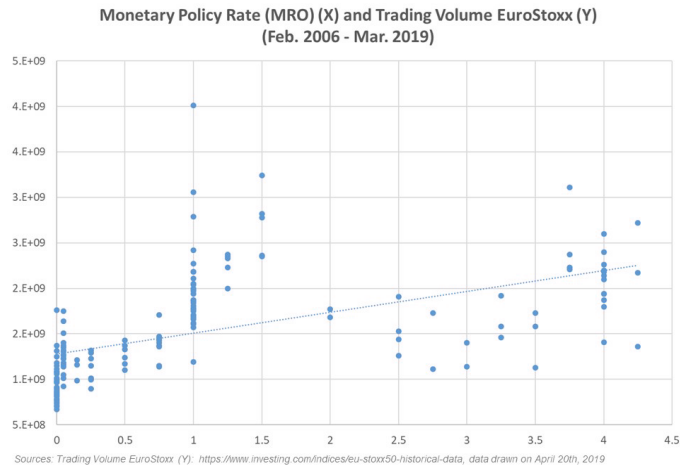


Figure 6: Relationship between central bank policy rate and asset trading volume

in future research.

In our model, contractionary monetary policy would increase the probability of the IBM entering an unstable regime. When monetary tightening increases asset price and consequently the volatility of reserve flows, the probability of an unstable adjustment process in the IBM increases and thus, IBM resilience is reduced. By contrast, an expansionary monetary policy means an increase in the money supply and a decrease in the policy rate, respectively. Following the same line of argumentation, expansionary policy would lower asset price volatility and hence add to IBM resilience as it reduces the probability of the IBM entering an unstable regime.

Recently, CB policymakers are considering to raise policy rates again, and introducing a contractionary monetary policy regime. When switching the regime, policymakers should be aware of a potential reduction in IBM resilience and the consequences for financial stability.

Given the assumption that volatility is positively related to monetary policy tightening holds: Monetary policy tightening is likely to reduce the resilience of the IBM (defined as the probability to be in a stable regime). By contrast, expansionary monetary policy would decrease the volatility in asset markets and hence add to the resilience of the IBM. This asymmetric reaction scheme to monetary policy shocks should be taken into consideration when entering a contractionary monetary policy phase. When switching the regime, policymakers should be aware of a potential reduction in interbank credit market resilience and the consequences for financial stability.

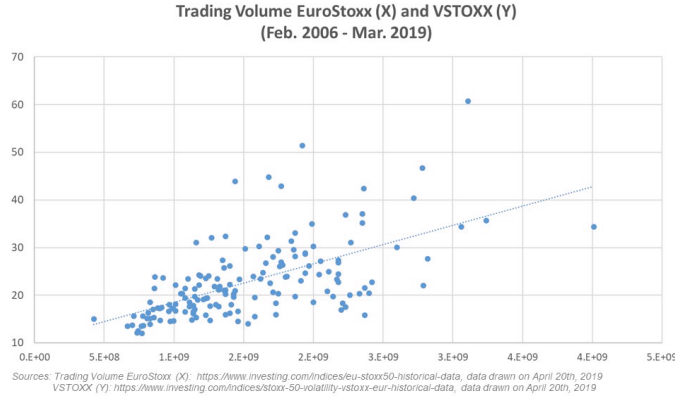


Figure 7: Relationship between asset trading volume and volatility

**Policy Implications** Financial stability, i.e. liquidity in the IBM, can be safeguarded ex-ante with the help of preventive measures as well as emergency operations in case the adverse scenario has already materialized.

**1. Prevention of the adverse scenario: Macroprudential policies** Preventive tools should enable banks to absorb or reduce the effects of a shock on reserves by providing them with a sufficiently high liquidity buffer.

In the context of our model, they should also safeguard the ability of a bank to provide interbank credit at all times, even if a limited cash inflow constrains its credit provision. Furthermore, risk indicators of volatility triggers and amplifiers as well as early warning systems are important so that countermeasures can be taken at an early stage. In this vein, macroprudential policies have been developed and partly implemented to ensure the stability of the financial system as a whole. However, the discussion on the effectiveness of these tools is still underway.

A first newly introduced macroprudential policy tool refers the liquidity risk management of banks. In 2013, the Basel Committee on Banking Supervision (BCBS) introduced the liquidity coverage ratio (LCR) with a shorter time horizon of 30 days and the net stable funding ratio (NSFR) with a longer time horizon of one year. The LCR requirement came into force in January 2015 and has to be fulfilled to 100% since January 2019. This LCR requires a bank to hold a stock of assets that can be liquidated quickly at least as high as the expected net cash outflows over the next 30 calendar days. This ratio is calculated on an ongoing basis and at least monthly reported to supervisors.

But can liquid asset holdings of a bank cover its need for liquidity in times

of crises?

The calculation of the LCR takes different kinds of liquid assets into consideration. In general, it distinguishes between Level 1 and Level 2 assets, where Level 1 assets include cash, CB reserves and certain marketable securities backed by sovereigns and CBs. Among those are marketable securities backed by sovereigns and CBs are included. But what if no one would be willing to buy these "marketable" assets? In the absence of asset demand, bank  $i$ 's "liquidity" will be reduced to its highly liquid CB money holdings, in the extreme case. The literature on the interaction of the LCR and monetary policy implementation is rather scarce. Theoretical contributions include, for instance, Bindseil and Lamoot (2011), Schmitz (2013) or Bech and Keister (2017). Schmitz (2013) finds that the implementation of the LCR leads to a shift from operations within the unsecured IBM to the CB. In addition, his analysis reveals that feedback and network dynamics can lead to (a) a more volatile structural liquidity deficit of the banking sector and (b) ultimately to a collapse of the (perceived) arbitrage relationship between borrowing in the unsecured IBM and the CB money market. By contrast, Aaron et al. (2015) suppose that lending in the IBM will probably remain under the LCR, but shift towards shorter maturities than 30 days. The detailed analysis of Bech and Keister (2017) examines the effect of the LCR under monetary policy normalization. The authors show that under a binding LCR requirement, banks' funding costs are rather determined by the quantity of high-liquid assets available in the banking sector than by CB reserves, which hinders the implementation of monetary policy. Building on the results of Bech and Keister (2017), the implementation of the LCR shifts attention away from CB reserves, which in our view would contribute to a less resilient financial system, reducing the power of the CB within the financial system.

Further tools measure each bank's contribution to systemic risk within the concept of "Systemic Expected Shortfall" (see Acharya et al., 2017) or assess interconnectedness across banks and systemic risk at the bank level, e.g. with respect to bank size, loan growth, leverage, or loan maturity (the concept of  $\Delta CoVar$ ). However, while these measures monitor an individual bank's contribution to systemic risk, they do not focus on the risk inherent in financial markets, namely the interbank credit market but also other financial markets which can transfer risk via volatility.

In our view, the risk of asset volatility with respect to its effects on the bank's portfolio and liquidity management, is still underrepresented in macroprudential policies and should be given further attention. A potential suggestion could be to adjust the LCR for a binding fraction of CB money holdings. In addition to the minimum reserve requirement on private deposits, which insures against a too high withdrawal of customer deposits, a reserve requirement on assets s.t. high volatility would potentially ex ante reduce the probability of reaching the unstable equilibrium, contributing to financial system resilience.

## 2. Temporary emergency operations to safeguard liquidity in IBM

Once a sufficiently large shock has materialized and banks can no longer borrow in the IBM, the CB can meet excess demand for liquidity by providing emergency operations on a temporary basis. In 2008, the ECB decided to adopt non-standard measures, the so-called "Enhanced Credit Support" (ECB, 2011). Among others, it switched to a fixed rate full allotment tender procedure and serves every quantity of liquidity demanded by the banking sector at the main refinancing rate, provided adequate collateral is given. Furthermore, the ECB relaxed the collateral requirements for its refinancing operations (ECB, 2011). These and further unconventional monetary policy measures have led to liquidity in the banking sector, although desired inflation effects are still not at hand.

In an environment of market liquidity tensions, the shock of monetary policy tightening can be reduced when banks expect and anticipate this shock. Therefore, the tool of forward guidance becomes an essential element.

Furthermore, temporary tools to absorb an unexpected exogenous shock of monetary policy tightening could be a temporary decrease of the spread between the interest rate on interbank credits and the policy rate charged by the CB.

## 5 Concluding Remarks

The predominant view of banks acting as financial intermediaries between savers and borrowers has induced us to develop a theoretical model of investment banks' portfolio management and associated financial vulnerabilities in the financial system. We pay special attention to dynamics in the interbank and financial system resilience. Based on financial market equilibria, a stochastic model of interbank market credit flows is introduced.

After an unexpected exogenous shock has materialized, a dynamic adjustment process towards a new market equilibrium is expected to set in. This adjustment path of the IBM differs depending on the environment, where we analyse normal and volatile conditions separately. Under normal conditions the IBM smoothly adjusts to the new equilibrium, operating in a stable regime. Two opposing gross forces drive the market on its way along the credit expansion schedule. The market is regarded as resilient and finally reaches a stable IBM equilibrium. However, under more volatile conditions the adjustment process can become unstable. Why is this the case? First, the adjustment path is constrained by the availability of CB money for interbank credit provision. While the credit expansion schedule is realized in expectations, stochastic reserve inflows can potentially become binding for interbank credit provision. Furthermore, it is found that not necessarily the level of reserve inflows is crucial but their volatility. Consequently, under volatile conditions, the IBM credit expansion is more likely to be constrained. Whenever the constraint is sufficiently large in absolute terms, this results in a bifurcation of the equilibrium. Higher volatility of liquidity flows changes the characteristics of the market adjustment process, including a potential market instability. Second, the probability of

switching to an unstable adjustment path increases under volatile conditions, which can ultimately lead to a market freeze. Defining the probability of IBM stability as market resilience, the volatility of reserve flows may threaten the resilience of the IBM. Our model yields a probability of the unstable adjustment path, depending on current interbank credit provision, and shows that a higher volatility of reserve flows reduces the resilience of the IBM. While we do not claim that volatility causes some financial turmoil, which is a well-known phenomenon, we emphasize that higher volatility can result in a fundamental market instability, i.e. a risk to the financial system.

In an application study, we show an asymmetric reaction scheme of the IBM with regard to monetary policy shocks. Given that monetary policy tightening increases the volatility of asset prices and hence the volatility of reserve flows in banks' balance sheet management, a contractionary monetary policy would reduce the resilience of the IBM. The likelihood of the market to fall into a regime of unstable dynamics would be increased. Thus, we identify a potential risk to financial stability stemming from a monetary policy regime-switch from an expansionary to a contractionary policy, which has a particular prominence in the recent discussion of monetary policy normalization.

Consequently, we emphasize the importance of system-wide, macroprudential policies that should pay special attention to the risk of asset price volatility and its effects on bank's portfolio and liquidity management to support and ensure the resilience of the financial system. A first step to safeguard liquidity in the IBM are preventive macroprudential policy tools, such as the LCR implemented under Basel III in 2015. However, its effectiveness is still under discussion. Once a shock has materialized, the CB can try to revitalize the IBM, for instance, with the help of emergency liquidity injections. Furthermore, the monetary policy tool of forward guidance becomes essential in avoiding the adverse scenario in the IBM. Therefore, policymakers should be aware of asymmetric effects of different monetary policy regimes on financial market resilience.

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